THE 1ST INTERNATIONAL SYMPOSIUM ON SMART MATERIAL AND MECHATRONICS

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Graduate School of Mechanical Engineering
Faculty of Engineering
University of Hasanuddin
PROCEEDING OF
THE 1st INTERNATIONAL SYMPOSIUM
ON SMART MATERIAL AND MECHATRONICS


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Foreword

First, we would like to thank all participants who are willing to send the results of scientific research papers and participated in the International Symposium on Smart Material and Mechatronics 2014. As the first International Symposium conducted by Graduate School of Mechanical Engineering, Hasanuddin University, and our challenge theme is Smart Material and System Mechatronics.

The International Symposium on Smart Material and Mechatronics 2014 presented as gifts birthday of Hasanuddin University to 58 years old. We hope, in this symposium some steps are to conduct research and publications acceleration in the field techno-science include Smart Materials and System Mechatronics. The both field of science that became one of the sections that need to be encouraged to become an advanced nation of Indonesia in the field of technology. Furthermore, the results of research are good input for accelerating industry.

In this symposium we invite on the field of research area, but not limited to:

- Metal Material, Smart Material, Concrete Material, Composite Material, Strength and stress of Material, Structure Analysis, Cad and Cam, Vibration and Acoustic, Transportation System, Environmental Study, Mining, Chemistry, Naval Architecture, Hydodynamics, Machining, Production, Heat and Mass Transfer, Thermodynamics, Fluid Mechanics, Agriculture Engineering, Education Engineering, conservation energy, new energy and renewable energy, internal and external combustion engine, Civil Engineering.


Thanks to all of my college and all of students of graduate school of Mechanical Engineering Hasanuddin University.

Makassar-Gowa, September 23, 2014
Yours

Rafiuddin Syam, PhD
Chairman
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Measurement and Control for Unmanned Ground, Aerial and Underwater Vehicles

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Abstract—In this keynote, we overview latest representative research results in our laboratory on several Unmanned Vehicles (UVs): i.e., Unmanned Ground Vehicles (UGVs) such as a mobile robot with two-wheeled independent driving mechanism, a car-like four-wheeled mobile robot on the ground, etc.; Unmanned Aerial Vehicles (UAVs) such as a VTOL aerial robot with four rotors in the air etc.; and Unmanned Underwater Vehicles (UUVs) such as a robotic manta as one kind of Autonomous Underwater Vehicles (AUVs) in the underwater etc.

First, we introduce an obstacle avoidance problem for a nonholonomic four-wheeled mobile robot as UGVs using an image-based control approach, where a fuzzy controller is designed for controlling a target line extracted from the camera image, together with the information on the potential field of the environment. In addition, we develop a stabilizing controller for such a mobile robot to realize an automatic parking system, by applying an invariant manifold method.

Secondly, we show a measurement system in 3D space for UAVs, where an indoor X4 Flyer, which is a VTOL type aerial robot with four rotors, is considered. In this research, a position measurement system in an indoor 3D space is developed by using a stereo camera. In particular, to enable measurement in a dark place, the position measurement system is built by attaching an infrared LED marker to an object and using two cameras equipped with an infrared transmitting filter.

Thirdly, among UUVs, we develop a robotic manta as a kind of fish robot with pectoral fins. Such a biomimetic thruster is expected to provide noiseless propulsion, and to be more maneuverable in complex near-shore environments and highly efficient in energy consumption, compared to the conventional AUVs with a propeller-based thruster.

Index Terms—Unmanned vehicles, nonholonomic wheeled mobile robots, VTOL aerial robots with four rotors, fish robots with pectoral fins.
Mechanical Properties of Composite Materials

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Abstract—An examination has been made of the mechanical and failure properties of several composite materials, such as a short and a long carbon fiber reinforced plastic (short- and long-CFRP) and metal based composite material. The short CFRP materials were used for a recycled CFRP which fabricated by the following process: the CFRP, consisting of epoxy resin with carbon fiber, is injected to a rectangular plate cavity after mixing with acrylonitrile butadiene styrene resin with different weight fractions of CFRP. The fatigue and ultimate tensile strength (UTS) increased with increasing CFRP content. These correlations, however, break down, especially for tensile strength, as the CFPR content becomes more than 70%. Influence of sample temperature on the bending strength of the long-CFRP was investigated, and it appears that the strength slightly decreases with increasing the temperature, due to the weakness in the matrix. Broken fiber and pull-out or debonding between the fiber and matrix were related to the main failure of the short- and long-CFRP samples. Mechanical properties of metal based composite materials have been also investigated, where fiber-like high hardness CuAl\(_2\) structure is formed in aluminum matrix. Excellent mechanical properties were obtained in this alloy, e.g., the higher strength and the higher ductility, compared to the same alloy without the fiber-like structure. There are strong anisotropic effects on the mechanical properties due to the fiber-like metal composite in a soft Al based matrix.

Index Terms—CFRP; Carbon fiber; Mechanical property; Crack growth; Failure mechanism

I. INTRODUCTION

In recent years, composite materials have received special attention because of the excellent mechanical properties. In particular, production amount of carbon fiber reinforced plastics (CFRP) have been increased due to their high strength and low specific weight [1]. CFRP material has come into practical use for the aerospace and automotive industries, because of their contribution to higher fuel efficiency. In fact, the demand for CFRPs has dramatically increased in recent years [2]. As aerospace and automotive parts are sometimes employed in atmosphere with high temperature, examination of mechanical properties of CFRP at high temperature would be required. In addition, development of the recycling technology for CFRP has been significantly important due to their high production amount. Indeed, post-use CFRP seems to be thrown away into landfill without any consideration of environmental problems [3]. This occurrence will be a problem in the future, because the amount of waste CFRP will increase [4]. Up to date, several researchers have investigated the mechanical properties of CFRP including recycled CFRP, the information available appears to be insufficient.

On the other hand, metal matrix composite material (FRM) is also important material as engineering material. This is because of their outstanding mechanical properties. Metal matrix composite with silicon carbide particle (SiC) are one of the widely known composites, which have high strength, high hardness, high wear resistance and high corrosion resistance [5]. Effect of clustering on mechanical properties of aluminum alloy 2024-SiC metal matrix composite has been investigated. Fracture toughness and tensile tests were carried out, and their mechanical strengths were estimated well by a model [6].

Although CFRP and FRM are excellent materials to use in various engineering application, there would have still technical issue for recycling technique and lack of information regarding their mechanical properties. In this study, our experimental results obtained previously for the material properties of long-CFRP, short-CFRP [7] and FRM [8]-[9] were summarized to consider the mechanical properties of the composite materials.

II. EXPERIMENTAL PROCEDURE

II-1. Long-CFRP and short-CFRP

The long-CFRP, consisting of epoxy resin (thermosetting high polymer) with a volume fraction of 60% carbon fiber, was used. Fig. 1 shows the photograph of the long-CFRP samples showing the carbon fibers and matrix. The short-CFRP samples were made by the following process. The long-CFRP was first crushed using a rotating blade to make small fragments for which the average length by width is 3.4 mm \(\times\) 0.4 mm. The crashed long-CFRP pieces were then separated individually into fiber and epoxy resin after the ball milling process. Most part of the surface of separated carbon fibers is not already coated by epoxy resin, while some fiber bundles were present that contained epoxy resin [3]. After the grinding process, it was found that the mean length of the carbon fibers is about 200 \(\mu\)m. The short-CFRP samples, consisting of acrylonitrile butadiene styrene resin and CFRP pieces, were fabricated using standard mixing, grinding and injection molding procedures. In this case, the CFRP pieces were added to the ABS resin before the injection process with five
different weight fractions of 0 (i.e., pure ABS), 10, 30, 50 and 70 wt.%. The injection molding process was carried out to make the short-CFRP with simple rectangular plates 150 mm × 150 mm × 3 mm.

Dumbbell-shaped specimen and compact tension (CT) specimen were used in this test, which obtained from the center area of the rectangular plate as shown in Fig. 2. In this case, the rectangular plate cut in two different directions from the mid-section, either with the loading direction (longitudinal axis of the specimen) in the direction perpendicular (Type T) or parallel (Type L) to the flow (or carbon fiber) direction. The dimension of the parallel area in the dumbbell-shaped specimen is 7 mm (l) × 3 mm (w) × 1 mm (t), and that of CT specimen is $W = 24.5$ mm and $B = 3$ mm. The CT specimen was designed based upon the ASTM standard E399 [10]. In the mid-section of the CT specimens, a through-slit (15 mm in length with a V-notch root angle of 45 degrees) was machined.

II-2. Metal composite aluminum alloy

In the present study, an attempt was made to create FRM materials via our heated mould continuous casting technology (HMC) with a eutectic aluminum alloy. Concept of this technology is as follows: unidirectional microstructure with thin fiber-like phases was created by the unidirectional rapid solidification process. In this approach, An Al-33% Cu eutectic alloy was selected to make metal composite Al alloy. Fig. 3 gives a schematic diagram of the heated mould continuous casting apparatus, consisting of a graphite crucible with runner, a graphite mould, a cooling device and pinch rolls for withdrawal of the cast metal. The cast samples in the shape of a long round bar (φ4 mm × 1 m) was made. The casting pressure was controlled by the level of molten metal in the crucible, controlled by furnace displacer block. The temperature of the molten metal was maintained at about 843K, which is 20K above the melting point of its Al alloy. The molten metal was cast through the runner and graphite mould before the cooling process. The graphite mould was heated to approximately 853K, which is just above the liquidus of the Al-Cu alloy. For the solidification process, the aluminum alloy was cooled directly by water flowing to the exit just out of the graphite mould (see Fig. 3). Interestingly, with this casting process, a unidirectional growth microstructure was created, which could be associated with metal composite material. Fig. 4 depicts microstructure of Al-33% Cu sample with the axial and transverse directions. The primary $\alpha$-Al phase is visible as a dark region. A fine fiber-like eutectic structure of CuAl$_2$ phases with unidirectional growth along its axial direction can be observed.

Fig. 5 displays the test specimens formed with a rectangular shape. Note, in this case, tiny special specimen was designed to examine the metal composite effect on the mechanical properties, namely anisotropic microstructural effects. The specimens are denoted as (i) axial direction (OL) and (ii) transverse direction (OT), as indicated in Fig. 5. Because of the tiny specimen, finite element analysis was conducted to verify the stress-strain distribution before the testing. Fig. 5 also indicates the FEA stress distribution on the loading direction (x-axis). From this result, it is clear that the high stress level is uniformly distributed in the sample of parallel area. Thus, the material properties can be estimated to understand their material characteristics.
III. RESULTS

III-1. Long-CFRP materials

Fig. 6 shows representative bending stress - strain curves for the long-CFRP with different fiber direction. As seen, different tensile properties are obtained depending on the fiber direction. It is clear that low bending properties are obtained as the CFRP with fiber direction of more than 45° against the loading direction, while high mechanical properties are detected for the CFRP with 0° fiber direction.

Fig. 7 depicts the fracture surfaces of their specimens after the bending tests. As seen, fiber surfaces are observed for the specimens with fiber direction of 45° and 90°. Those samples would be fractured by the crack growth between the fibers, namely delamination between the fiber and matrix. On the other hand, fibers are completely fractured for 0°-CFRP sample, which makes high bending strength.

Fig. 8 presents bending stress - strain curves for the CFRP tested at different sample temperatures, e.g., 20°C, 50°C and 100°C. There is clear temperature effect on the bending properties, where the higher the mechanical properties are obtained for the specimen tested at the lower temperature. Similar trends were also seen in their fatigue properties. Fig. 9 indicates the S-N curves for their CFRP samples. It is obvious that high fatigue strength is detected for the CFRP at low temperature. Their fracture characteristics were further investigated. Fig. 10 shows the fracture surfaces of the CFRPs after the bending test at different temperatures. It is interest to mention that there are different dense of the epoxy. It is seen that low density of epoxy is obvious for the samples at the higher testing temperatures. This result infers that the epoxy may have been melted during the heating process.
III-2. Short-CFRP materials

Fig. 11 shows the ultimate tensile strength ($\sigma_{UTS}$) for all the short-CFRP samples. Different tensile properties are obtained depending on the CFRP content and type (fiber direction). There is no clear anisotropic effect on the tensile properties for the CFRP 0% samples: $\sigma_{UTS} = 38.8$ MPa for Type T and $\sigma_{UTS} = 40.2$ MPa for Type L. For both samples Type T and L, the tensile strength increases with increasing CFRP content, but a considerable drop in the tensile strength was detected for CFRP 70%. The overall tensile strength for Type L is higher than that for Type T, particularly CFRP 30%- and CFRP 50%-Type L, e.g., the mean $\sigma_{UTS}$ value for CFRP 50%-Type L is more than 1.6 times higher than the CFRP 50%-Type T one. This corresponds to the anisotropic effect in the sample, where the fiber direction prevails for the strength although the fiber length is as short as about 200 $\mu$m as mentioned above.

Fig. 12 shows the relationship between the stress amplitude and cycle number to failure (S-N curve) of the short-CFRP. It should be noted first that the arrows in this figure indicate the specimens which did not fail within $10^7$ cycles. From Fig. 12(a), the S-N relationships, including the endurance limit ($\sigma_{en}$), seem to be similar level for all Type T samples, while the slope of their S-N relationships is slightly different depending on the CFRP content. For example, the higher the CFRP content (e.g., CFRP 70%), the lower the slope of S-N relations, in which S vs. N for CFRP 70%-Type T crosses those for the other Type T samples around $10^3 \sim 10^4$ cycles as indicated in Fig. 12(a).

For CFRP 70%-Type T, the lowest slope of the S vs. N curve is obtained for CFRP 70%-Type L (Fig. 12(b)), which also crosses the other ones at around $10^3$ cycles but only for 0%- and 10%-Type L. Interestingly, the endurance limit for both CFRP 70% is the same level of about 15.4 MPa. The S-N curves for CFRP 30%- and 50%-Type L are located at a higher level compared to the others, even though the endurance limits for CFRP 30%- and 50%-Type L are close to that for CFRP 70%-Type L. An important observation from Fig. 12(a)(b) is that relatively high endurance limit was obtained for both CFRP 70% in spite of the low tensile properties (Fig. 11). Such fatigue properties for CFRP 70% are associated with different
crack growth rates. For instance, a rough fracture surface makes low crack growth rate due to the low crack driving force arising from severe crack closure [11].

To understand clearly the fatigue behavior of the short-CFRP samples, the $S$-$N$ relationships were quantitatively evaluated by a power law dependence of cyclic stresses and cycles to failure:

$$\sigma_i = \sigma_f N^b$$

(1)

where $\sigma_i$ is the stress amplitude, $N_f$ represents the cycle number to final fracture, $\sigma_f$ is the fatigue strength coefficient and $b$ is the fatigue exponent. Those values ($\sigma_f$ and $b$) were obtained by least square analysis. In this case, an increased fatigue life is expected for a decreasing fatigue strength exponent $b$ and increasing fatigue strength coefficient $\sigma_f$. In the present case, the $\sigma_f$ and $b$ for the CFRP 50%-Type L sample shows high fatigue strength, e.g., $\sigma_f = 51.3$ and $b = 0.07$. On the other hand, different fatigue properties were obtained for both CFRP 70% samples with lower $b$ and lower $\sigma_f$ values ($\sigma_f = 21.3$ and $b = 0.02$).

III-3. Metal composite materials (Al-33%Cu alloy)

Fig. 13 shows the stress-strain curves for the Al-33%Cu samples: OL and OT samples. It can be seen that the relatively linear stress vs. strain relations are obtained for the both samples. The tensile strength and elongation to failure are obviously high in the OL sample compared to the other one due to the fiber-like composite effect. The tensile properties of both Al-33%Cu alloys for OL and OT are $\sigma_{UTS} = 489.8$ MPa and $\varepsilon_f = 4.9\%$ and $\sigma_{UTS} = 384.1$ MPa and $\varepsilon_f = 4.2\%$, respectively. Such different tensile properties (OL vs. OT) are reflected to the reinforcement by the fibrous structure. The fine eutectic structure in the longitudinal direction can enhance the material properties (OL), and that tensile strength is much higher than that for the conventional cast Al alloys.

On the other hand, the high material ductility obtained for the OL samples can be explained using the failure mechanism.

![Fig. 13 Stress-strain curves for the Al-33%Cu samples, obtain from axial (OL) and transverse (OT) directions [8].](image)

Fig. 14 shows SEM images of the microstructure of both Al-33%Cu alloys. As seen in the OL sample, elongated microstructural characteristic was obtained near the crack, which would be caused by the fibrous structure. On the contrary, the crack, created in-between the fiber and matrix, can be observed for OT samples.

![Fig. 14 SEM images of the Al-33% Cu alloys showing the crack paths in the mid-section of the samples: (a) axial direction (OL) and (b) transverse direction (OT) [8].](image)
MPa, which is about twice as high as that of the OT samples. It should be pointed out that S-N relationship for the OL is formed more plateau compared to the other one. This may be affected by the material brittleness for the OL samples. In fact, such S-N relations is sometimes seen in relatively brittle materials, e.g., ceramics [12][13].

![Fig. 15 S-N curve for the Al-33%Cu samples, obtained in the axial direction (OL) and transverse direction (OT) [8].](image)

**IV. CONCLUSIONS**

An examination has been made of the mechanical and failure properties for the composite materials. The results have yielded the following conclusions.

1. Mechanical properties (tensile strength and fatigue strength) of the CFRP samples are directly attributed to the sample temperature and fiber directions. The epoxy seems to be melted when heated to the higher temperature, leading to the low mechanical properties.

2. The tensile strength of the short-CFRP is found to depend not only on the CFRP content, but also on the fiber direction. The tensile strength increases with increasing CFRP content, but drops suddenly for short-CFRP with higher fiber content, i.e., 70%. In addition, under the same CFRP content, the higher tensile strength is detected as the fiber direction is parallel to the loading direction.

3. A clear anisotropic microstructure was obtained, namely a fine lamellar eutectic structure with unidirectional growth along its axial direction. The eutectic structure was formed by the primary α-Al phase and CuAl2 phase, i.e., fiber-like reinforcement. The tensile and fatigue properties of the samples in the longitudinal direction of the loading are more than 30% higher than those for the cast samples perpendicular to the casting direction.

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**REFERENCES**


The Effect of Tool Dimension, Tool Overhang and Cutting Parameters Towards Tool Vibration and Surface Roughness on Turning Process

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Abstract— Turning process is the removal of metal from the outer diameter of a rotating cylindrical workpiece. Turning is used to reduce the diameter of the workpiece, usually to a specified dimension, and to produce a smooth finish on the metal. This research investigates the effect of feed rate, spindle speed, tool overhang and tool dimensions toward vibration amplitude and surface roughness on turning process. This study uses both statistical and graphical analysis of the data collected. The experimentation was carried out on conventional lathe machine with straight turning operation. Material used as workpiece was St.60 carbon steel which was turned with HSS tool bit with the dimension of 3/8 Inches and 1/2 Inches. Cutting parameters varied by spindle speed, feed rate, and tool overhang, while the depth of cut is maintained at a depth of 0.5 mm. The vibration data of cutting tool obtained from a transducer (vibrometer) mounted at a distance of 10 mm from the tip of the cutting tool during the cutting process takes place, whereas the surface roughness data obtained from measurements of surface roughness apparatus after turning process. The results showed that, The effect of feed rate, spindle speed, tool overhang, and tool dimension simultaneously towards vibration amplitude and surface roughness has a greater effect on the use of 3/8 inches cutting tool than 1/2 inches cutting tool. With the use of the same tool dimensions obtained that, The most influential parameters on the vibration amplitude is tool overhang while the most influential parameter on surface roughness value is feed rate.

Key words— Turning, vibration, surface roughness, cutting tool

I. INTRODUCTION

Challenges faced by today’s modern machining industry primarily focused on achieving a high quality product. One of them are the quality of surface roughness. Surface roughness of a product of machining process can affect some functions of these products such as surface friction, heat transfer, spreading capabilities of lubrication, coating, and others. Thus, in practical field, the desired of surface roughness value will be the reference of cutting parameters selection [1]. Turning is one of the main machining processes used in the process of cutting a rotating cylindrical workpiece. Lots of machinery components made through turning process. Problems are often encountered in all of the machining process especially on turning, is the vibration during the material cutting process. This vibration will affect the quality of the products, one of them is the surface roughness [1].

Nowadays, a standard procedure used to avoid vibration during turning is planning the selection of cutting speed, feed rate, and depth of cut carefully. A method applied is usually based on an operator’s experience and also trial and error method to gain a proper cutting parameters in the machining process.

Vibration in machining process occurs throughout the cutting process takes place which is derived from some sources, such as frame structure of the machine, cutting tool type, types of material that are cutting, etc. Vibration on machining process is very complicated because it involves lots of variables. Nevertheless, at least two kinds of vibrations occurred on machining process, this covers both force vibration and self-excited vibration. Force vibration is usually gained from components in the machine itself, for example because there are damaged gear components, imbalances on machine components, misalignment of the shaft, the electrical motor rotation, and etc. Self-excited vibration which is so-called Chatter caused by the interaction between the release of chips and cutting tool which causes interference with the cutting area. Chatter or self-excited always affects on the surface roughness of machining product. Therefore a vibration which is caused by self excited vibration related to the surface roughness as the result of machining [2].

Some previous research, both descriptive and experiment have studied how vibration affects surface roughness towards surface roughness as a product of machining process [1][2][3][4][5]. One of those researches is the effect of spindle speed, feed rate, and depth of cut towards tool vibration amplitude and surface roughness of the workpiece on the lathe machine, in which concludes that spindle speed is the most influential towards vibration and so does the surface roughness, then followed by the feed rate and the last is the depth of cut. Based on that research, the writer conducted a further research towards some variables which has not been experimented before, it is the effect of tool overhang and cutting tool dimension in which involving the same variation of cutting conditions that have been studied before.

II. THEORETICAL BACKGROUND

A. Vibration in metal cutting process

Vibration is a back and forth motion about its fixed equilibrium position. The equilibrium position means a
condition in which an object is on motionless position if there is no force acting on the object. Vibration has similar amplitude (distance deviation furthest to the midpoint) [6]. All objects that have mass and elasticity are able to vibrate.

In the machining process, there are three mechanical vibrations caused by insufficiency of dynamic stiffness in machinery equipment. The vibrations are free vibration, force vibration, and self-excited vibration. A tool holder, workpiece and the machine itself are parts of machinery which causes vibration. The free vibration is usually caused by shocks effect, such as, the presence of impulse waves that are transferred to the cutting tool or at the time between the beginning of the cutting tool with the workpiece. Force vibration is caused by periodic force which occurred in the system, for example due to the imbalance of machine components for instance, gears system, spindle or bearing. Self-excited vibration usually occurs as a result of dynamic instability that occurs during metal cutting processes. As it shows, the self-excited vibration is the most uncontrolled vibration while two other vibrations can be controlled through arranging cutting parameters on the machine [7].

B. Surface roughness

Surface roughness is a measurable characteristic based on the roughness deviations as defined in the preceding. Surface finish is a more subjective term denoting smoothness and general quality of a surface. In popular usage, surface finish is often used as a synonym for surface roughness.

The most commonly used measure of surface texture is surface roughness. With respect to Figure 1, surface roughness can be defined as the average of the vertical deviations from the nominal surface over a specified surface length. An arithmetic average (AA) is generally used, based on the absolute values of the deviations, and this roughness value is referred to by the name average roughness. In equation form

\[ R_a = \frac{1}{L_m} \int_{L_m}^{L_m} |y| \, dx \]

where \( R_a \) = arithmetic mean value of roughness, m (in); \( y \) = the vertical deviation from nominal surface (converted to absolute value), m (in); and \( L_m \) = the specified distance over which the surface deviations are measured.

The AA method is the most widely used averaging method for surface roughness today. An alternative, sometimes used in the United States, is the root-mean-square (RMS) average, which is the square root of the mean of the squared deviations over the measuring length. RMS surface roughness values will almost always be greater than the AA values because the larger deviations will figure more prominently in the calculation of the RMS value.

C. General overview of turning process

Turning process is the removal of metal from the outer diameter of a rotating cylindrical workpiece. Turning is used to reduce the diameter of the workpiece, usually to a specified dimension, and to produce a smooth finish on the metal.

Three main parameters in turning operation are cutting speed, feed rate, and depth of cut. Other factors such as workpiece material and type of cutting tool actually has a considerable influence. However, the three parameters mentioned above are parts that can be set by the operator directly on the lathe machine.

Cutting speed (also called surface speed or simply speed) may be defined as the rate (or speed) that the material moves past the cutting edge of the tool, irrespective of the machining operation used. The equation of cutting speed can be determined from the equation below

\[ C_s = \frac{\pi DN}{1000} \]  

Where \( C_s \) = cutting speed; m/minute, \( D \) = workpiece diameter /mm, \( N \) = spindle speed, revolution / minute. The spindle speed (N) in eq. (1) is a measure of the frequency of a rotation. It annotates the number of turns completed in one minute around a fixed axis. The preferred speed is determined by working backward from the desired surface speed (sfm or m/min) and incorporating the diameter (of workpiece or cutter).

Feed rate, \( V_f \), refers to how fast a lathe-tool should move through the material being cut. This is calculated using the Feed per Revolution for the particular material. It is expressed in units of distance per revolution. Feed rate is determined based on machine power, material properties of workpiece, tool material, tool shape, and the most important is the expected surface roughness.

Depth of Cut, the thickness of the material that is removed by one pass of the cutting tool over the workpiece. [8]

D. Regression Analysis

Regression Analysis is applied to study and measure the statistical relationship among two or more variables. In simple regression analysis two variables are analyzed, whereas in the multiple regression analysis more than two variables are analyzed. In regression analysis, a regression equation was about to set and used to describe a pattern or a function of the relationship between variables. Variables to be called the dependent variable is usually plotted on y-axis, while the independent variable is the variable that is assumed to give effect to the variation in the dependent variable and it is usually plotted on x-axis.

Multiple linear regression, On this multiple linear regression, there are several independent variables (X1, X2, X3, ... Xn) which are connected to one dependent variable (Y), those are parts of multivariate analysis to estimate the regression coefficient to describe the effect of independent variable towards dependent variable. In a multiple regression test, all of the predictor variables are included in the regression calculation simultaneously.
If there are two independent variables \((X_1)\) and \((X_2)\) and the dependent variable \((Y)\), then the equation of multiple regression of two independent variables are used to determine the coefficients of the multiple regression equation is determined by the following equation:

\[
Y = a + b_1X_1 + b_2X_2 + \ldots + b_nX_n
\]  

(2)

### E. Correlation Analysis

Analysis of correlation is an inferential analysis used to determine the degrees of freedom or strength of the relationship, shape or causal and correlation among research variables. Type of statistical hypothesis testing correlations includes simple correlations (bivariate), multiple correlation and partial correlation.

Pearson’s Product Moment Correlation, this correlation is used for interval/ratio data in which must meet the following requirements:

- The sample is taken randomly
- Each variable of data is normally-distributed
- A linear regression equation
- Equation:

\[
r_y = \frac{\sum x \sum y - \sum x \sum y}{\sqrt{[\sum x^2 - (\sum x)^2][\sum y^2 - (\sum y)^2]}}
\]

(3)

Coefficient of Determination: The Coefficient of Determination is denoted as \(r^2\). This value states the proportion of the overall variation in the value of the dependent variable that can be explained or caused by a linear relationship with the independent variables, the rest is explained by other variables (errors or other variables). Coefficient of determination expressed as the square of the correlation coefficient \(r^2\) x 100\% = \(n\%\) meaning that the value of the dependent variable can be explained by the independent variables of \(n\%\), while the residual value of \((100 - n)\%\) explained by an error (error) or the influence of other variables. Meanwhile, for correlation analysis with more dependent variables, there is a correlation coefficient which is significantly sensitive with amount of variables. Usually for multiple correlation analysis, adjustment coefficients of determination are often used.

**Multiple Correlation**, multiple correlation is the correlation between two or more independent variables together with the dependent variable. Value which shows directions and strength of the relationship between two or more independent variables on the dependent variable is called multiple correlations and denoted as \(R\).

The Equation of multiple correlation of two independent variable \(X_1\) and \(X_2\) with one dependent variable \((Y)\) as \([9]\) :

\[
R_{y,12} = \sqrt{r_{11}^2 + r_{22}^2 - 2r_{11}r_{22}r_{12}}
\]

(4)

Where \(R_{y,12}\) = coefficient of multiple correlation among \(X_1 \), \(X_2\) and \(Y\), \(r_{11}\) = correlation coefficient between \(X_1\) and \(Y\), \(r_{22}\) = correlation coefficient between \(X_2\) and \(Y\), \(r_{12}\) = correlation coefficient between \(X_1\) with \(X_2\).

The tested hypothesis is two tailed test:

\[
H_0 : p_{y,12} = 0
\]

\[
H_1 : p_{y,12} \neq 0
\]

Hypothesis test of multiple correlation using F-test with degrees of freedom (df) consists of:

\[
df_c = df \text{ numerator } = k \ (k = \text{ total of independent variable})
\]

\[
df_e = df \text{ denominator } = n - k - 1 \ (n = \text{ numbers of pairs of data or sample})
\]

Value conversion of correlation coefficient \(R\) to \(F_{\text{count}}\) uses the following equation:

\[
F_a = \frac{R^2 / k}{(1 - R^2)/(n - k - 1)}
\]

(5)

Hypothesis testing criteria, namely:

Accept \(H_0\) if \(F_{\text{count}} < F_{\text{table}}\) dan reject \(H_0\) if \(F_{\text{count}} > F_{\text{table}}\.

### III. RESEARCH METHODOLOGY

#### A. Experimental setup

Material used as workpiece was St.60 carbon steel which was turned with HSS tool bit (The Bohler Super Mo Rapid Extra 1200 Brand) with the dimension of 3/8 Inches and ½ Inches. The cutting tool angles used were Side Relief = 11°, Front Relief = 8°, Side Rake = 12°, Back Rake = 8° [10]. The experimentation was carried out on conventional lathe machine and the method of cutting is shown in Fig. 1, referring to the experimental set up that has been conducted by previous researchers [11].

Figure 2, shows that workpiece which will be turned then divided into four segments separated by grooves. The purpose of this segmental separation is to minimize the affects of tool wear which can effects surface quality towards the effectiveness of measurement. Thus, in collected data measurement, tool bit cuts four times before being substituted by a sharpened cutting tool.

Figure 2. Schematic of experimental set-up for turning

#### B. Method of Collecting data

Measurement of data is undertaken by a well-trained and experienced lathe operator in the using of vibration measurement instrument and surface roughness devices. Collecting of measurement datas was arranged as factorial designed so that the interactions between independent variables can be observed more effectively. The independent variables in the study are feed rate\(V_f\), spindle speed, tool overhang, and the tool dimension. While dependent variables is the result of the
cutting tool vibration (V_{rms}) and the surface roughness (R_a) of workpiece. The details of cutting condition and the groups of experimental testing are shown in Table 1.

Table 1 Groups of Experimental testing variables

<table>
<thead>
<tr>
<th>Spindle Speed (N)</th>
<th>Feed rate (V_i) mm/rev</th>
<th>Depth of cut (a) mm</th>
<th>Tool Overhang mm</th>
<th>Tool Dimensions inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
<td>0.05</td>
<td>0.5</td>
<td>25,30,35,40</td>
<td>3/8, 1/2</td>
</tr>
<tr>
<td>170</td>
<td>0.08</td>
<td>0.5</td>
<td>25,30,35,40</td>
<td>3/8, 1/2</td>
</tr>
<tr>
<td>250</td>
<td>0.05</td>
<td>0.5</td>
<td>25,30,35,40</td>
<td>3/8, 1/2</td>
</tr>
<tr>
<td>350</td>
<td>0.05</td>
<td>0.5</td>
<td>25,30,35,40</td>
<td>3/8, 1/2</td>
</tr>
<tr>
<td>800</td>
<td>0.24</td>
<td>0.5</td>
<td>25,30,35,40</td>
<td>3/8, 1/2</td>
</tr>
</tbody>
</table>

C. Method of Data Analysis

As gained from cutting process on the lathe, measuring data for vibration amplitude (V_{rms}) and surface roughness (R_a) is calculated graphically and statistically. The data were attained through being plotted in graph. Further analysis is undertaken by using both manual calculation [12] and Statistical Package for Social Sciences (SPSS) by regression and correlation methods to determine how influential the relationship among the variables (tool dimension, spindle speed, feed rate, and tool overhang) to the value of the vibration amplitude and surface roughness of workpiece[13].

IV. MODEL ANALYSIS AND DISCUSSION

A. Result

The result of cutting tool vibration towards feed rate and variation of spindle speed and tool overhang can be seen in Figure 3, where it appears that the use of ½ inches cutting tool at the same length of tool overhang, addition of feed rate on the turning process will increase cutting tool vibration, where the highest vibration value occurs in 0.24 mm/rev feed rate.

Moreover, conditions where feed rate is maintained at a fixed speed and spindle speed varied at different value, the tool vibration will be higher if spindle speed is increased. However, the magnitude of vibration is smaller with a vibration caused by variations in the parameters of feeding. On the use of 3/8 inches cutting tool as shown in Figure 4, vibration value is higher compared to vibration value generated by the use of ½ inches cutting tool. On the use of ½ inches cutting tool obtained the highest vibration on cutting tool, that is V_{rms} = 0.65 cm/s while the vibration of 3/8 inches cutting tool is V_{rms} = 0.78 cm/s at spindle speed 880 rpm, feeding 0.24 mm/rev, and cutting tool overhang 40 mm.

The effects of variation on feed rate towards surface roughness using ½ inches cutting tool as shown in Figure 5, indicates that increasing the feed rate will increase surface roughness on workpiece where the highest value obtained on feeding 0.24 mm/rev. On the variation of cutting tool overhang,
the longer the tool bit the higher the surface roughness value where 40 mm tool overhang has the highest roughness value.

By using 3/8 inches tool bit as shown in Figure 6, the surface roughness value will be greater than the roughness values obtained in the use of ½ inches in every similar cutting parameter condition used. On the use of ½ inches tool bit the highest surface roughness value is \( R_a = 8.54 \mu m \) while on 3/8 inches tool bit reaches \( R_a = 10.34 \mu m \) at a spindle speed of 170 rpm, feeding 0.24 mm/rev, and tool overhang 40 mm.

![Figure 5](image5.png)
**Figure 5.** Comparison plot between surface roughness and feed rate on variation of spindle speed and tool overhang by using 1/2 inches cutting tool dimension

![Figure 6](image6.png)
**Figure 6.** Comparison plot between surface roughness and feed rate on variation of spindle speed and tool overhang by using 3/8 inches cutting tool dimension

To determine a detailed characteristics effect between dependent and independent variables, the data processing is done with statistical methods to determine the correlation and regression equation of each variables as shown in Table 2 and Table 3.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>The result of correlation statistical analysis and tool vibration regression dan ½ inches and 3/8 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>% INCHES CUTTING TOOL</td>
<td>½ INCHES CUTTING TOOL</td>
</tr>
<tr>
<td>Regression</td>
<td>( y = -0.2044 + 1.151 \times 10^{-3} \times x )</td>
</tr>
<tr>
<td>Equations</td>
<td>( y = 0.01548X_1 + 1.1445X_2 )</td>
</tr>
<tr>
<td>( x_1 )</td>
<td>0.277</td>
</tr>
<tr>
<td>( x_2 )</td>
<td>0.697</td>
</tr>
<tr>
<td>( x_3 )</td>
<td>0.818</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3</th>
<th>The result of correlation statistical analysis and turning result of surface roughness regression by using ½ inches tool and 3/8 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>% INCHES CUTTING TOOL</td>
<td>½ INCHES CUTTING TOOL</td>
</tr>
<tr>
<td>Regression</td>
<td>( y = 0.9067 - 0.00535X_1 )</td>
</tr>
<tr>
<td>Equations</td>
<td>( y = 0.09546X_1 + 17.303X_2 )</td>
</tr>
<tr>
<td>( x_1 )</td>
<td>-0.552</td>
</tr>
<tr>
<td>( x_2 )</td>
<td>0.338</td>
</tr>
<tr>
<td>( x_3 )</td>
<td>0.71</td>
</tr>
</tbody>
</table>

**B. Discussion**

This study shows that there is an effect of feed rate, spindle speed, tool overhang, and tool dimension toward vibration amplitude and surface roughness on turning process where the most influential parameter towards vibration amplitude is tool overhang, while the most affective parameter towards surface roughness is feed rate.

The experimental result of the effect of independent variables (spindle speed, feed rate, tool overhang) towards vibration amplitude found that, the addition of feed rate on turning process will increase the tool vibration because the more feeding given the faster cutting tool cut of the workpiece, as the result, the frictional forces that occur will be greater due to the magnitude of compressive force on the tip of the cutting tool and workpiece. Moreover, a condition where feeding keeps being constant and the spindle speed varied on different values resulting the increasing of tool vibration if spindle speed is increased. However, vibration obtained will not be as higher as vibration by feeding parameter variation. This vibration is caused by radial cutting force that occurs as a result of interaction between the tip of cutting tool and the rotating workpiece.

The effect of vibration on the cutting tool overhang variation shows that, the more the tools overhang from the tool holder, the greater the vibration results. The length of cutting tool overhang contributes to the deflection which is caused by cutting force that lead to vibration on cutting tool. At the same conditions of cutting parameters, the vibration that occurs in the use of ½ inch tool bit larger than 3/8 inches. This is caused by the stiffness of the ½ inch tool bit larger than 3/8 inches. Material stiffness is determined by volume and elasticity modulus of material, while the magnitude of the deflection is inversely proportional to the value of the rigidity, while the vibration tends to be even greater if the value of deflection increases [14].
Statistically, the coefficient of determination (R²) for ½ inches cutting tool is 0.9442. This shows that, 94.42% of the variation of the amplitude of vibration is the result of the variation of spindle speed, feed rate and tool overhang simultaneously. While the rest 5.6% is caused by other factors. Because the R-square value close to 1, then this indicates the strength of the relationship between the independent and dependent variables in this case. On the use of 3/8 inches cutting tool shows that R square is 0.963. This clearly reveals that the effect of spindle speed, feed rate, and tool overhang variables all at once toward tool vibration amplitude is greater than the use of ½ inches tool. On the regression equation of turning vibration amplitude on ½ inches tool, the Constants of -0.3844 states that, if the independent variables like spindle speed, feed rate and tool overhang equals to zero, then the vibration amplitude is -0.3844 μm. Regression coefficient (X₁) of 1.351.10⁴ states that, the addition of spindle speed of 1 rpm will decrease the vibration amplitude of -1.351.10⁴ cm/s. Regression coefficient (X₂) of 0.015488 states that, every 1mm addition of tool overhang will increase vibration amplitude 0.015488 cm/s. Regression coefficient (X₃) of 1.144454 states that, addition of every 1 mm/rev feed rates will increase vibration amplitude 1.14445 cm/s. From the two equations of regression above, it can be seen that coefficient of X₁, X₂ and X₃ on the use of 3/8 inches cutting tool is higher than independent variables coefficient on ½ inches, on the other words, response of independent variable towards vibration amplitude for the use of 3/8 inches tool is greater than the use of ½ inches tool.

To determine the most influential independent variables on the magnitude of the vibration amplitude, the correlation analysis tests is conducted. From the calculation of the correlation coefficient on ½ inches tool shows that the most influential factor on lathe vibration amplitude is tool overhang with correlation value 0.6968 at 99% confidence level, the next is feed rate 0.6182 and the last is spindle speed 0.2767.

In addition, correlation analysis on the use of 3/8 inches cutting tool, shows that the most influential factor on the tool vibration amplitude is tool overhang on the correlation value of 0.718, then the feed rate 0.602 and the last is spindle speed which reaches 0.293. as all correlation coefficients are positive, it means that, by increasing the amount of spindle speed, tool overhang, and feed rate will increase tool vibration amplitude. Nevertheless, value of correlation coefficient on the use of tool is 3/8 inches which has a higher correlation value than the use of ½ inches for its all independent variables.

From the results of statistical data processing, for ½ inches tool bit, shows that 95.1% of the variation in surface roughness value is a result of the influence of variable spindle speed, feed rate and cutting tool overhang simultaneously. While the remained of 4.9% is the result of other factors. On the use of 3/8 inches tool bit found that the effect is greater than ½ inches usage ie 95.9%. From the regression equation generated by the use of both types of cutting tool seen that the coefficient of X₁, X₂ and X₃ on the use of 3/8 inches tool bit is greater than the coefficient of the independent variable on the use of 1/2 inches tool bit, in other words, the response to the independent variable of vibration amplitude at the use of 3/8 inch tool bit is much greater than the use of ½ inches tool bit.

The most influential independent variable towards surface roughness value based on correlation analysis test among variables, both for ½ inches and 3/8 inches tools are feed rate, then spindle speed, and the last is tool overhang. Minus sign on the correlation coefficient on the influence of spindle speed states that, the greater the spindle speed is, the smaller the value of surface roughness (Rₐ) to be generated. where the smaller the value of Rₐ, the smoother is the surface [15].

C. Conclusion
The effect of feed rate, spindle speed, tool overhang, and tool dimension simultaneously towards vibration amplitude by using ½ inches tool bit is 94.4 %, while the use of 3/8 inches tool bit is 96.3%. The effect of feed rate, spindle speed, tool overhang and tool dimension all at once towards surface roughness by using ½ inches tool bit is 95.1%, while the use of 3/8 inches tool bit is 95.9%. Amplitude correlation of tool vibration by using ½ inches tool towards tool overhang 69.68%, towards feed rate 61.82% and spindle speed 27.67%.

From the regression equation generated by the use of both types of cutting tool seen that the coefficient of X₁, X₂ and X₃ on the use of 3/8 inches tool bit is greater than the coefficient of the independent variable on the use of 1/2 inches tool bit, in other words, the response to the independent variable of vibration amplitude at the use of 3/8 inch tool bit is much greater than the use of ½ inches tool bit.

The most influential independent variable towards surface roughness value based on correlation analysis test among variables, both for ½ inches and 3/8 inches tools are feed rate, then spindle speed, and the last is tool overhang. Minus sign on the correlation coefficient on the influence of spindle speed states that, the greater the spindle speed is, the smaller the value of surface roughness (Rₐ) to be generated. where the smaller the value of Rₐ, the smoother is the surface [15].

REFERENCES

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Effect of Water Volume and Biogas Volumetric Flowrate in Biogas Purification Through Water Scrubbing Method

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Abstract—Energy supply is a crucial issue in the world in the last few years. The increase in energy demand caused by population growth and resource depletion of world oil reserves provides determination to produce and to use renewable energies. One of the them is biogas. However, until now the use of biogas has not yet been maximized because of its poor purity. According to the above problem, the research has been carried out using the method of water absorption. Under this method it is expected that the rural community is able to apply it. Therefore, their economy and productivity can be increased. This study includes variations of absorbing water volume (V) and input biogas volume flow rate (Q). Raw biogas which is flowed into the absorbent will be analyzed according to the determined absorbing water volume and input biogas volume rate. Improvement on biogas composition through the biogas purification method was obtained. The level of CO\(_2\) and H\(_2\)S was reduced significantly specifically in the early minutes of purification process. On the other hand, the level of CH\(_4\) was increased improving the quality of raw biogas. However, by the time of biogas purification the composition of purified biogas was nearly similar to the raw biogas. The main reason for this result was an increasing in pH of absorbent. It was shown that higher water volume and slower biogas volume rate obtained better results in reducing the CO\(_2\) and H\(_2\)S and increasing CH\(_4\) compared to those of lower water volume and higher biogas volume rate respectively. The purification method has a good promising in improving the quality of raw biogas and has advantages as it is cheap and easy to be operated.

Keywords—Biogas, CH\(_4\), CO\(_2\), H\(_2\)S, water absorption

I. INTRODUCTION

In the last few years the continuously uninterrupted supply of energy has been a crucial problem in Indonesia. The increase of energy demand which is caused by population growth and acceleration in industries has pressured the government to explore much new and alternative energy to maintain the development. One of the alternative energy is biogas. Biogas is a promising energy among other alternative fuels as it is renewable with abundant feedstock and can be produced in rural area with relatively low operational cost [1, 2]. Therefore, biogas can be the solution for this renewable energy promotion scheme as well as an alternative for reduction of greenhouse gases emissions.

Biogas, a clean and renewable from of energy can be a good substitution of conventional sources of energy which are causing ecological-environmental problems and at the time depleting at a faster rate [3, 4]. Biogas is the combustible gas produced through an anaerobic digestion at low-temperature and without oxygen. Thus it application includes electricity, heating and cooking. On the other hand, there is lack of good management of the ever-increasing amounts of manure solid and liquid waste in many communities. Most of the rural communities discharged the manure without treatment directly onto wasteland or into rivers and streams. This behavior leads to unhygienic environment with attendant bad odors and flies [5]. With appropriate treatment, the manure can be converted into biogas. Biogas is defined as mixture of gases, consisting of methane (CH\(_4\)), carbon dioxide (CO\(_2\)), hydrogen sulfide (H\(_2\)S) and traces of other gases like nitrogen (N\(_2\)), oxygen (O\(_2\)), hydrogen (H\(_2\)) and ammonia (NH\(_3\)). The composition of biogas depends on the organic material as well as on the conversion technology used, varying between 50-75% CH\(_4\), 25-45% CO\(_2\), and 0-20 000 ppm of H\(_2\)S [6].

From the constituents of biogas, CH\(_4\) and CO\(_2\) are the main compounds in determining the quality of biogas. If the level of CH\(_4\) is high, the biogas will has higher calorific value. On the other hand, if the level of CO\(_2\) is high, the quality of biogas will be worse, marked by lower calorific value. Therefore, to improve the calorific value of biogas in order to be used effectively as fuel, the level of CO\(_2\) should be reduced or eliminated [6]. On the other hand, H\(_2\)S, a kind of highly toxic and corrosive gas, inhibits the biogas process directly, as well as indirectly in the case of higher H\(_2\)S concentrations in digestor. To avoid the negative effects of H\(_2\)S, a reduction of H\(_2\)S concentration in biogas is required before combustion [6, 7].

Removal of CO\(_2\) and H\(_2\)S from biogas is the main factor to improve the biogas quality [8]. To pursue this aim, a purification method is required to treat raw biogas. Some biogas purification methods have been performed, and water scrubbing method can be a solution as it is a simple and cheap
method among the methods [9].

Apart from cheap and simple, the water scrubbing method is easy to use specifically for cattlemen in rural areas. It is possible as the method use simple technology. Therefore, applying the biogas purification method is expected triggering the productivity and economy of rural community.

II. EXPERIMENTAL PROCEDURE

A. Raw biogas

The raw biogas used in the experiment come from anaerobic process in a digester located in the Renewable and New Energy Laboratory, engineering faculty Mataram University. The raw material for the biogas is from cow dung. The ratio of cow dung and water for biogas production in digester is 1 : 1. According to the previous experiment, it was found that this ratio could produce maximum biogas volume in relatively shorter period of anaerobic process. The produced biogas is then flowed to a receiving-station before directed to biogas scrubbing unit. Before collecting the experimental data of purified biogas, data of raw biogas components such as CO$_2$, H$_2$S and CH$_4$ was taken. The value for each component was 33.6%, 208.33 ppm and 59.36% respectively for CO$_2$, H$_2$S and CH$_4$.

B. Experimental variables and equipments

The experiment was performed by applying some variations such as biogas volume flow rate and water volume. The biogas volumetric rates were Q$_1$ = 1 lt/min, Q$_2$ = 2 lt/min, and Q$_3$ = 3 lt/min while the water volume was 10, 15 and 25 liters. The data were taken continuously for 30 minutes long for each operating condition. The research also has a purpose to know the relative humidity of the purified biogas as the contact with water may rise the relative humidity of biogas.

The component of biogas was measured using a biogas tester (GEO TECH) which measured compounds such as CH$_4$, CO$_2$, O$_2$ and H$_2$S with accuracy level of ± 0.5% vol. The relative humidity of purified biogas was measured using humidity sensor (SHT 11) which has ability to measure humidity under temperature range from -40 to 123 °C. The range of humidity measurement starts from 0 to 100%. To increase the biogas stream pressure which goes to scrubbing unit, biogas vacuum pump model BP-01 equipped with double-stage-pump was used. Biogas volume rate was measured accurately using biogas dedicated flow meter which has ability to measure flow rate until 4 m$^3$/hr.

C. Biogas scrubbing unit.

The biogas scrubbing unit used for the research has 250 mm long, 250 mm wide and 750 mm high. The unit was made from glass in order to observe visually the flow pattern governed by biogas in absorbent. The biogas input channel was located downstream at the top of the unit to allow the absorbent and biogas has longer contact. The schematic diagram of the unit is shown in Figure 1 below.

![Figure 1. Schematic diagram of water scrubbing unit](image)

The scrubbing unit was set up and connected to measurements apparatus and other components as can be seen in Figure 2 below.

![Figure 2. Schematic diagram of experimental setup](image)

III. RESULTS AND DISCUSSION

A. Methane (CH$_4$)

Methane is the main component in biogas and can reach as much as 55% after anaerobic process in digester [10].

![Figure 3. Methane concentration at 15 liter of water volume](image)
This percentage is considered relatively low for heating and as a fuel purposes. The experiment results show that the level of methane before purification is 59.36%. However, after the purification process, the level of CH₄ was increased. Results show that the concentration of CH₄ was improved to 60.4% where reached in the operating condition of 25 liter of water volume and 1 lt/min for biogas volumetric flow rate respectively. Additionally, the lowest improvement for CH₄ was of 59.36%, was gained in operating condition of 15 liter of water volume and 3 lt/min for biogas volumetric flow rate respectively (Figure 3).

It was shown that the higher water volume, the higher content of methane in biogas (Figure 4). It is resulted by the longer contact time occurred between water and biogas molecule in higher water volume operating condition. The contact between molecules leads to the absorption of the impurities substances in biogas into water molecule. Under higher water volume, the rate of reaching the higher methane concentration is faster compared to that of lower water volume (Figure 5).

However, the level of methane is maintained at constant rate even without more improvement. This is resulted by the maximum portion of acid substances absorbed into biogas molecule. This is indicated by the increase of acidity level of absorbent water. The change of water acidity brings the ability of absorbent water down to minimum. Therefore, it is required to maintain the absorbent acidity, pH 7 is the best for biogas scrubbing, in order to keep the absorbent water performance.

B. Carbon dioxide

Carbon dioxide is an impurities gas which has relatively high percentage in biogas. Carbon dioxide is an unburned gas and therefore resulted in the calorific value of biogas reduce significantly. The more CO₂ in biogas, the less calorific value of biogas is. In order to improve the biogas calorific value, reducing the content of CO₂ through biogas purification is a must. Carbon dioxide is a water-soluble gas. At room temperature, the solubility of carbon dioxide is about 90 cm³ of CO₂ per 100 ml water (Shakashiri, 2014). The application of water scrubbing method is expected to improve the quality of biogas by reducing carbon dioxide content.

The research showed that the most effective condition to reduce CO₂ was gained at 25 liter of water volume and 1 lt/min of biogas volumetric flow rate. While 15 liter of water volume and 3 lt/min of biogas volumetric flow rate showed the least effective to improve biogas quality as shown in Figure 6 and Figure 7.
Higher mixing rate occurred mainly due to slower biogas flow rate triggered faster reaction of molecules bonding among water, CO\textsubscript{2} and H\textsubscript{2}S molecules. This increased the partial pressure of the molecules to water molecules creating relatively strong bond among the molecules. Supported by higher water volume, the previous acid water created by CO\textsubscript{2} and H\textsubscript{2}S content in water was minimized. This condition made the concentration of CH\textsubscript{4} in biogas increased.

C. Hydrogen sulfide (H\textsubscript{2}S)

Although the concentration of hydrogen sulfide is very small in biogas but it has adverse effect both to environment and health [12]. Combustion of H\textsubscript{2}S leads to sulfur dioxide emissions which have harmful environmental effects. Removing H\textsubscript{2}S as soon as possible is recommended to protect downstream equipment, increase safety, and enable possible utilization of more efficient technologies such as combustion engines and fuel cells [13].

Hydrogen sulfide dissolves in water under 437 ml/100 ml of water at 0° C and 186 ml/100 ml of water at 40° C [14].

Before purification process, the concentration of H\textsubscript{2}S in biogas is 208.33 ppm, and reduced to 151 ppm after the treatment. Similar to carbon dioxide result, the highest reduction of H\textsubscript{2}S is gained in slower biogas volumetric flow rate (1 l/min) and higher water volume (25 liter) as shown in Figure 9. Other results at 15 and 20 l/min are shown in Figure 10. However, after about 20 minutes the productivity of absorbent decreased as the measured H\textsubscript{2}S in biogas almost similar to initial raw biogas. It indicated that the absorbent has been filled with H\textsubscript{2}S, CO\textsubscript{2} and other impurity gases from biogas. Therefore, this method is feasible to be applied for biogas purification specifically in the early measuring time. For longer continuous measurement, a modification and improvement are required not only to scrubbing unit but also to operating conditions to obtain better results.

IV. SUMMARY

Biogas purification through water scrubbing method is promising. This method is feasible as it can improve the biogas quality by reducing the biogas impurities compounds such as CO\textsubscript{2} and H\textsubscript{2}S. Moreover, this method has low
operational cost, durable and easy to be operated. This allows rural communities to apply this method for gaining their own energy resources. The research has found that the most effective condition to achieve the best results is running the experiment at slower biogas volumetric flow rate and higher water volume. At this operating condition the CO\textsubscript{2} can be improved up to 10.5%, and H\textsubscript{2}S up to 27.5%. A further research is required to make this method more promising and efficient as the reduction of CO\textsubscript{2} and H\textsubscript{2}S is occurred at the early minutes of measurement. Maintaining the pH of absorbent and eliminating moisture content of purified biogas are also a challenge in order to obtain high quality of biogas.

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Effect of Solution Treatment Process on Hardness of Alumina Reinforced Al-9Zn Composite Produced by Squeeze Casting

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Abstract—Characteristics of aluminium matrix composites reinforced by alumina have been developed to improve mechanical properties. One of the determining factors in the development of this material is parameter of solution treatment process. This study discusses the performance of the composite matrix of Al-9Zn-6Mg-3Si reinforced by alumina powder of 5% volume fraction. Composite are manufactured by squeeze casting process with the pressure of 20 Ton in the metal mould. To improve mechanical properties, the precipitation hardening process is conducted through variation of temperature of solution treatment of 450, 475 and 500 °C and holding time of solution treatment of 30, 60 and 90 minutes. Materials are characterized by hardness testing and microstructure observation. The results showed that the optimum condition of hardness was produced by solution treatment temperature of 500 °C and 90 minutes holding time of 86 HRB.

Keywords—aluminium matrix composite, alumina, squeeze casting, hardness

I. INTRODUCTION

Various engineering components in manufacturing technology need of material with good mechanical characteristics. Many innovations have been made to create a new kind of lightweight materials with excellent mechanical properties. Composite materials can be used as one of the alternatives to answer this challenge. Composite material can combine the excellent properties of consisting constituents to produce a new material with better characteristic, which offer several properties excellence such as high strength and stiffness, good toughness, good strength in high temperature, high wear resistance and having high ratio strength to weight [1,2].

In the current development, aluminium matrix composite is very promising, not only its good mechanical properties but also relates to its low density. Aluminum alloy is chosen as the matrix because this metal is light in weight, relatively cheap and easy to fabricate. Moreover, aluminium is a metal that have been produced independently in Indonesia, therefore it can be developed even further as many application for domestic needs.

The drawback is this material has lower strength than other commercial material such as cast iron, steel or copper. However the strength of aluminium can be increased through alloying, cold working and heat treatment through precipitation hardening process.

One of the aluminium alloys is Al-Zn, which exhibits the highest strength and in many cases they have higher strength than steel. This alloys is the combination of zinc and magnesium that produce the AA7xxx alloy which can be heated and formed a very high strength. For example, AA 7075 with composition of: Zn 5.0-6.0%, Mg 2.0-3.0%, Cu 1.0%-2.0% gives specific tensile strength of 580 MPa [3]. Zn element will increase hardness optimally, after the heat treatment precipitation hardening process [4]. The increase in Zn element up to 9% can increase hardness particularly after precipitation hardening, however Zn content in present study was limited to 9% because the higher the content, the possibility for hot cracking to occur is increase [5]. Based on this, in order to increase the hardness, Zn and Mg alloy elements added. Then heat treatment is conducted by precipitation hardening process on the composite to optimize the hardness. This research studies the influence of precipitation hardening parameter such as solution treatment temperature and holding time towards hardness of the aluminium matrix composite.

II. EXPERIMENTAL METHODS

Material used in this research is Al-3Si ingot added with alloying element, with 6 wt.% Mg and 9 wt.% Zn. Melting process conducted in the crucible furnace on the temperature of 850-870 °C. Powder alumina reinforcement with the size of 0.45 micron was poured with 5% volume fraction, then stirred with the velocity of 7500 rpm. Composite produced by squeeze casting process with the application of pressure of 20 ton in a preheated mould, in order to optimize the solidification process and minimized defects in the interface. The composite was then underwent heat treatment by precipitation hardening process to enhanced its mechanical properties. Precipitation hardening process on cast composite
plate is started by solution treatment with temperature variation of 450, 475 and 500 °C and variation of holding time of 30, 60 and 90 minutes; and followed by quenching in water, and then aging process is performed in temperature of 200 °C for 2 hours. Material characterization is conducted with chemical composition, microstructure observation with optical and electron microscope and hardness testing.

III. RESULTS AND DISCUSSION

Composite characteristic is significantly influenced by the content of alloying elements. Alloying of the matrix was conducted to improve its mechanical properties and the quality of the cast metal. Ingot aluminium with silicone element used for enhanced castability of the casting material. Adding Mg content improved wettability on the interface area between the matrix and alumina reinforcement [6]. It was renowned that the interface condition is very important in determining the needed properties of the composite systems because it functions as the media for transferring the load from reinforcement-matrix-reinforce [7]. Whereas, the addition of Zn will increase hardness and strength of aluminium alloy after precipitation hardening process [8].

Table 1. The compositions of the matrix.

<table>
<thead>
<tr>
<th>Content (wt. %)</th>
<th>Zn</th>
<th>Mg</th>
<th>Si</th>
<th>Fe</th>
<th>Mn</th>
<th>Cu</th>
<th>Ni</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9.16</td>
<td>6.12</td>
<td>2.90</td>
<td>0.22</td>
<td>0.003</td>
<td>0.003</td>
<td>0.206</td>
<td>Balance</td>
</tr>
</tbody>
</table>

Table 1 shows the chemical compositions of the composite. As listed in the table, besides the intentional additions, other elements such as Fe, Mn and Cu are also present. Even small amount of these impurities causes the formation of a new phase component [9]. Through casting various intermetallic phases are formed between aluminium dendrites [9,10]. These intermetallic phases have different structures, stabilities and mechanical properties. Based on this reason, the cast composite require solution treatment to improve mechanical properties. During this treatment some transformation of intermetallic phases such as plate-like β-Al12FeSi into more rounded discrete α-Al12(FeMn)3Si particles; and dissolution of β-Mg3Si particles [11]. These transformations will give maximum hardness after aging process [11,12]. The hardening process is conducted in order to improve hardness and toughness of a matrix. The heat treatment process will decrease Mg3Si on grain boundary and increase volume fraction of α-aluminium on matrix, which then will produce precipitate MgZn2, which settle in the grain, due to aging process [8].

The microstructure of the studied alloys is given in Figure 1. The heat treatment process will optimize the Zn function though precipitation mechanism, this could be seen from other particle morphology/second phase, distribution and shape. The figure shows that the matrix have more globular shaped structure with solution temperature of 500 °C. It indicates that the higher temperature of solution treatment will dissolve dendritic structure. The higher solution treatment temperature the hardening process started earliest and proceeded fastest. The figure also shows the squeeze casting technology seen to be succesfully in preventing the occurrence of shrinkage due to the solidification process.

To observe the presence of precipitate more clearly SEM/EDS examination was conducted, as seen in Figure 2. Micro analysis using the SEM-EDS result on the Table 2 showed that there was MgZn2 precipitations present in the matrix that inhibit dislocation process resulting in the increase in mechanical properties of the Al-9Zn-6Mg-3Si composite [13]. Alumina in the composite showed to be distributed evenly so that it can be concluded that the stirring process with 7500 rpm seen to be distributing the alumina particles evenly.
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Figure 2. SEM examination on the composite with Al-9Zn-6Mg-3Si matrix with 5 % alumina reinforcement, dissolution temperature of 500 °C, holding time duration of 30 minutes, and aging temperature 200 °C.

Table 2. EDX on Al-9Zn-6Mg-3Si composite with alumina reinforcement, on position according to Figure 3.

<table>
<thead>
<tr>
<th>No.</th>
<th>Composition (wt. %)</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
<td>Mg</td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>2.49</td>
</tr>
<tr>
<td>2</td>
<td>11.49</td>
<td>17.37</td>
</tr>
<tr>
<td>3</td>
<td>4.45</td>
<td>3.15</td>
</tr>
<tr>
<td>4</td>
<td>3.14</td>
<td>4.16</td>
</tr>
</tbody>
</table>

Table 3 shows the effect of solution temperature and holding time on hardness after aging process of the composite. Increasing solution treatment temperature of 450 to 475 and 500 °C improves hardness for all holding time of 30, 60, and 90 minutes. It has been discovered that the hardness is well correlated by the solution heat treatment temperature with linear characteristic. This condition is owing to fact that the amount of alloying elements in a supersaturated solution will form the hardening particle of MgZn$_2$ phase precipitated during aging process, rises along with increasing of solution treatment temperature. The figure also illustrates that the duration of dissolution as much as 60 or 90 minutes did not exhibiting significant influence. This was possible due to the Zn has been diffused completely into the Al matrix during the duration of dissolution as much as 60 minutes, thus with the reason for energy efficiency the optimum condition design for the duration of dissolution taken was 60 minutes.

Figure 3: Effect of solution treatment temperature to matrix hardness of Al-9Zn-6Mg-3Si reinforced with 5 % alumina fraction volume, with various holding time of solution treatment of 30, 60, and 90 minutes.

The higher solution treatment temperature maximalized the dissolved Zn in the matrix, whereas increasing the hardness by forming MgZn$_2$ phase precipitated in matrix, which inhibits the dislocation movement. In the present study, the Zn content was limited to only 9 wt. % Zn because increasing Zn content will lead to hot cracking.

IV. CONCLUSIONS

From the testing and analysis on Al-9Zn-6Mg-3Si matrix composite with 5% volume fraction of alumina reinforcement it can be concluded that:

1. Increasing solution treatment temperature from 450 °C to 475 and 500 °C improved the hardness of the composite with the highest value was HRB 86.
2. Increasing solution treatment holding time from 30 minutes to 60 minutes improved the hardness of the composite, while the improvement was slight by rising holding time from 60 to 90 minutes.
3. The improving hardness after heat treatment process was caused by the formation of MgZn$_2$ phase precipitation in composite.

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Review of Carbon Fiber Reinforced Polymer
Reinforced Material in Concrete Structure

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Abstract—Carbon Fiber Reinforced Polymer (FRP) is a material that is lightweight, strong, anti-magnetic and corrosion resistant. This material can be used as an option to replace the steel material in concrete construction or as material to improve the strength of existing construction. CFRP is quite easy to be attached to the concrete structure and proved economically used as a material for repairing damaged structures and increase the resilience of structural beams, columns, bridges and other parts of the structure against earthquakes. CFRP materials can be shaped sheet to be attached to the concrete surface. Another reason is due to the use of CFRP has a higher ultimate strength and lower weight compared to steel reinforcement so that the handling is significantly easier. Through this paper suggests that CFRP materials can be applied to concrete structures, especially on concrete columns. Through the results of experiments conducted proved that the concrete columns externally wrapped with CFRP materials can increase the strength. This treatment is obtained after testing experiments on 130 mm diameter column with a height of 700 mm with concentric loading method to collapse. The experimental results indicate that a column is wrapped externally with CFRP materials can achieve a load capacity of 250 kN compared to the concrete columns externally without CFRP material which only reached 150 kN. If the column is given internally reinforcing steel and given externally CFRP materials can reach 270 kN. It shows that CFRP materials can be used for concrete structures can even replace reinforcing steel that has been widely used in building construction in Indonesia.

Key words—CFRP material, concrete structure, increase strength.

I. INTRODUCTION

Technological developments, especially the rapidly growing field of materials characterized by the appearance of materials such as FRP Composite. For building construction such as bridges or buildings previously used material of bamboo, wood, and steel that serves as reinforcement. However, the material for structural applications is updated by an expert building or construction material in the world along with the emergence of the material weakness. Bamboo materials such as those used for the construction proved to have some drawbacks, such as bamboo has a very low resistance, so the potential for bamboo powder beetles attacked, so the buildings are made of durable bamboo. Therefore the order of the building from bamboo that is not preserved only seen as a temporary building components simply do not hold more than 5 years.

For wood materials are also widely used for the construction of houses, offices, and bridges in particular in the village, but this material was also proved to have weaknesses. The disadvantage is extremely flammable, can be eaten by termites, may expand and creep, stretch for apps roof with wood construction is often limited due to the size of the timber on the market is only about 4 meters, and other weaknesses in terms of procurement, then in the long run the price of wood are increasingly expensive because of the decreasing availability of natural wood materials. Other materials such as concrete have been widely used in Indonesia, but it also had shortcomings in terms of usage for construction. Weaknesses were found among forms that have made it difficult to change, the weak against the strong pull, has a heavy weight, great sound reflections power, and execution of work requiring high accuracy.

Meanwhile, the material of the steel used for the construction of buildings is still relatively large and very dominant utilized in Indonesia to date. This material has many advantages such as high tensile strength, not eaten by termites, able to carry a heavy burden, resistant to high temperatures, low maintenance costs, and easily molded according to the needs of the construction. However, it turns out, according to experts looking at the field of construction materials still have a shortage of them can be rusty, weak against the compressive force, not as flexible as wood can be cut and shaped a variety of profiles, not solid, and not resistant to fire, and in the case of slender structures harmless against buckling. Therefore, the various shortcomings of the steel material and other materials such as bamboo, wood, and concrete. So the development of
Civil engineering construction material appears more promising and superior to other materials that CFRP material. Superiority in terms of stress and strain in the CFRP material compared to other materials can be seen in Figure 1 below (Tamon U, 2004).

For the construction of the developing world of technology in the field of civil engineering materials and structural systems running very fast. This is demonstrated by the increasing proliferation of research and discoveries are oriented to the use of high performance materials coupled with the structure of the research system, the better. The combination of the use of high-performance materials in structural components is reasonable and in certain circumstances can not be avoided anymore. These conditions, among others, due to the demands of mechanical performance, durability, ease of construction, environmental and economic aspects. Application of CFRP materials can function as a repair and strengthening of concrete structures. Retrofitting with CFRP system function can improve strength and provide increased flexural capacity, shear, axial, and ductility. CFRP materials for building construction has many advantages, including high durability CFRP and more economical use in corrosive environments than are easily corroded steel material.

The use of CFRP is more popular considering the number of benefits that can be obtained as the weight of the unit is a small, easy to apply and are handled, the cost of installation and low maintenance. Material can provide the most economical solution in retrofitting problem because it can dramatically reduce the cost of labor. CFRP can be used to increase the bending and shear capacity of reinforced concrete beams, bending plate, push, shear and flexural column. CFRP in the form of sheet, plate or bar can be mounted on the surface of the beam or plate having a stretch as a flexure reinforcement. As the beam shear reinforcement, CFRP sheets can be glued to the side of the beam. Usage on columns, CFRP sheets can be placed on the outside of the column to increase the ductility and strength.

CFRP material that can stick to the structural elements such as beams, columns, plates, then given the adhesive epoxy resin has the basic ingredients. This adhesive is made from a mixture of two components. Its main component is an organic liquid that is loaded into the epoxy, binding arrangement or oxygen atoms and two carbon atoms. Was added to the reaction mixture to obtain the final mix. The surface to be attached should be prepared to obtain an effective juxtaposition including cleanup efforts on the surface of the structural element to be attached to the CFRP materials are free from contaminants oxide, oil, grease, and dust.

In this research, testing the strength of the CFRP material serves as reinforcement in concrete columns. The columns were tested circular column with a diameter of 130 mm and length is 700 mm column. The focus of research is directed at improving the lateral voltage such that it adds strength, slow collapse process as well as a wide cross-section of the column is ductile collapse. The results of this study, results in a significant force in the column. This suggests that the use of CFRP materials can be used as a function of reinforcement and become an alternative to steel reinforcement that has been most widely used in building construction in Indonesia.

II. LITERATURE REVIEW

A. Research results of CFRP materials for Construction

Elmabelsy G and M Saatcioglu conduct research related to the improvement in the round concrete columns designed with FRP materials in 2004 in Canada. They perform tests of three large-scale bridge columns are reported in this paper. All columns had a 508 mm circular cross-section and were designed to have predominantly flexural response with a shear span of 2.0 m Measured to the point of application of load, consisting of 1.7 m of concrete column height and 0.3m of top loading beam height. They were reinforced with 12 - 19.6 mm diameter, 400 MPa grade deformed reinforcement, Equally distributed along the section perimeter. Each bar was spliced near the base with a splice length of 390 mm, corresponding to 20 times the bar diameter. Each column had a diameter of 11.3 mm deformed transverse reinforcement, spaced at 300 mm in the form of circular hoops with overlapping ends. The first column tested (BR-C8) was the reference column reflecting as-built conditions, without any seismic retrofit. The companion two columns were retrofitted with MBrace CF 130 carbon fiber sheets. Column BR-C8-1 had four plies of CFRP sheets, whereas Column BR-C8-2 had two plies wrapped around the column. The surface of columns was first treated with an epoxy-based primer. The CFRP sheets were pre-cut to the required length and applied on columns with epoxy saturant. Coupons were made from CFRP jacket and tested to establish the actual stress-strain relationship of composite materials. Accordingly, the jackets had approximately 60,000 MPa elastic modulus and ultimate strength of 700 MPa, with linear elastic behavior. From these tests yield data shown in Figure 2, 3, and 4.
Referring as built conditions

Figure 3. Column BR-C8-1, retrofitted with 4 plies of CFRP sheets

Figure 5. Experimental stress-strain curves for Toronto specimens

By looking at figure 2, 3, and 4 can be reported that the columns with spliced longitudinal reinforcement in their potential plastic hinge regions near the base have limited drift capacity. The circular column tested in this investigation developed lateral drift ratio of 1% prior to significant decay strength. The failure resulted from slippage of spliced reinforcement. Then, the circular columns retrofitted with CFRP sheets showed significantly improved hysteresis behavior. Hoop tensioned developed in the CFRP jacket maintained the bond between reinforcement and concrete in the splice region. The column with four plies of CFRP sheets (jacket thickness of 3.6 mm) was able to sustain in excess of 6% lateral drift ratio without significant decay strength. The companion column with two plies of sheets (jacket thickness of 1.8 mm) showed 4% to 5% drift ratio with pinched hysteresis loops.

Benzaid R and Mesbah AH also conduct research investigations on round and rectangular concrete columns of CFRP externally supplied. The experimental program was carried out using column specimens with a square cross section of 140x140 mm and a height of 280 mm. For all RC specimens the diameter of the longitudinal and transverse reinforcing steel bars were respectively 12 mm and 8 mm. The longitudinal steel ratio was constant for all specimens of 2.25% and equal to . The yield strength of the longitudinal and transverse reinforcement was 500 MPa and 235 MPa, respectively.

The results of this investigation reported that in all cases the presence of external CFRP jackets increased the mechanical properties of PC and RC specimens, in different amount according to the number of composite layers, the concrete properties and the cross-section shape, thus the use of Carbon Fiber Reinforced Polymer is an efficient means of providing confinement of concrete for strength and ductility enhancement.

Samdani S and AS Sheikh also conduct research related to concrete columns given CFRP confinement. Twenty-eight nearly full-scale concrete columns were tested under monotonic concentric load at the University of Toronto. The variables tested in the experimental study included the type of FRP (glass or carbon), the number of layers of FRP, the orientation of fibers in the FRP shell and the amount of lateral reinforcement. All specimens were 356 mm in diameter, 1524 mm high standing. The response of the concrete confined with FRP showed two slopes of the ascending branch before the peak stress. The first slope was approximately equal to that of unconfined concrete. The second slope, being less steep, started near the peak stress of the unconfined concrete and continued until the peak. This was followed by a significant post-peak response that continued until the FRP shell was sufficiently ruptured, resulting in a sudden drop of stress in concrete. Figure 5 shows the axial stress-axial strain curves for some of Toronto specimens, confined with 1 and 2 layers of CFRP and GFRP.

From figure 5 we see that the concrete was not given CFRP and GFRP rebars experiencing rapid collapse. However, if given the CFRP and GFRP materials externally, the stress and strain increased significantly from concrete without reinforcement of CFRP and GFRP. If given 2 layers of CFRP and GFRP then continue to experience an increase of 1 layer of CFRP and GFRP rebars. The incidence of laboratory results indicate that given the additional CFRP layers, the more stress and strain increased.

Ongpeng CMJ doing research for improvement in the column using CFRP materials in 2006 in Manila. In his study, ninety four specimens of sizes 180mm diameter by 500mm height were fabricated and tested. This means fully wrapped CFRP specimens were used with the unconfined compressive strength of 30 MPa, 120 mm spacing for the steel ties, using two plies of CFRP, and the first specimens out of a total of three identical specimens. In wrapping CFRP to the concrete specimens cured for 28 days, the fibers were oriented 90° with respect to the longitudinal axis of the concrete column. In the preparation of the epoxy matrix, the resin and hardener
ratio is 4:1 and was hand mixed for at least 5 minutes. The overlap of CFRP is 35 mm and 70 mm for the one- and two-layer of CFRP respectively. The results of this study can be seen in Figure 6 the stress-strain diagrams of the three specimens that have no steel ties and 40-mm spacing of steel ties, respectively, with increasing amount of CFRP ply used from zero to two plies. It can be observed that the confinement effect of using CFRP and steel ties had increased the compressive strength and the average longitudinal strain represents that the ductility of the specimen.

Figure 7 Stress-Strain diagram of specimens with steel ties

Furthermore, Ongpeng CMJ and Oreta CW also conducted research on the effect of CFRP on restraints on a column by using Artificial Neural Networks. In this study, there are three sets of the data collected from references. It was categorized as follows: SC (Steel Confinement) data sets that steel ties used alone as confining material, CC (CFRP Confinement) set - that the data used alone as confining CFRP material, and SCC (Steel and/or CFRP Confinement) data sets that used both, steel ties and/or CFRP, as confining materials.

From these results, it was found the effect of CFRP on concrete columns. Effect of CFRP materials can be seen in the image below. Figures 8 and 9 that there is an abrupt increase is of at least 65% to 100% in $f'_{cc}$ from zero-ply to one-ply of CFRP Regardless of the spacing of lateral steel ties. However, by adding another ply of CFRP to a total of two plies, the increase of was minimal. One common geometric property between the column by Mander et al 1988b Hoshikuma et al 1997 and is the outer diameter D. Both columns have are relatively large outer diameter D = 500 mm for both, and the core diameter, d = 438 mm and d = 500 mm respectively.

Figure 8. Mander et al 1988b with addition of CFRP sheets as confinement (D=500mm, d=438mm, L=1500mm, $p_{cc}$=1.6%, $f_{ys}$=340 Mpa, lateral steel bar diameter=12 mm, and $f'_{cc}$=28 Mpa)

In figure 10, using closer tie spacing, which results to an increase in $p_{s}$, led to a gradual increase in $f'_{cc}$. On the other hand, increasing the over-all thickness of the CFRP by varying the number of CFRP ply also shows significant enhancement of compressive strength. Except for the RC column having no steel ties, an addition of 1-ply led to no increase in $f'_{cc}$.

Figure 9. Hoshikuma 1997 with addition of CFRP sheets as confinement (D=500mm, d=500mm, L=1500mm, $p_{cc}$=1.01%, $f_{ys}$=295 Mpa, and $f'_{cc}$=28.8 Mpa)

In figure 11 can be seen throughh enhancement due to superposition effect of each material are less than that of the actual experimental data for 1-ply and 2-plies of CFRP. On the other hand, the ANN model SCC9-7-1B, which assumed no superposition of strength enhancement on each confining materials, but rather the total enhancement due to the interaction of both.

Figure 10. Sakai et al 2000 with addition of CFRP sheets as confinement (D=200mm, d=185mm, L=600mm, $p_{cc}$=1.18%, $f_{ys}$=376 Mpa, and $f'_{cc}$=29.8 Mpa)

In figure 11 can be seen throughh enhancement due to superposition effect of each material are less than that of the actual experimental data for 1-ply and 2-plies of CFRP. On the other hand, the ANN model SCC9-7-1B, which assumed no superposition of strength enhancement on each confining materials, but rather the total enhancement due to the interaction of both.
B. Application of CFRP in the construction

In research Hota G and Liang R in 2011 relating to the use of CFRP Civil Infrastructures. This study is an example of CFRP retrofitting has been Widely used successfully to Strengthen the structures as an effective disaster prevention approach or to restore the damaged structures after disasters such as hurricanes and Earthquakes. In the United States, many of the existing highway or railroad bridges have either reached the end of Reviews their service life or require rehabilitation to continue in service. Due to Decreased funding levels for new constructions, government agencies are interested in utilizing FRP wraps to rehabilitate structures at a fraction of the outright replacement cost and extend the structural service life for few more decades. The advantages of CFRP wraps include a minimum of traffic disruption, efficient labor utilization, ease of rehabilitation, optimization of load transfer, and cost effectiveness. CFC-WVU laboratory has been actively involved with FRP wrapping advanced technology development, Including specific design methods, material selection, field installation procedures, performance requirements and subsequent inspection techniques.

Figure 12 is a group of photos showing how damaged piles of 11 timber railroad bridges on South Branch Valley Railroad (SBVR) lines in Moorefield, WV were rapidly rehabilitated and restored in-situ without affecting the rail traffic, with the use of Fiber Reinforced Polymer (FRP) composites (July 2010). These timber bridges consisted of total span lengths varying from 75 ft. to 1200 ft. with timber pile bents spaced 15-20 ft apart. The deteriorated piles were cracked, heart-rotted, and damaged to varying lengths. This rapid rehabilitation technique can be used on various other structural members including steel and reinforced concrete members in a highly cost effective manner to extend the service life of structural systems.

Furthermore, much of the existing building stock in Europe, as well as in developing countries, has been designed According to old standards and has little or no seismic provision and Often suffers from poor materials and construction practices. As a result, many existing buildings have deficient lateral load resistance, insufficient energy dissipation and can Rapidly lose during Earthquakes Reviews their strength, leading to collapse. Retrofit of seismically deficient structures before Earthquakes provides a feasible and cost-effective approach to improving Reviews their load carrying capacity and reducing Reviews their vulnerability. Over the last decade, the use of externally bonded fiber composite materials (FRPs) has offered engineers a new solution for strengthening seismically deficient buildings (Figure 13). The initial cost of FRP for strengthening is usually higher than conventional structural materials. However, they are much Easier to apply, and this is where composites offer significant economic benefits.
III. RESEARCH MODEL

In this article the authors also present the results of research on the use of CFRP materials are applied to the round concrete columns that serve as external reinforcement in concrete columns. The work is done through analysis and experimental studies. The study analysis was conducted to study the stress strain models that utilize concrete as a material CFRP reinforcement in concrete columns.

Models stress strain of CFRP material is then summarized and implemented in the form of a computer program Confined Column v.1.0 (CC-v.1.0) that have been made to produce a stress strain relationship chart. The program is used to validate the results of experimental studies.

In this study the implementation of the test specimen used in the column that is round with a diameter of 130 mm diameter by 700 mm long round columns. In this study conducted experiments on plain concrete columns (PS), which uses concrete columns internally reinforced steel (BT), and given a plain concrete column steel reinforcement internally and externally CFRP material (B-1 LS). Concrete used is normal strength concrete with a target compressive strength of 20.75 MPa. For longitudinal reinforcing steel used 6 ∅ 10 and ridden spiral reinforcement is ∅ 8-50 mm. Furthermore, an analysis and evaluation of the results of testing that has been done to study the behavior of restrained concrete columns with fiber polymer (CFRP) as well as models of effective restraint. In addition, we will get the formulation / formulas stress strain constitutive relations that occur due to the confined of the fiber polymer (CFRP). The resulting formulation results will be validated using the constitutive equations of the results of other researchers with the help of Confined Column v.1.0 program (CC-v.1.0) that have been made.

IV. RESULT AND DISCUSSION

Model collapse on circular concrete columns after testing in the laboratory can be seen in figure 13 below.

![Figure 13. Collapse of Specimen Model PS, BT, and B-1 LS](image)

Based on laboratory test results obtained from the maximum load of each variation of the concrete columns were tested, as shown in Table 1 in the column of concrete without confinement (PS), concrete columns with transverse reinforcement confinement and longitudinal reinforcement (BT), and concrete columns with confinement transverse and longitudinal steel reinforcement and external confinement with CFRP 1 (one) layer spacing (B-1 LS). In Table 1 are shown the maximum load difference of different variations of the test specimen.

<table>
<thead>
<tr>
<th>No</th>
<th>Specimen Code</th>
<th>Maximum Load (kN)</th>
<th>Maximum Load Average (kN)</th>
<th>Increased Maximum Load (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PS-A</td>
<td>150</td>
<td>150</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>PS-B</td>
<td>140</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>PS-C</td>
<td>160</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>BT-A</td>
<td>230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>BT-B</td>
<td>250</td>
<td>240</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>BT-C</td>
<td>240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>B-1 LS-A</td>
<td>280</td>
<td>270</td>
<td>80</td>
</tr>
<tr>
<td>8</td>
<td>B-1 LS-B</td>
<td>270</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>B-1 LS-C</td>
<td>260</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Research Results

Based on the research that has been summarized in Table 1 show that the concrete column specimen without restraint (PS) capable of withstanding a load of 150 kN, while the concrete columns with transverse reinforcement confinement and longitudinal reinforcement (BT) is able to withstand a load of 240 kN, and the concrete columns with transverse reinforcement confinement and longitudinal reinforcement as well as externally with CFRP confinement (B-1 LS) capable of withstanding a load of 270 kN. This suggests that an increase in the strength of the concrete column specimen BT by 60% when compared to columns that are not confined, while the test specimen B-1 LS increase is as high as 80% when compared to the concrete columns that are not confined. It shows that the functioning of the confinement of transverse and longitudinal steel reinforcement and confinement externally with the use of CFRP materials.

Stress strain curves for all test objects can be seen in Figure 14 as the comparative column specimens studied. Concrete column specimens were observed without the use of confinement, and concrete columns using CFRP restraint. In Figure 14 it can be seen that the presence of transverse and longitudinal reinforcement (Specimen BT) can improve axial compressive stress. The most influence on the value of confinement is the specimen B-1 LS because in addition to using the transverse and longitudinal reinforcement, also using CFRP material as an external confinement. Increased confinement posed CFRP compared to concrete specimen (BT) is 12.5%. The results showed that with the use of CFRP materials as an external confinement can increase the capacity of the concrete column. It is appropriate that disclosed by Mac Gregor (1997) which states loading triaxial strength of concrete with concrete (confinement) is greater than the compressive uniaxial loading.

A. Validation of Experimental Results

Validation of Value Unconfined Concrete Strength

The result of the increase in strength of confined concrete validation (K) to review the model formulation by previous researchers using triaxial test results can be seen in Table 2. The model being simulated is a model of Campione and...
Miraglo (2003), the model of Li et al (2003), and the model of Lam and Eng (2003).

![Stress strain curve of specimens](image)

**Figure 14. Stress strain curve of specimens**

Formulation of the model equations are then processed to determine predicted for confined concrete strength (K) as a validation of the experimental results of short column testing (short column) with CFRP confined concrete is given a concentric load. Validation is performed to determine the accuracy of each equation in predicting an increase in confined concrete strength (K) based on the experimental results. All three models are reviewed each have a value of COV (Coefficient of Variation) above 9%. Among the three models, the model of Lam and Teng have COV higher value, is 10.71%, which means closer to the experimental results with a 11.13% COV value. Meanwhile, the model of Li et al have COV values of 10.07%, and The Campione and Miraglo model has the value COV of 9.27% of the experimental results. All three models are reviewed indicates that predicted for confined concrete strength (K) to the experimental results are considered quite good because it has the value COV proximity to the experimental results.

**TABEL 2. COV VALUE OF PREDICTION RESULT VS EXPERIMENTAL RESULT**

<table>
<thead>
<tr>
<th>Model</th>
<th>COV (%) for ((K = f_{cc} / f_{ut}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campione and Miraglo (2003)</td>
<td>9.27 %</td>
</tr>
<tr>
<td>Li et al (2003)</td>
<td>10.07 %</td>
</tr>
<tr>
<td>Lam and Teng (2003)</td>
<td>10.71 %</td>
</tr>
<tr>
<td>Experimental Result</td>
<td>11.13 %</td>
</tr>
</tbody>
</table>

Source: Analysis Results

**Curve model validation of stress-strain unconfined concrete for experimental results**

Stress strain curve modeling confined concrete (confined concrete) transverse and longitudinal reinforcement and externally CFRP layers are calculated based on the results of experiments on 9 test specimens in the form of columns of normal strength concrete (NSC), and tested with concentric loading. Proposed stress strain curve is given one part based on the results of laboratory testing through system testing using Load Control technique with the speed of movement (stroke) of 0.012 mm / sec. The results of testing this model produces a stress strain curve the shape of the ascending branch. The resulting model is then summarized and carefully observed the movement of the model curve shape of the experimental results. The resulting shape of the curve in general form a parabolic curve with peak coordinates \((f_{cc}, \varepsilon_{cc})\). The results of the model formulation of the stress strain curve of the experimental results with comparison of some models of previous investigators are shown in Table 3, while, for the model of confined concrete stress strain curve of the experimental results with two models, namely the model in terms of Li et al (2003) and Model Campione and Miraglo (2003) is shown in figure 15.

**TABLE 3. CURVE MODEL OF STRESS STRAIN FOR CONFINED CONCRETE**

<table>
<thead>
<tr>
<th>Researchers</th>
<th>Curve Model of Stress Strain for Confined Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ascending Branch</td>
</tr>
<tr>
<td>Lam and Teng Model (2003)</td>
<td>(f_r = E_{cr} \varepsilon_r - \left(\frac{E_{cr}}{E_{cr,max}}\right)^n \varepsilon_r^n)</td>
</tr>
<tr>
<td>Model Li et al (2003)</td>
<td>(f_r = \frac{f_{cr}}{\varepsilon_{cr}} \left(\frac{\varepsilon_{cr}}{\varepsilon_{cr,max}}\right)^n)</td>
</tr>
<tr>
<td>Campione and Miraglo Model (2003)</td>
<td>(f_r = \frac{E_{cr}}{E_{cr,max}} \varepsilon_r + \left(\frac{E_{cr}}{E_{cr,max}}\right)^n \varepsilon_r^n)</td>
</tr>
<tr>
<td>Proposed Model Experimental Result</td>
<td>(f_r = 10193(\varepsilon_r - 1364 \varepsilon_r^2))</td>
</tr>
</tbody>
</table>

Source: Research Result of Lam and Teng, Li et al, and Campione and Miraglo Model

**Figure 15. Proposed Model of Confined Stress Strain Curve with Li et al, and Campione and Miraglo Model**
V. CONCLUSION

Based on the results of experimental studies that have been done, it can be concluded as follows:

- Calculation results of experiments on the effectiveness of the confinement of a plain column (PS), reinforced column (BT), as well as external confinement CFRP reinforced column (B-1 LS) with a COV value of 11.13% is considered good enough to see the result of validation of the value of K generated by Lam and Teng model, Li et al model, and Campione and Miragile model and the experimental result which each have a COV value of 10.71%, 10.07%, and 9.27%.

- The capacity of strength that occurred in plain concrete column (PS) is 150 kN. If given additional concrete column internally reinforced steel, the strength increased capacity is 240 kN. Effect capacity is the greatest force if given the confinement of steel concrete columns internally with CFRP material externally is equal to 270 kN. Thus, the addition of transverse and longitudinal reinforcement confinement (BT) has increased the strength by 60% when compared with plain column without confinement (PS), and an increase in capacity of the column concrete were confined by transverse and longitudinal reinforcement (BT) to concrete column were confined with transverse and longitudinal reinforcement or external confinement 1 layer CFRP spacing (B-1 LS) of 12.5%. With the results of these experiment that utilize CFRP material as an external confinement can provide increased strength to the concrete column and can be an alternative material for building construction and other building as reinforcement.

- Model of constitutive formulation proposed for stress strain can predict the stress strain curve of CFRP confined to the accuracy of the model is not much different from the model of Li et al, as well as the Miragile and Campione model.

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Material properties of various light metals produced by heated mold continuous casting

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Abstract—In the present work, an attempt was made to develop high quality cast aluminum alloys via a new casting technology, e.g., the heated mold continuous casting (HMC) with ultrasonic vibration (UV) process. With the UV process in the continuous casting process, fine and spherical grains were obtained, where the lattice structure is formed similarly before the UV process while dislocation density increases. The mechanical properties of the UV-HMC Al alloys are higher than those for the related cast Al alloys without UV although still high material ductility is obtained. The lattice and dislocation characteristics of the continuous cast samples made with and without the UV processes were analyzed systematically by the EBSD observations to interrupt clearly their mechanical properties.

Index Terms: aluminum alloy; ultrasonic vibration; continuous casting; mechanical property; microstructural characteristic

I. INTRODUCTION

In recent years, high fuel efficiency of automotive is required in our society, because of environmental issue. To make this, the reduction in exhaust gasses from the automotive, such as carbon dioxide and nitrogen oxide, would be required, as the number of automotive has been increasing to be more than 1 billion in the world. The automotive consists of a number of the related parts, and many of them have been made by cast irons and steels. It has been expected to replace Fe–based automotive parts with more lightweight metals, e.g., aluminum alloys. The specific weight of Fe is about 7.8, which is more than 2.8 higher than that for Al. Recently, the production amount of automotive parts, made of Al alloy, has been increasing gradually.

It is general consideration that small grains with spherical shape are significantly important to make excellent mechanical properties. To obtain such microstructural characteristics, some practical techniques of rapid solidification, high casting flow and adding fine nucleating elements are employed. Furthermore, new technologies have been proposed with mechanical modification, including electromagnetic vibration [1], mechanical vibration and mechanical shearing processes.

Aghayani and Niroumand [2] have examined the effects of ultrasonic vibration (UV) treatment on microstructural features and tensile strength. The melt alloy in sand molds was subjected to ultrasonic waves of different power levels for 5 min under frequency of about 20 kHz and the maximum power of 600 W, in which strong effect on the size and sphericity of alpha dendrites is obvious. Moreover, high applied ultrasonic power resulted in small, more rounded and uniformly distributed α–grain and eutectic particles. Feng et al. [3] have attempted to treat UV into the melt hypereutectic Al–23%Si alloy in a horn crucible.

From the above previous works, it appears that a number of experimental works have been conducted to make high quality cast Al alloys by the UV process [3]. However, the authors believe that there would have still chance to apply the UV technology in casting process. This is because, in the previous studies, the ultrasonic vibration is conducted only to the melt in crucibles and molds, i.e., simple approach. Moreover, there is apparently lack of the investigations to understand clearly the detailed vibration effect on the material properties. This is because the previous examination has been executed with the limited vibration conditions, e.g., a few vibration amplitudes and frequencies.

Thus, in the present study, an attempt was made to propose a new casting system of a heated mold continuous casting method with ultrasonic vibration in advance. With this casting system, mechanical properties of several Al alloys have been investigated. To understand clearly the effects of the UV process on the material properties of the cast Al alloys, the lattice and dislocation characteristics were scientifically analyzed.

II. EXPERIMENTAL PROCEDURE

II-1. Material preparation

In the present study, two aluminum alloys (AC4CH and ADC6) and pure aluminum (99.9%Al) were used. In order to create the high mechanical properties of cast aluminum alloys, a hybrid casting system was originally proposed, where an ultrasonic vibration (UV) device was added to our original heated mold continuous casting system, see Fig. 1. In this case, a small UV device (PEF-L25A, Sanki Corp.) was employed. The specification of this device is as follows: electric voltage: 0–240V and frequency: 40–400Hz. Such vibration is applied directly to the cast sample during the casting process. The HMC arrangement consists of a graphite crucible in a furnace, a graphite mold of 5 mm in diameter, a cooling device and a dummy rod for withdrawal of the cast sample. The graphite mold is jointed with the graphite crucible. The cooling system
was set just out of the mold. The ultrasonic vibration system was attached near the cooling system, and the vibrations were executed directly to the casting rod during the casting process. The melts in the crucible were fed continuously into the mold at 1.9 mm/s.

In the gravity casting (GC) process, the melt was poured directly into a metal mold. Note, the GC process would not be a represent conventional gravity casting process, as our gravity casting system does not include sprue, runner and gate.

II-2. Experimental

Microstructure, lattice structure and strain characteristics were investigated by various approaches including energy-dispersive X-ray spectroscopy (EDX), electron backscatter diffraction (EBSD).

EDX analysis was carried out to investigate the microstructural characteristics with an acceleration voltage of 20 kV a scanning electron microscope. The EBSD analysis was conducted to observe the crystal orientation characteristics with an acceleration voltage of 15 kV, beam current 5 nA and step size 0.5–20 μm. The samples were prepared with sectioning to less than 5 mm thick and with mirror flatness. This EBSD analysis was executed with HKL Channel 5 software.

III. RESULTS

III-1. microstructural characteristics

Fig. 2 depicts the optical micrographs for the pure aluminum, AC4CH and ADC6 alloys produced by GC and HMC processes. In this case, the HMC process was carried out with and without ultrasonic vibration. It can be seen that fine α-Al phase and tiny eutectic structures are observed in the HMC samples compared to their GC ones. In addition, those grains seem to be altered slightly to more fine spherical shape of α-Al grains with the ultrasonic vibration. Interestingly, core-like structures can be characterized in the middle of their grain for the UV pure-aluminum. From the EDX analysis, such core-like structure is related with the iron element (Fig. 3).
Fig. 4 presents the crystal orientation maps (IPF) for pure Al and ADC6, obtained by the EBSD analysis. It is obvious that a relatively uniform lattice structure is obtained over a large area in the HMC samples without ultrasonic vibration, where almost perfectly orientated crystal structure, i.e., single crystal-like formation.

It is interest to mention that even if the UV process conducted strongly, the crystal orientations are still relatively organized. However, their lattice structures, i.e., misorientation angle, are slightly disordered.

<table>
<thead>
<tr>
<th>HMC–pure Al</th>
<th>SEM image</th>
<th>Al-Kα</th>
<th>Fe-Kα</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure Al without UV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pure Al with UV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADC6 without UV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADC6 with UV</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4 The crystal orientation maps for pure aluminum and ADC6 by HMC with and without ultrasonic vibration.
Fig. 5 shows the electric conductivity (EC) of the cast samples. Note, in this case, the EC values were measured using the same specimen of $\phi 1 \text{ mm} \times 100 \text{ mm}$. To understand EC characteristics clearly, this was also carried out for commercial wrought pure Cu, wrought pure Al and continuous cast Al alloys. The data obtained in Fig. 5 is indicated with the rate of the EC value based upon the copper wire. It is clear that the electric conductivity for the commercial wrought pure Al wire is about 60% of the Cu wire one. Interestingly, slight improvement of the electric conductivity for the HMC–pure Al is obvious, which is approximately 15% higher than that for the wrought pure Al wire. This may be attributed to the uniformly organized crystal orientation, as mentioned in Fig. 4. Furthermore, it is obvious that the EC values for the cast Al alloys without UV (AC4CH and ADC6) are about 25% higher than those for UV. This is also influenced by the different crystal orientation characteristics.

Fig. 5 Rate of the electric conductivity for various metals on the basis of the copper wire one.

Fig. 6 displays the Vickers hardness of HMC–ADC6 alloy as a function of the vibration frequency. As seen, the hardness level of the Al alloy does not change significantly even if the frequency is altered. However, it is obvious that high hardness value is obtained for the sample with higher vibration amplitude. The highest hardness by UV is about 7% high compared to that for the cast samples without UV.

Fig. 6 Vickers hardness of HMC–ADC6 alloy as a function of the vibration frequency and vibration amplitude.

On the other hand, slight high ductility for the UV samples is attributed to the grain refinement and spherical structure. Fig. 9 represents the relationship between stress amplitude and cyclic number to final fracture (S-N curve) for ADC6 with and without the UV process. It is obvious that, like the tensile properties, the S-N curve for ADC6-UW is located to the higher level compared to the without UV one, namely the higher fatigue strength for ADC6-UW. On the basis of the above experimental results, it could be briefly summarized that the UV process is useful to improve the mechanical properties of the cast aluminum alloys.

Fig. 7 represents the representative tensile stress-versus-strain curves for HMC–ADC6 alloys with and without UV process. It is clear that there are different trends of the tensile properties depending on the UV process. Based upon the stress–strain curves obtained, ultimate tensile strength and fracture strain are summarized in Fig. 8. The tensile properties slightly increase for ADC6 with the vibration process. Such increment of the tensile strength would be caused by the change of the microstructural and lattice structures, as mentioned above. On the other hand, slight high ductility for the UV samples is attributed to the grain refinement and spherical structure.

Fig. 7 Representative tensile stress vs. tensile strain curves for ADC6 produced by the HMC process with and without ultrasonic vibration process.
IV. CONCLUSIONS

1) Electric conductivity for the HMC–pure aluminum is about 15% higher than that for the wrought pure Al wire. This is attributed to the uniformly organized crystal orientation. With the UV process, the EC levels for HMC-Al alloys decrease about 25% compared to those without UV, which is affected by the randomly distributed lattice structure arising from the UV process.

2) The hardness level of the ADC6 alloy is not changed significantly with increasing the UV frequency. In contrast, the high hardness was obtained as loaded at the high vibration amplitude. The highest hardness by UV is about 7% high compared to the mean hardness of the cast samples without UV.

3) The tensile strength and fatigue strength increase for the ADC6 alloy with the UV process. In addition, similar to the mechanical strength, the material ductility is also relatively increased with the UV process. Such increments of the strength are attributed to the change of the microstructural and lattice structures.

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REFERENCES


Microstructure and Mechanical Properties of Al-10Zn-4.5Mg-xCu Turbine Impeller Produced by Investment Casting

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Abstract--- Aluminium alloy can be applied for a turbine impeller of Organic Rankine Cycle power plant that operates at temperatures below 150 °C. Aluminum turbine impeller can enhance efficiency of turbine due to light weight material. Al 7xxx commonly use for impeller due to good mechanical properties. Turbine impeller commonly produced by machining but which is time-consuming and less efficient because of material removal. It can be replace by Investment casting to produce impeller turbine due to their complex geometry and precision. This study identifies effect Cu content of Al-9Zn-4Mg-xCu on the microstructure and mechanical properties of turbine impeller produce by investment casting. The study also identifies casting defect of turbine impeller. The structures consisted of α-Al, MgZn2, CuMgAl2 and CuAl2. Higher Cu content is the higher hardness value due to CuAl2 phase. Visual examination showed that the turbine impeller was free of macro defects and misruns.

Keywords: investment casting, aluminum alloys, turbine impeller, organic rankine cycle

I. INTRODUCTION

Process technology to produce turbine impeller is commonly by machining and investment casting because the geometry of turbine impeller is more complex, need highly precise, and the tips of the blades are very thin. Fabrication by machining produces is high precision but the cost is high due to lengthy process and material removal. Alternatively, investment casting can produce a highly precise parts characterized with more complex geometry. It is cheaper than machining since the material removal is not required [1]. However the microstructure and mechanical properties of cast products highly depend on alloys, ceramic shell, gating system solidification process. The failure rate in production of the impeller by investment casting has been 30-40% [2]. Some defects commonly appear in products of investment casting: these include misruns, inclusion, macro and micro porosity and hot cracks [3,4].

Al 7xxx commonly use for impeller due to lightweight, high strength to weight ratio, high corrosion resistance and excellent mechanical properties. Compressor turbocharger that operates on conditions similar to ORC turbine impeller, used Al-(1-2) Mg-(2-3) Cu (wt. %) with addition of titanium [5]. Wallace et al. [6], produced turbocharger impeller that operates at temperature of 90 °C by using thixocasting method. The composition of the alloy is Al-6Si-3Cu-0.35Mn (wt. %) with tensile strength at 400 MPa and the elongation of 7.7 %. The addition of Zn, Mg and Cu considerably increase the strength of Al alloys, due to precipitation of a much dispersed MgZn2 and CuAl2 phase during ageing.

The aims of this study is to produce turbine impeller for an ORC power plant by investment casting. The turbine impeller was made from Al-9Zn-4Mg with varied additions of Cu content. Microstructure and mechanical properties were identified to show the effect of additional Cu content.

II EXPERIMENTAL METHOD

The gating system and ceramic mold is used refer to previous research [7]. An Al ingot, Mg and Cu ingots were used as master alloys. Mg content was 4 wt. % and Cu content varied at 1, 3, and 5 wt. %. The alloys were melted in a graphite crucible. Degassing was conducted by using argon gases to avoid gas porosity. The nominal composition of the cast alloys is presented in Table 1.

| Table 1: Composition of cast alloys |
|---|---|---|---|---|---|---|
| Alloys | Zn | Mg | Cu | Fe | Mn | Al |
| I | 10.73 | 4.48 | 1.02 | 0.21 | 0.006 | Balance |
| II | 11.21 | 4.45 | 3.18 | 0.25 | 0.009 | Balance |
| III | 9.6 | 4.39 | 4.94 | 0.22 | 0.011 | Balance |

The melting alloys was pouring into ceramic mold at temperature 750 °C while preheating temperature for the ceramic shell mold was 730 °C. After solidification, the ceramic shell mold was broken. The turbine impeller casting product was characterized by visual examination. Microstructural characterization by Optical microscopy and scanning electron microscopy (SEM). Mechanical properties was identified by hardness testing were cut from the hub of the impeller. The hardness based on the Rockwell B scale

III RESULTS AND DISCUSSION

A. Visual inspection

Turbine impeller casts were free of macro defects, such as misruns, macro porosity, and surface cracks. Smooth surfaces were obtained for all cast specimens. The successful elimination of defects resulted from a good design of gating system, ceramic shell molds, and casting parameters (i.e.,
pouring temperature and preheating temperature for shell molds][2].

The poor design gating system will lead to misruns and shrinkage. The smooth surface indicated that no reaction occurred between the alloys and the first layer of the ceramic mold. The absence of misruns and shrinkages in the cast showed that the permeability of the molds was adequate to expand the gases within [4].

![Figure 1](image1.png)

**Figure 1** (a) cast product of investment casting b) Turbine impeller that made of Al-9Zn-4Mg-5Cu produced by investment casting.

B. Effect of Cu on Microstructures

Figure 2 shows microstructures of the hub of impeller with varied Cu content. Microstructures of the Al-10.7Zn-4.48Mg-1.02Cu alloy are shown in Figures 2a and 2b. It can be seen the dendritic grain structure with the second phase around the grain boundaries. The second phase commonly found in Al-Zn-Mg-Cu alloys are MgZn2, Mg2ZnAl2, Al-MgZn2Al2 and Al-MgZn. The addition of Cu form CuMgAl2 and CuAl2 phase.

The microstructures of the Al-11.21Zn-4.45Mg-3.18Cu alloy are shown in Figures 2c and 2d. The structure is relatively the same as that of the Al-10.7Zn-4.48Mg-1.02Cu. But it has a finer grain size and the second phase in the grain boundary look thicker. The microstructures of the Al-9.6Zn-4.39Mg-4.94Cu alloy are shown in Figures 2e and 2f. The grain size more finer than the others. The CuAl2 phase in the grain boundary also thicker than the others. The CuAl2 and CuMgAl2 formed in this alloys due to higher Cu content. Different amount of in CuAl2 and CuMgAl2 phase caused significant differences in mechanical properties.

![Figure 2](image2.png)

**Figure 2** Microstructures of the hub of turbine impeller of Al-10Zn-4.5Mg-xCu with (a, b) 1 (c, d) 3 and (e, f) 5 wt. % Cu produced by investment casting.

<table>
<thead>
<tr>
<th>No</th>
<th>Rata-rata unsur (wt.%</th>
<th>Phase may form</th>
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<tr>
<td></td>
<td>Zn</td>
<td>Mg</td>
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<tr>
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<td>2.70</td>
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<tr>
<td>2</td>
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<tr>
<td>4</td>
<td>4.15</td>
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![Figure 3](image3.png)

**Figure 3** Backscattered SEM of a tip of impeller of Al-11.21Zn-4.45Mg-3.18Cu alloy.

**Table 2** Elemental composition on the structure in the alloy Al-11.21Zn-4.45Mg-3.18Cu at position shown in Figure 3.
Figure 3 shows the FE SEM of Al-11.21Zn-4.48Mg-1.02Cu alloy. The α-Al matrix can be seen (position 1), and the CuMgAlz phases (position 2), the thicker phase around boundary is MgZn2, MgZn3Al5, Al-Mg-Zn-Al3 or Al-MgZn2 and it is clear that the white phases are CuAl2 (position 4)). The alloys and the corresponding elemental analysis is provide in Table 2. Phase formations on as-cast 1 Cu and 5 Cu containing alloys were similar except for quantities. The presence of a second phase MgZn2 and CuAl2 will increase the hardness as cast and are expected to be precipitates after heat treatment [7].

![Graph](https://via.placeholder.com/150)

Figure 4 Effect of Cu on hardness of the Al-10Zn-4.5Mg-xCu alloys

C. Effects of Cu on hardness value

Figure 4 shows the effect of Cu on the hardness of the Al-10Zn-4.5Mg-xCu alloys. The addition of Cu significantly increases the hardness value. The highest hardness value was obtained by 5Cu of 77 HRB. The alloy contain 5 wt. % Cu has finer grain than 1 and 3 wt. % Cu caused highest hardness value, also the higher Cu content lead to more phase CuAl2 and CuMgAl2 which is hard and tough. The presence of phase CuAl2 and CuMgAl2 leads to significantly higher hardness. MgZn2 phase also contribute to increase mechanical properties of the alloys [8].

IV CONCLUSION

The turbine impeller produce by investment casting show free from macro defect such as misrun, macro porosity, shrinkage and others surface defects. It is indicate that gating system design, casting parameters and ceramic shell mold work optimally.

Microstructures of turbine impeller made of Al-10Zn-4.5Mg-xCu alloys fabricated by investment casting mainly consisted of α-Al, MgZn2, CuAl2, and CuMgAl2. Alloy containing 5 wt. % Cu achieved the hardness of 77 HRB. The higher the Cu content the higher the hardness value due to finer grain size and promote more CuAl2 and CuMgAl2 phases which is hard and tough.

ACKNOWLEDGMENTS

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Study of Performance Improvement of Various Stoves with Waste Biomass Briquettes Fuel

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Abstract—The utilization of effective and efficient biomass briquettes is strongly influenced by the type of stoves used and how to use them. This study aims to make coconut shell charcoal briquettes as stove fuel, to conduct the proximate, heating value and physical property tests, and then to test the performance of temperature, water boiling ability and the efficiency of three types of stoves before and after modification. The method used is an experimental method by utilizing waste coconut shell charcoal briquettes as stove fuel on three different types before and after modification. The results of the analysis of the chemical composition test with average proximate analysis were 1.67 % of water content, 13.03 % of ash content, 28.69 % of volatile matters, and 56.69 % of fixed carbon. Heating value was obtained in 4949 kcal/kg, compressive strength 0.489 gr/cm² and density 0.705 gr/cm³. The results of combustion tests on three different types of stoves before and after modification indicated that the stove burners K’1 and K’3 were two types (codes) of the most superior briquette stove in terms of the boiling ability and modifications to suit the combustion efficiency (K’1 for 71.30 % and K’3 for 70.73 %). Both of these stoves have their respective advantages. K’3 stove, in particular, can be locally produced (from clay) and affordable in price. The three stoves had significant increase in performance improvement after modification.

Key words: coconut shell charcoal briquettes, chemical composition, calorific value, physical property, and stove efficiency

I. INTRODUCTION
Indonesia was formerly known as one of the OPEC countries, a world oil-producing organization. However, since 2003 Indonesia has turned into an oil-importing country. In 2005, Indonesia’s energy consumption was approximately 700 barrels of oil equivalent (BOE) per year. This amount, approximately 57% of energy comes from oil, 24% gas, 13% coal, and the remainder is from hydroelectric, geothermal, and so on.

Due to the impact of the prolonged economic crisis, the conditions change drastically when the fuel subsidies were gradually being phased out. Several layers of society, not only the lower class and the middle class but also the domestic industry, began to feel the weight of the fuel subsidy removal. Facts and data show that the use of fossil fuel was reaching to the end, because the amount of oil reserves were running low. High oil prices are unstable and continue to rise. The issues that fossil fuels cause environmental damage already started to prove. Along with the growth of the world population which continues to increase, people are encouraged to find alternative sources of new energy by utilizing renewable energy sources.

Some types of energy sources which can be renewed and developed are solar energy, ocean thermal energy (OTEC) and biomass energy. These biomass or organic materials can be processed as alternative fuel, such as briquette. Coconut shell charcoal is the product obtained from the incomplete combustion of coconut shell. Charcoal gives a higher heat and less smoke and can be smoothed and then compressed into briquettes in a variety of forms, in which the use of briquettes will be more practical, efficient and economical as well as easy to get than firewood.

The studies carried in connection with coconut shell briquettes that have more heating value than other biomass briquettes i.e.: Siti Jamilatun (2008 and 2011), found that coconut shell briquette was the most optimum and economic alternative fuel, which was quite high in heating value 5779.11 kkal/kg. Herotje Siwi (2010) obtained the heating value of coconut shell of 4569.22 kkal/kg and Meli and Muslimin (2010) obtained 5410.77 kkal/kg. The heating value difference in some previous research were probably because of the briquette’s different manufacturing process and material composition. Esmar Budi (2011) found that coconut shell charcoal has carbon content of 76.32% which was potentially good as fuel.

Based on the above considerations, biomass energy in the form of coconut shell briquette used as fuel in various briquette stoves, and their modification to improve performances in increasing the effectiveness and efficiency of alternative fuels to ease the burden of government, especially to the people who had a hard time finding kerosene. Therefore, it is necessary to study performance improvement possibility of various stoves with waste biomass fuel briquettes to reduce the dependence on petroleum, especially kerosene, and to look for a more economic alternative energy.

II. THEORETICAL BACKGROUND
Briquette stove a cooking appliance that uses fuel from briquette, which was a solid material that has been processed either with or without carbonization process derived from coal biomass or the like. Nowadays, the use of briquette is not unfamiliar anymore, because of the recommendation of government to diversify energy. Moreover, Indonesia’s coal reserves were very abundant, as well as biomass. Materials used in producing the stove affect the appearance, durability, and quality of heat utilization. The types consist of:
1. Britubara Stove (briquette-coal) is one type of stoves which are coated with flame-retardant materials and heat resistant. However, if it is not carefully used, it will be easily broken and it can not be used anymore. Hereinafter referred to as K1 stove.
2. KM stove is a stove briquette made of durable metal material, but is not stainless so the appearance changes along with the duration of use. Hereinafter referred to as K2 stove.
3. Clay oven or is commonly called brazier, is made of pottery raw materials, such as burnt clay, is widely available in the community and is generally used mostly in rural communities. Hereinafter referred to as K3 stove.

Coconut (Cocos nucifera) is a plant that grows in tropical regions and lowlands which now has become industrial plantation crops. Plants of this palmae tribe has a straight trunk and the only species in genus cocos. This plant is believed to have come from the shores of Indian Ocean on the Asian side, but has since spread throughout many world tropical beaches. Coconut is also a multipurpose tree in the tropical community[1].

Fuel briquettes are defined as fuels produced from organic material through compaction, external charcoaling, full carbonation or combined. The others means briquetting according is basically a densification of compacting process which aims to improve the physical properties of a material so as to facilitate its handling[3].

Biomass materials used to make the briquettes are from:
1. Wood processing wastes such as: logging residues, bark, saw dust, shavinos, waste timber.
2. Agricultural wastes such as: straw, bagasse, dried leaves.
3. Fibrous material wastes such as: cotton fiber, jute, coconut coir.
4. Food processing wastes such as: nut skin, fruit seeds, fruit peel.
5. Cellulose such as: paper waste, cardboard.

Based on its shape, briquette shape can be divided into two types, namely bee nest and egg.
1) Cylinder-type (bee nest), for household use. This type of briquette is more known and popular, cylindrical shape with a large hole in the middle and several small holes.

2) Egg-type, for domestic industry. This type of briquette is usually used for burning lime, brick, tile, pottery, and blacksmith. It is oval-shaped with customized size[4].

Several factors used as the standard of charcoal briquettes are:[5]
a. Water content (moisture)
   The water content in the fuel, the water contained in the wood or wood products is defined as moisture content.
b. Ash content (Ash)
   Ash or mineral contained in the solid fuel is a fireproof material after combustion process. Ash is burnt material when it is solidified
c. Volatile matters
   Volatile matters are one of characteristics contained in briquette. The more content of volatile matters in the bio-briquette, the easier it is to burn and lit so the combustion rate is faster.
d. Fixed carbon
   The content of fixed carbon or also called fixed carbon content (FCC) which is contained in fuels such as charcoal (char), is a component which does not form a gas when it burns.
e. Heating value
   Heating value of the fuel is the amount of heat generated from and caused by a gram of fuel to raise the temperature of one gram of water from 3.5 °C – 4.5 °C, with unit of calories.

Loam or clay soil is a soil with a very fine grain, is plastic (malleable) and has adhesive power. Clay soil is divided into two types, primary and secondary clay. Type of clay soil used in this research is secondary clay. This is because of its physical form, which after burning, the clay remains with the color of darkish light brown. This is the characteristic of secondary-type clay[6].

Cassava flour (tapioca flour) is starch obtained from cassava root tubers. Tapioca has physical properties similar to sago starch, so the use of both can be interchanged. It is widely-used in food industry, such as in puddling making, soup, etc.

Combustion is rapid reaction between the fuels from the air. This process is the release of thermal energy from the fuel. This thermal energy is released during the combustion reaction, where the oxygen, CO2, water and other substances contained in the combustion gases through the release of heat.

III. RESEARCH METHOD

This study was conducted between February and April 2014 with a range of activities including: measuring the dimensional of the three stoves that would be modified, making coconut shell charcoal briquettes in the shape of a bee nest, proximate and heating value testing, physical property testing as well as water boiling testing and briquette combustion on three different stove before and after modification. The modification efforts intended to improve the stove cooking time and their...
efficiency by getting a high temperature and to minimize heat loss. The process of making briquettes and combustion test was carried out in Production Process Engineering Laboratory UNHAS Makassar, proximate and heating value tests were carried out in Animal Feed Chemical Laboratory, Faculty of Animal Husbandry UNHAS Makassar and physical test was carried out in Laboratory of Metal Science, Faculty of Engineering UKIP Makassar. All data including combustion time, flame temperature, water temperature, and ambience temperature displayed on this study derived from measurements on experiments conducted in the laboratory, while the formula used to calculate the thermal efficiency was obtained from several reference books.

A. Materials and Equipment

Materials and equipment used in this study were as follows:

1. Material:
   a. Coconut shell
   b. Tapioca starch
   c. Clay
   d. Water

2. Equipment:
   - Briquette press machine
   - Coffee grinder
   - Carbonization drum
   - Sieves (40-60 mesh)
   - Briquette stove
   - Thermocouple
   - Scales
   - Water
   - Bomb calorimeter
   - Aluminum pot
   - Beaker glass

B. Modified Stoves

The method used in this study was an experimental method, which was to modify 3 different types of stoves.

1. Britubara Stove (K1), made by PT Britubara Indoraya Indonesia, made of porcelain-coated steel plate, heat-resistant (1500 °C), which was a surface heat-resistant cylinders. This stove modified by adding aluminum plate cylinder with a thickness of 0,9 mm, a diameter of 90 mm, a high of 140 mm by making one rows of air holes surrounding the cylinder. The diameter of each air holes 10 mm and the distance between the air holes was 20 mm. The purpose was to add insulation to reduce the heat loss to the walls in radial direction. Photo K1 stove and photo adding cylinder modification can be seen in Figure 3 below.

2. KM stove (K2) was distributed by UD Barokah at Jalan Ketilang number 9 Makassar, South Sulawesi. This stove was made from steel plate. This stove would be modified on the exterior walls of the air hole stove. By adding 8 pieces of air hole which were originally 11 mm in diameter. And with asbestos insulation and zinc bound with wire. The distance between each air hole to others was 31 mm. With this addition and insulations, more air was expected to enter, so the combustion could produce higher temperature and shorter cooking time. Photo K2 stove and photo modification of K2 stove can be seen in Figure 4 below.

3. K3 stove was made by Takalar’s pottery center with wood charcoal as fuel and as a substitute for kerosene stove. This stove was made of clay (pottery) which was very easy to find in traditional markets. This stove would be modified by adding aluminum plate cylinder with a thickness of 0,9 mm, a diameter of 90 mm,a high of 140 mm by making one row of air holes surrounding the cylinder. The diameter of each air holes 10 mm and the distance between the air holes was 20 mm. The purpose was to add insulation to reduce the heat loss to the walls in radial direction. Photo K3 stove and photo adding cylinder could be seen in Figure 5 below.
C. Research Procedure

1. Preparation of coconut shell charcoal briquettes in the shape of bee nest.

2. Proximate analysis testing to obtain water content (moisture), ash content (ash), volatile matters, fixed carbon and heating value.

3. Physical testing to obtain compressive strength and density.

4. Briquette combustion and water boiling testing on the three different types of stove before and after modification.

   The testing consisted of two parts: briquette burning/water boiling and calculations efficiency ($\eta_{th}$):

   $$\eta_{th} = \frac{Q_c + Q_p}{LHV \times M_{bb}}... (1)$$

   $$\eta_{th} = \frac{(M_a \times C_{p_{av}} \times (T_a - T_v)) + (M_{bb} \times C_{p_{air}} \times (T_a - T_v)) + (M_a \times H_v)}{LHV \times M_{bb}}... (2)$$

   where:

   - $\eta_{th}$: thermal efficiency of briquette burning (%).
   - $M_a$: initial water mass (kg).
   - $M_{bb}$: remaining briquette mass in the stove (kg).
   - $M_w$: mass of water vapor (kg).
   - $H_v$: vapor latent heat (kJ/kg).
   - $C_{p_{air}}$: water specific heat (kJ/kgC).
   - $C_{p_{al}}$: aluminum/pot material specific heat (kJ/kgC).
   - $LHV$: briquette lower heating value (kJ/kg).
   - $T_a$: water’s ambient temperature
   - $T_v$: water vapor temperature (100°C)
   - $T_c$: POT TEMPERATURE (°C)

IV. RESULTS AND DISCUSSION

A. Results of Research

1. Produced briquette with specification:
   a) Cylinder-shape briquette (bee nest)
      Briquettes produced had average diameter dimension of (d) = 65 mm, high (t) = 45 mm, hole in the center hole (d1) = 15 mm and around (d2) = 8 mm (four holes).
   b) Briquettes mass and volume
      The briquette mass was 93.3 gr

2. Proximate and heating value testing results shown below in table 2

3. Briquette physical test (Compressive Strength and density)
   Physical examination consists of 2 parts:

   1) Compressive Strength
      The result of compressive force was obtained as 14.39 kgf.
      Maximum pressure that could be accepted by the briquette was obtained by the equation:

      $$P_{max} = \frac{F}{A}$$

      where:
      - $F$ = compressive force = 14.39 kgf
      - $A$ = compressive area = 29.39 cm²

      The compressive strength found:

      $$P_{max} = \frac{14.39 \times 29.39}{29.39} = 0.489 \text{ kgf/cm}^2$$

   2) Density
      Density of briquette was obtained using the following equation:

      $$\rho = \frac{m}{V_{total}}$$

      where:
      - $m$ = mass of briquette (gr) = 93.3 gr
      - $V_{total}$ = briquette total volume (cm³) = 132.2568 cm³

      So that:

      $$\rho = \frac{93.3 \times 10^{-3}}{132.2568} = 0.705 \text{ gr/cm}^3$$

4. Combustion / boiling testing and thermal efficiency
   a. Briquette combustion
      Briquette combustion data test by using water boiling method for three types of stove before and after modification were collected every 5 minutes, i.e.: flame temperature, water temperature, water mass, briquette mass before, after combustion, and vapor mass. The data are presented in figure 6 to 11.
Figure 6. Graph of temperature vs combustion time at K1 stove

Figure 7. Graph of temperature vs combustion time at K’1 stove

Figure 8. Graph of temperature vs combustion time at K2 stove

Figure 9. Graph of temperature vs combustion time at K’2 stove

Figure 10. Graph of temperature vs combustion time at K3 stove

Figure 11. Graph of temperature vs combustion time at K’3 stove

Figure 6-7 was a graph of relationship between temperature and briquette combustion time of K1 stove before and after modification. It could be seen in the Figure 6 that water boiling ability of K1 before modification only two times at the 48th minute and 123rd minute (blue line). The last, the water could be only heated reached 96 °C (red line), where the maximum flame temperature was 309 °C. And compared with Figure 7 the K1 stove after modification (K’1) could boil water 5 times at the 24th, 51st, 91st, 142nd, and 229th minute (blue line), could only heat the water until 96°C (red line), where the maximum flame temperature was 393°C.

Figure 8-9 was a graph of relationship between temperature and briquette combustion time of K2 stove before and after modification. It could be seen in the Figure 8 that water boiling ability of K2 before modification only three times at the 31st, 67th, and 111th minute (blue line). The last, the water only heated reached 94°C (red line), where the maximum flame temperature was 451°C. And compared in Figure 9 the K2 stove after modification (K’2) could boil water 4 times at the 31st, 67th, 107th, and 165th minute (blue line), could only heat the water until 83°C (red line), where the maximum flame temperature was 398°C.

Figure 10-11 was a graph of relationship between temperature and briquette combustion time of K3 stove before and after modification. It could be seen in the Figure 10 that water boiling ability of K2 before modification only one time at the 83rd minute (blue line), the last the water could be only heated reached 86 °C (red line), where the maximum flame
temperature was 255 °C. And compared in Figure 11 the K3 stove after modification (K’3) could boil water 5 times at the 27th, 58th, 93rd, 157th, and 227th minute (blue line), could only heat the water until 87°C (red line), where the maximum flame temperature was 373°C.

b. Combustion efficiency

Example for thermal efficiency calculation was for K1 stove boiling water for 2 times with maximum flame temperature of 309 °C with briquette burning time for 240 minutes (4 hours), and spending briquette 0.22 kg. Furthermore, the data could be seen as follows:

\[
\eta = \frac{\text{calorific value of briquette} \times \text{burning time}}{\text{density of briquette} \times \text{boiling water time}}
\]

\[
\eta = \frac{958.6 \times 10^6}{304.5 \times 10^6} = 31.30\%
\]

The comparison of the three types of stoves data testing before and after modification in water boiling ability, maximum flame temperature, and thermal efficiency of the burnt-out briquettes presented in the Table 3 below.

| Table 3. Tabulation of stove performance improvement |
|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|                    | No. of Briquette | Briquette | Briquette | Briquette | Briquette | Briquette |
|                    | Diameter (mm)    | Length (cm) | Water Content (%) | Fixed Carbon (%) | Ash (%) | Volatile Matters (%) |
| 1                   | 1                | 12         | 75          | 75          | 75       | 75       |
| 2                   | 2                | 20         | 45          | 45          | 45       | 45       |
| 3                   | 3                | 15         | 150         | 150         | 150      | 150      |

K1 stove before modification had maximum flame temperature, water boiling ability, thermal efficiency and burnt-out briquette mass respectively as : 309 °C, 2 times within 240 minutes, and 24.96%. After modification of K’1, the maximum flame temperature was 393 °C, 5 times boiling within 345 minutes and efficiency 71.30%. K2 stove before modification was respectively 451°C, 3 times within 215 minutes and efficiency 36.69 %. And after modification of K’2 stove was 4 times within 240 minutes, 398 °C and 54.17 %. K3 stove after modification produced 255°C, 5 times within 180 minutes, and 15.07%. K’3 stove after modification was 5 times within 335 minutes, 373°C, and 70.73 %.

B. Discussion

Briquettes were burned in a bee nest shape with diameter dimension of 65 mm, height of 45 mm, one 15 mm hole and 4 small holes with diameter 8 mm. The average proximate test result showed water content of 1.67 %, ash of 13.03 %, volatile matters of 28.61 %, fixed carbon of 56.69 %, and ash of 13.03 %, fixed carbon of 56.69 %. Heating value was obtained in 4949 kcal/kg, compressive strength of 0.489 gr/cm² with the density of 0.705 gr/cm³. The overall results of proximate and physical property tests did not meet the existing quality standard of briquettes, except for water content and volatile matters.

The results of performance testing of 3 types of stove before modification obtained : that K2 stove was superior in terms of water boiling ability, maximum flame temperature, and thermal efficiency of each of 3 times within 215 minutes, 451°C and 36.69%. Followed by K3 stove with water boiling 2 times within 240 minutes, 309 °C and 24.92 %. And the lowest was K3 stove which was to boil water as much as one time within 180 minutes, 255 °C and 15.70 %. Water boiling ability and the best thermal efficiency after modification were produced by K’1 and K’3 stoves which was 5 times, where K3 stove was 10 minutes faster than K’1 stove with each efficiency 71.30% and 70.73 %. Of the overall testing both before and after modification, the most superior are K’1 and K’3 stoves. Both of these stoves had their respective advantages, which K’1 stove was slightly more superior in terms of thermal efficiency and maximum flame temperature. Nevertheless, K’3 stove excels in ignition time and also had the additional advantage as it could be produced locally (from clay) and affordable in price. The best efficiency improvement was obtained by K1 stove for 46.34 % (from 24.96 % -71.30%), K2 stove for 17.485 (from 44.

V. CONCLUSION AND SUGGESTION

A. Conclusion

Briquettes had been made in the form of bee nest, with the diameter of 65 mm, height of 45 mm, a 15 mm hole, and 4 holes with diameter of 8 mm. The average proximate test result showed water content of 1.67 %, ash of 13.03 %, volatile matters of 28.61 %, and fixed carbon of 56.69 %. Heating value was obtained in 4949 kcal/kg, compressive strength of 0.489 gr/cm² with the density of 0.705 gr/cm³. The overall results of proximate and physical property tests did not meet the existing quality standard of briquettes, except for water content and volatile matters.

K1 stove before modification only two times water boiling with maximum temperature of 309°C and efficiency 24.92%. And after the modification, K’1 stove’s water boiling had suffered almost as many as 5 times with temperature of 393 °C, efficiency was 71.30%. This was because the addition of a modified aluminum cylinder plate hole above the line that was able to maintain the briquette’s fire heater for almost more than 5 hours.

K2 stove before modification produces 3 times water boiling with temperature of 451°C and efficiency of 36.69%. K2 was also the best before modification because the preparation of the briquettes in the combustion chamber is arranged horizontally. And after the modification of 8 holes variation with asbestos insulation and zinc bound with wire, that had K’2 stove. So, the performance improvement could be obtained twice better than previous modification with the process of water boiling to 4 times.

K3 stove before modification only boiling the water one time with flame temperature of 255 °C and efficiency 15.70 %. After modification of K’1 stove, water boiling ability was obtained 5 times with not too high temperature of 373 °C and efficiency of 70.73%. This was due to the additional modification of one top row aluminum cylinder plate which was also able to sustain the flame briquette for 335 minutes.

B. Suggestion

K1 stove after modification only times water boiling with maximum temperature of 309°C and efficiency 24.92%. And after the modification, K’1 stove’s water boiling had suffered almost as many as 5 times with temperature of 393 °C, efficiency was 71.30%. This was because the addition of a modified aluminum cylinder plate hole above the line that was able to maintain the briquette’s fire heater for almost more than 5 hours.

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V. CONCLUSION AND SUGGESTION

A. Conclusion

Briquettes had been made in the form of bee nest, with the diameter of 65 mm, height of 45 mm, a 15 mm hole, and 4 holes with diameter of 8 mm. The average proximate test result showed water content of 1.67 %, ash of 13.03 %, volatile matters of 28.61 %, and fixed carbon of 56.69 %. Heating value was obtained in 4949 kcal/kg, compressive strength of 0.489 gr/cm² with the density of 0.705 gr/cm³. The overall results of proximate and physical property tests did not meet the existing quality standard of briquettes, except for water content and volatile matters.

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36.69%-54.17%) and K3 stove for 55.03% (from 15.70-70.73%)

B. Suggestions

Improved performance had been successfully performed on three different types of stoves. But there were still deficiencies found in this research that the process of water boiling (cooking time) was quite long and less amount of materials cooked. Therefore, it was necessary to conduct further research, especially in terms of designing the optimal stove with more fuel capacity and more ingredients that could be cooked in relatively short time. Emission testing was also necessary to conduct.

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Position Control of an X4-Flyer Using a Tether

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Abstract—In Japan, aging of infrastructures, such as roads, bridges, and water and sewer services, etc. poses a problem, and it is required to extend the life-span of such infrastructures by maintenance. Among infrastructures, especially bridges are periodically inspected by short range visual observations, which check the damage and deterioration of the surface. However, since there are some cases where the short range visual observation is difficult, an alternative method is required so as to replace the short range visual observation with it. So, "X4-Flyer" is very attractive because of realizing a movement at high altitude easily. The objective of this study is to develop a tethered X4-Flyer, so that the conventional short range visual observation of bridges is replaced by it. In this paper, a method for the measurement and control of the position is described by using a tether for controlling the position of the X4-Flyer. In addition, it is checked whether the tethered X4-Flyer can control the position using the proposed method or not, letting it fly in a state in which a tether is being attached.

Index Terms— Aerial Robotics, Unmanned Aerial Vehicles, vehicle dynamics, Control.

I. INTRODUCTION

In Japan, there are about 700,000 bridges whose length is 2[m] and more. Aging of such bridges is a serious problem [1], because those about 50[%] and more exceed 50 years in 2030, which is the life of a bridge. As a general rule, an inspection period of the bridge is determined to be five years and less by the short range visual observation to cracks and corrosion [1]. The short range visual observation by a human is widely used to evaluate the degree of damage and understand the damage status of concrete structures such as bridges, because it is possible to check the deterioration and damage of the surface cracks, etc. However, there exists a case where the bridge inspection vehicle cannot be used due to an insufficient space under the bridge digit, and also exists a case where a close visual inspection is difficult because of a large-scaled traffic control, a necessity of installation of scaffolding, etc. For this reason, it needs a substitutive method of the short range visual observation. So, an aerial robot to move at high altitude easily is very attractive. In particular, an "X4-Flyer", which is a kind of VTOL type aerial robot, has high maneuverability, compared to conventional VTOL aerial robots possessing other rotor arrangements [2]. Therefore, it is expected to be used in various applications, such as security, pipe inspection, etc. [3] [4]. It needs to control the position and attitude of the X-4 Flyer, if it is used for the inspection of infrastructures, such as bridges etc. Although the position control using the GPS is common, it is difficult to use such a control method in environments, such as a tunnel or under a bridge, where the GPS signal does not reach to or is weak. In addition, the manual operation by a joystick etc. is difficult when affected by disturbances such as wind etc. Lupashin and D’Andrea [5] have proposed a method for controlling an X4-Flyer using a tether, not relying on the operation of a joystick or the use of GPS. However, this method only controls the tilt of the aircraft towards the tether, so that it is impossible to vary independently the altitude and position of the X4-Flyer, respectively. Therefore, it is thought to be difficult to be used in an inspection of infrastructures, such as bridges etc., as it is.

In this study, it aims at developing the X4-Flyer with tether to replace the short range visual observation of infrastructure. The position and attitude are controlled by the inertial sensor and the altitude sensor that are attached on the airframe of the X4-Flyer, and by a tether attached at the bottom of the airframe. In this paper, we first describe the summary of the X4-Flyer and a controller for the position and attitude. Then, a method is explained for measuring the position of the X4-Flyer by applying a tether. In addition, it is checked whether the tethered X4-Flyer can control the position using the proposed method or not, letting it fly in a state in which a tether is being attached.

II. OVERVIEW OF AN X4-FLYER

Fig. 1 shows the coordinate systems and the appearance of X4-Flyer, respectively. The body coordinate system of the X4-Flyer is denoted by $\mathbf{B}$ and the inertial coordinate system is $\mathbf{E}$,
III. CONTROLLER OF THE X4-FLYER

A. Controller of the Attitude Angle

In this article, the attitude of the X4-Flyer is controlled using a PD control method developed in Bouabdallah’s [6]. When defining the P gains of the controller as \( k_1, k_3, \) and \( k_5 \), the D gains of the controller as \( k_2, k_4, \) and \( k_6 \), the target value of the attitude of the aircraft as \( \phi_d, \theta_d, \) and \( \psi_d \), control inputs as \( U_1, U_2, U_3, \) and \( U_4 \), the PD controllers for postures are given by

\[
U_2 = -k_1(\phi - \phi_d) - k_2\phi \\
U_3 = -k_3(\theta - \theta_d) - k_4\theta \\
U_4 = -k_5(\psi - \psi_d) - k_6\psi
\]  

(1)

B. Controller of the Position

The position control of the X4-Flyer is performed by changing the attitude of the airframe. It is found from Fig.1 that the X4-Flyer can move \( X \)-direction and \( Y \)-direction by tilting the airframe to the direction \(-\theta\) and \( \phi \), respectively. Therefore, the X4-Flyer in this paper is controlled to \( X \)-axis and \( Y \)-axis directions by changing the target value \( \theta_d \) and \( \phi_d \) in Eq. (4), respectively. That is, a feedback-loop is constructed to generate and change the target values of attitude angles of the airframe, by using the errors from the current position to the target position of the airframe. Here about the position control, a PD controller is assumed to be used as the control at the attitude angles. When defining the P gains of the controller as \( k_7 \) and \( k_9 \), the D gains of the controller as \( k_8 \) and \( k_{10} \), and the target values of attitude of the airframe as \( x_d \) and \( y_d \), the PD position controllers are given by

\[
\theta_d = -k_7(x - x_d) - k_8\dot{x}. \\
\phi_d = -k_9(y - y_d) - k_{10}\dot{y}
\]  

(2)

The X4-Flyer is equipped with a tether, maintaining in the state where it is stretched. Then, the control input \( U_1 \) is set to be constant so as to generate a constant thrust to the height of \( Z \)-axis direction.

IV. POSITION MEASUREMENT

In this study, the airframe position of the \( X \)- and \( Y \)-axis directions is determined by measuring the airframe height and the slope of the tether is attached to the X4-Flyer. In this section, a mechanism is described for measuring the slope of the tether, and it is applied to measuring the airframe position.

A. Mechanism for Position Measurement

Fig.2 shows a situation where a device for measuring the inclination of the tether is attached to the airframe. This device consists of a gimbal mechanism equipped with potentiometers. This gimbal mechanism is composed of orthogonal two axes, which can incline in any direction respectively. The inclination of the X4-Flyer can be known by measuring the slope of each axis, because two axes move in any direction.

B. Position Measurement Using the Tether

Fig.3 shows the relationship between the inclination of the tether and the airframe position. Let the \( E_x \), \( E_y \), and \( E_z \)-axis positions of the airframe be \( x_a, y_a, \) and \( z_a \). \( c \) denotes the distance from the origin of the coordinates to a point at which a perpendicular line given from the center of the
airframe intersects the $E_x - E_y$ plane, and $l$ is the length of the tether. The slopes of the tether against the perpendicular line directed to $E_x$-axis and $E_y$-axis are defined by $\alpha$ and $\beta$, respectively, and the $\gamma$ is a slope of the tether. Then, the airframe position in the $E_x$-axis is given by

$$x_a = z_a \tan \alpha$$  \hspace{1cm} (3)

Furthermore, the airframe position in the $E_y$-axis is reduced to

$$y_a = z_a \tan \beta$$  \hspace{1cm} (4)

The height $z_a$ is required to measure the position of the X4-Flyer using Eq. (3) and Eq. (4). Now, the height $z_a$ is fixed to the height at which the tether is extended up to the maximum length, satisfying the condition that the slope of the tether to the airframe becomes $0[\text{deg}]$.

V. EXPERIMENTS THE POSITION CONTROL USING THE TETHER

The position of the X4-Flyer is measured and controlled by using the position measurement method that applied the tether, shown in the previous section. In this paper, the proposed method is verified by mounting the position measuring device by the tether on the X4-Flyer, and measuring and controlling its position.

A. Experimental Conditions

Fig. 4 shows the X4-Flyer used in the experiment. The center of gravity of the airframe is approximately consistent with the center of the airframe, by collecting heavy loads, such as electronic circuits, batteries, etc., near the center of the airframe. Also, a brushless DC motor is used for rotating the rotor. The experimental setup is shown in Fig.5. A Wi-Fi module mounted on the X4-Flyer can realize wireless communication with a PC, so that it can be operated by a controller (i.e., a gamepad) via the PC and obtain the log data. Assume that the length of the tether is $l = 1[\text{m}]$ and the experiments are conducted by fixing the other end of the tether on the ground. The target positions and attitudes in flight are set to $\phi \theta \psi \dot{\phi} \dot{\theta} \dot{\psi} x y z^T = (0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ -1)^T$. The values provided from the gamepad are used for the control input $U_1$ in the height direction to perform an operation such as takeoff etc. The constant gains in the PD controller for performing the attitude control are set to $k_1 = 4.5$, $k_2 = 1.5$, $k_3 = 4.5$, $k_4 = 1.5$, $k_5 = 1.2$, and $k_6 = 0.4$. The constant gains in the PD controller for performing the position control are set to $k_7 = 0.12$, $k_8 = 0.8$, $k_9 = 0.18$, and $k_{10} = 0.2$.

B. Results and Consideration

The experimental results are shown in Fig. 6 to Fig.8. It is seen from Fig. 6 that the error in $X$-axis direction is in the range of $\pm 0.2[\text{m}]$. It is seen from Fig. 7 that the error in $Y$-axis direction is in the range of at most $\pm 0.25[\text{m}]$. However, it is found from Fig.8 that the airframe position in the $X$-axis direction deviates about $-0.2[\text{m}]$. Furthermore, this graph shows that the flight range of the airframe is in the range of at most $0.4[\text{m}]$ from $-0.6[\text{m}]$.

From these results, it is considered that the airframe position can be measured and controlled by using the tether. However, it is considered that the constant gain in the position controller can be tuned more suitably to reduce the deviation in the $X$-axis direction as shown in Fig. 6. In addition, it is effective to consider that a PID controller is introduced to the position control so as to stabilize the flight range of the airframe in a narrower space, as shown in Fig. 8. However, it is considered that since the position of the airframe shown in these graphs are affected by the inclination of the aircraft when measuring the inclination of the tether, it is a larger or smaller value than the actual position in some cases.
VI. CONCLUSION

In this paper, a method for measuring and controlling the position of an X4-Flyer has been described by using a tether. Furthermore, the proposed method was verified using a real system. It was concluded that although the airframe position was able to be measured, the accuracy of the position control was to be not too high because the airframe position in X-axis direction deviated. For future work, the introduction of a PID controller as the position controller is considered to improve the accuracy of the position control. In addition, the flight experiment of the X4-Flyer is being fixed to the ground tether, so that, we are going to have a flight experiment that the tether will be handled by a human so that in the future.

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Development of a Mobile Robot as a Test Bed for Tele-Presentation

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Abstract—In this paper, a human-sized tracked wheel robot with a large payload capacity for tele-presentation is presented. The robot is equipped with different sensors for obstacle avoidance and localization. A high definition web camera installed atop a pan and tilt assembly was in place as a remote environment feedback for users. An LCD monitor provides the visual display of the operator in the remote environment using the standard Skype teleconferencing software. Remote control was done via the internet through the free Teamviewer VNC remote desktop software. Moreover, this paper presents the design details, fabrication and evaluation of individual components. Core mobile robot movement and navigational controls were developed and tested. The effectiveness of the mobile robot as a test bed for tele-presentation were evaluated and analyzed by way of its real time response and time delay effects of the network.

Index Terms—telepresence, teleoperation, remote sensing, Skype, Teamviewer.

I. INTRODUCTION

A. BACKGROUND

Telepresence has been the hype of the modern day fictional films like the Surrogate, Avatar, Sleep Dealer and Gamer. In Surrogate for example, a person will be assigned to a robot replica of oneself which one has to control via his mind in a recliner seat at home. The much younger, stronger, better looking replica will then do your biddings in the world. The real technology behind such fantastical fiction is grounded both in far-out research and practical robotics. In the present day real world, telerobots are presently limited to physical interfaces-through wireless internet connections, video cameras, joysticks, and sometimes audio. Humans move robots around at the office, in the operating room, underwater, on the battlefield, and on Mars. Examples of advances in today’s telepresence robots are the RP-7 of InTouch Health Systems and QB of Blackwell’s Anybots [5]. RP-7 is a mobile robotic platform that enables the physician to be remotely present. Through the integration of key technologies, RP-7 can remove time and distance barriers and effectively extend the physician's reach to manage patient care. The Robot’s visualization system consists of a camera, microphone, and a speaker. Mobility and navigation is possible via a holonomic drive system and an array of infrared sensors. Physicians teleoperate the robots through the internet by seating in a control station-a computer with a joystick and a webcam. The wide angle display of the robot cameras presents the doctor with the view of the robot’s environment for navigation and to examine patients and converse with the hospital staff. Blackwell’s QB on the other hand is a general purpose remote telepresence robot. It is a Wi-Fi enabled, vaguely body-shaped wheeled robot with an ET-looking head that has cameras for eyes and a display in its chest that shows an image of the person it’s standing in for. You can slap on virtual-reality goggles, sensor gloves, and a backpack of electronics to link to it over the Internet for an immersive telepresence experience. Or you can just connect to the robot through your laptop’s browser.

Telerobots, teleoperators, and remotely operated vehicles belong to a class of machines used to accomplish a task remotely, without the need for human presence on site. They are typically used in situations that are too hazardous to human health or survival, like deep water, outer space, or toxic environments. A growing number of telerobots is used for applications where it would be too expensive or too time-consuming to send humans, for example in telemedicine or tele maintenance that requires highly trained individuals with special skills. Sheridan [11] defines a telerobot as a machine with sensors of the environment and devices to perform mechanical work. The human operator supervises the telerobot through a computer intermediary. The operator communicates to computer information about goals, plans, and orders relative to a remote task, getting back integrated information about accomplishments, difficulties and sensory data. The telerobot executes a task based on the information received from the human operator plus its own artificial sensing and intelligence.

The cost of a telerobotic system can be considerably reduced by using personal computers and prevailing standard software for most of the computing tasks[1]. Another way to reduce costs for some applications is to use the free Internet for communication between the computer that the operator interacts with and the computer that controls the robot. Telepresence robots on the other hand are specialized types of networked telerobots that offer the operator some form of both visual and tactile feedback giving him a sense of as if he is at the actual site of the robot.

Compared to plain robotic systems, in which a robot executes a motion or other program without further consultation of a user or operator, telerobotic systems provide
information to and require commands from the user. Their control architectures can be described by the style and level of autonomy.

Using standard internet technology for telerobotic applications offer the advantage of low cost deployment. There is no longer a requirement for expensive purpose built equipment at each operator’s location. Almost every computer connected to the internet can be used to control a teleoperable device. The downside is the limitation of the varying bandwidth and the time delays.

The internet offers the infrastructure for communication but still the operator requires software that displays the user interface and communicates with the telerobot over the internet. Powerful browsers are freely available and often updated with increased functionality. User interfaces can be developed using a web browser only can be achieved. Operator visual feedback can also be realized using readily and freely available Skype software, freeing the developer from developing its own visual feedback.

Existing commercial telepresence robots are way far expensive ranging from 6000 to 15000 dollars. Some have their own dedicated web servers to manage control, and visual feedback commands thus adding to the cost overhead by charging users a monthly subscription fee[5]. This research was conceptualized bearing in mind the cost savings when an elementary telepresence robot will be developed from off the shelf components and doing away with a dedicated web server.

Having a dedicated web control infrastructure however leads to a much effective telepresence robot by ensuring an almost zero communication downtime, thus a significant reduction in delays, by efficiently rerouting IP packets to other routes. Since the robot to be designed do away with this type of infrastructure, a controller/robot communication system must be developed with the ultimate goal of minimizing the effects of transmission delays.

Telepresence robots are useful in various areas such as remote presentation, teleconferencing, telemedicine: remote diagnosis, remote treatment of patients with the aid of a medical staff and remote consultation, military applications, remote surveillance, teleoperation, advertising and remote education. Due to these benefits, a low cost telepresence robot from off the shelf components was developed. A heightened perception of the presence of the speaker in the remote area was sought and for safety purposes, a control scheme with minimal delay effects was developed.

Most of the existing telepresence robots are either private projects or commercial ones. Each of the robots have their own advantages and disadvantages and this study would like to fill in the gaps left by these telepresence robots. In this study, a robot was developed that somewhat mimics the properties of these established telepresence robots but has some inherent characteristics that somehow complements the shortcomings of these previously reviewed robots. First of all a robot made up of locally available materials was built and thus leads to a low cost platform. The blueprint for the robot was laid out as simple as possible so that a generalized model can be easily duplicated. The design of the hardware was open sourced and the sources of the components were easily obtained locally. The electronic controls components of the robot come in kits that can be obtained in local stores. So in general, a telepresence robot that can be built using modular components was developed. In terms of robot control software, most of the previously reviewed robots have their own proprietary software and most of them are closed source. In this particular telepresence robot, it was decided to use free and open source software. This decision was based on the notion that open source and free software can contribute to the robot’s low price and a generalized robot can be synthesized by just anyone with the right means. The previously reviewed telepresence robot are considered complex in terms of control and software and the designed robot however was not. Moreover, the teleconferencing component of the robot came from the freely available Skype software. Overall, a telepresence robot designed with modular components and free software was developed. This means that anyone with sufficient knowledge in electronics and computer programming can develop their own telepresence robot since the components can be obtained readily.

To solve the problem stated thus we have done the following:

1. Designed and constructed a web controlled telepresence robot platform with the following features
   a. A tracked wheel differential drive motion capable robot with motion control system incorporating two sets of optical wheel encoders for dead reckoning linear displacement measurements and speed control using pulse width modulation.
   b. Incorporated a webcam, microphone sets and an LCD display for two way audio and video transmission between the robot and remote controller.
   c. Employed three sets of ultrasonic distance sensor for the robots obstacle avoidance system.
   d. Incorporated on the robot a digital compass for direction sensing based on the 4 cardinal directions.
   e. Incorporated on the robot a 3 axis accelerometer for inclination measurement on the three cartesian axis.
   f. Use of the Skype teleconference software for the audio and video information transmission between the robot and the remote controller.
   g. Low cost and sourced from Commercial off the Shelf (COTS) materials.

2. Developed a purely local robot control using a processing GUI whose control is ported to the operator via TEAMVIEWER VNC.

3. Tested the effectiveness of the robot as a telepresence agent based on the evaluation of the time delay between the transmission and execution of control commands.

4. Developed and optimized control algorithms for the robots navigational control.
II. SYSTEM DESIGN

To reduce complexity, the telepresence robot was a passive terminal with minimal autonomy. A little intelligence however was incorporated through the sensors in a way wherein the robot can have control in case sensors detect obstacles. Mobility was limited to positioning controls, although the prototype can be designed for much general and complex teleoperation task, modelling, calibration and testing for the prototype would be done for remote tele-presentation only. The software used for teleconferencing was limited to Skype and robot control was achieved through forwarding the remote desktop to the controlling computers screen using Teamviewer. The Processing programming language was adopted in developing the robot controllers GUI.

The choice of the type of robot was based on some existing commercial telerobot designs. The robot first and foremost must be able to move around in the remote environment thus a suitable mobile platform was designed. Since the robots task was to interact with other people on the remote site as naturally as possible, a human sized robot was designed.

The robot can be remotely controlled by a remote PC. Fig. 1 shows the overall scheme of the system. Basically, the system consist of two computers, one top of the robot and other will be the remote controller station. These PC’s were both connected to the net and communicates with each other via Skype and Teamviewer VNC package.

![Figure 1. The telerobotic system showing the telepresence robot and its remote controller station](image)

Video, audio data were relayed from the remote PC to the controlling PC in the robot and vice versa. In this setup, the computer in the remote robot runs a java controller program whose inputs were controller commands and sensor data. The controller commands were implemented by normal inputs consisting of buttons, sliders and textbox in a Graphical User Interface (GUI). Outputs were implemented as text labels and graphical elements like gauges and arrows. This GUI were virtually transported on the remote controller station, appearing on the controllers monitor and thus controlled remotely. Fig. 2 shows the Graphical User Interface (GUI) in the remote controllers end.

![Figure 2. The robot Graphical User Interface](image)

![Figure 3. The remote Robot System](image)

A. Hardware Design

The hardware of the robot platform is shown in Fig. 3 and Fig. 4. The remote robots skeletal system was made up of a combination of 1x1 square aluminum bars comprising the robot frame and a main vertical post made up of a 15/8 by 1 5/8 14 gauge slotted angle bar. The post acts as a backbone to support the visual feedback system consisting of the 14 inch LCD monitor and the camera system. Nuts and bolts of various sizes were utilized as fasteners. Acrylic plastic sheets with thickness of 2.5 mm and 3 mm was used as coverings. A tracked industrial platform acts as the robot base. The main controller of the robot was a microcomputer with an Intel-based processor. This computer processes the video feed from the robot mounted camera, processes the audio feed from the microphone, outputs the received video information from the controlling PC to a robot mounted LCD, outputs the received audio signal from the controlling PC to the robot speakers, control and monitor the communication link between the controller and the robot, and perform motion and tactile commands to the robot as well as process the robots sensors relaying feedback signals to the controlling PC. The robot moves via a differentially driven track wheels which are in turn...
controlled by an arduino microcontroller via motor controller boards. Slave microcontrollers were employed to process sensor data and a pan and tilt mechanism for the web camera system. Robot navigation and tactile commands were achieved by the use of three ultrasonic sensors arrays spaced symmetrically around the body of the robot. Connectivity on the robot site was provided through 3G internet service via a 3G wireless router installed in the remote site. The overall block diagram of the system is described in Fig 5.

Two Nissan mt3-12 high torque DC geared motors were employed to drive two threaded drive chains. The drive chains are configured for a differential drive robot base. The two motors were controlled by two 6.0 Ampere H-bridge motor driver kits from E-gizmo Mechatronix Central. These kits control the direction and speed of both motors. The axle connected to the shaft of the motor was coupled to an optical encoder wheel. Two sets of optical incremental wheel encoder system were developed for the two motors using infrared reflective sensor combined with the wheel encoder mounted on the motor shaft. These absolute encoders determine the relative distance travelled by the robot at a certain time difference. A Phillips KMZ52 based electronic compass acts as a sensor for azimuth position. The output of this sensor was used as an input to the motor controller system.

A proportional integral control scheme was employed for the mobile robot to control its displacement and heading. The output signal of the PI controller will be a PWM signal which will be the input to the motor controllers. Two sets of PWM controllers were employed, one for the left motor and one for the right motor. Fig.6 shows the PI controller implementations for the robot.

The controller station consists of a laptop PC equipped with a web cam, a microphone and speakers. Broadband Internet access must be provided for this PC using any of the existing services in the Philippines like DSL, 3G, 4G or Wimax. This controller PC must have Skype, Teamviewer, Java Runtime installed. The hardware of the controller station is shown in Fig.7.

The controller PC will be the one responsible controlling the remote PC mounted on the robot. The two computers must communicate via the internet using Skype and The VNC software Teamviewer.

B. System Software Design
The video and audio transmission between the robot and the controller was handled by the Skype Software. Both the Robot PC and The Controller PC have Skype installed, each with their corresponding Skype accounts registered. Banking on the popularity of this software, it was assumed that this part of the design was already been taken cared off.

![Figure 5. Overall block diagram of remote robot](image-url)
since the software has already been proven in the internet in terms of affectivity and efficiency. Albeit to say, the system therefore was highly dependent on Skype in terms of reliability of connection and transmission delays of the video and audio information.

On the remote robot computer, a Graphical User Interface was implemented using the java based Processing language. This interface was actually a TCP client which connects with the wifi server module of the robot. These client sends control signals to the server and at the same time receives feedback data from the server. This GUI was then virtually transported on the controller monitor through the Teamviewer software. That is, the remote controller screen has a display of the remote robots PC desktop. Through Teamviewer, the remote controller PC can control the GUI on the robot PC. The effectivity of sensing and executing control commands via this setup was dependent on the transmission delay on the internet and it was investigated through a series of experiments.

The Graphical User interface permits the control of the movement of the robot. Two methods of robot control movements were allowed, manual direct control and semiautomatic. In the manual control, 5 directional buttons corresponding to forward, left, right, backward, stop were used. Clicking on the desired a particular button effects the desired movement of the robot. Eight bit values ranging from 0 to 255 can be used to implement PWM speed values to the motors. While the robot is executing a particular robot movement, the clicking of another movement button will stop the robot. One has to click the button again to effect the desired movement. Once the robot is moving, the ultrasonic sensors are active. When an obstacle is directly in front of any of the three ultrasonic sensors, the robot will stop its movement and sends the “obstacle detected” robot status on the robot GUI. One can in anytime stop the movement of the robot by sending any commands to the robots GUI. In the manual method, the robot implements the command and wait strategy wherein the robot executes the sent command and then waits for the next command. Some commands have a definite duration in terms of execution and once the control routine is finished, the robot stops and waits for the next command. Examples for this are the pan and tilt commands for the camera.

In the semiautomatic mode of control, sliders and buttons are implemented. Two possible movements are implemented in this method:

Figure 6. Two PI controller implementation. (a) for position (b) for angular heading

Figure 7. Controller hardware setup

Figure 8. The overall robot system hardware: (a) overall robot system; (b) LCD video system; (c) Web camera mounted on pan and tilt servo mechanism; (d) Control electronics consisting of microcontrollers, motor controllers and power conditioning circuits.
1. distance traversal
2. angular heading seeking

In the distance traversal, the user uses the distance slider to enter the required distance of travel. One then clicks the navigate button and the robot moves forward to the required travel distance. This movement is implemented using a Proportional Integral controller algorithm where the inputs are the actual travel distance and desired travel distance. The output of the controller will be the PWM signals on the two motors driving the track wheels. The actual travelled distance was measured using an optical encoder.

In the angular heading seeking movement, one uses the heading slider to choose the desired heading. The heading angle correspond to the earth magnetic pole directions with 0 degrees as north, 90 degrees as east, 180 degrees as south and 270 degrees as west. To lock to the desired heading, one clicks the FIND button and the robot turns towards the desired angle. The robot turns towards the desired angle using a PI controller where the inputs are the desired angle and the actual heading angle. The output of this controller will then be the PWM signals that drives the robot motors. The implementation of the PI controller in this system is complemented with a logical system wherein the choice of turning direction is dependent on the amount of angle to be traversed. The system is programmed wherein the turning angle to be traversed will be the one which entails lesser turning distance. For example if the present heading angle is 90 degrees and the desired angle is 180 degrees, there are two possible scenarios for implementing this heading seeking:

1. Clockwise at an angular displacement of 90 degrees
2. Counterclockwise at angular displacement of 270 degrees (360-90).

For this example, the robot selects the clockwise movement for it entails lesser angular displacement to be covered.

The actual heading angle was measured by a digital compass sensor whose output is a serial data sent to the robot controller. The actual desired angular headings of the robot are displayed on the GUI using a circular gauge with two dials. The red dial is for the actual heading and the blue dial is the desired heading. Whenever the robot moves, this actual heading dials location is updated. One can also manually update the actual angular position by clicking the READCOMPASS button. The Robots Pan and Tilt Camera can be controlled via the Tilt Angle and Pan Angle sliders in the GUI. The Pan angle slider value corresponds to the amount of angular degrees the camera pans. These angular values can range from 0 to 180 degrees. The tilt angle slider values correspond to the amount of degrees the camera tilts. These angular values can range from 0 to 180 degrees. By clicking the neutral button, one can reset the camera to point to a default viewing position which is the usual orientation of a webcam. Neutral position corresponds to a pan angle of 85 degrees and a tilt angle of 90 degrees. An overall GUI for the robot controller was employed on the robot. This GUI serves as a frontend to a telnet session between the robot PC and The Wi-Fi to serial converter server. The Wi-Fi to serial converter

There were three arduino microcontroller board utilized in the implementation of the control of the robot. One Atmega 328 based master microcontroller board acts as the master controller and two Atmega8l based microcontroller board acts as slaves. One of the slave module acts as the controller for the pan and tilt servo motor assembly. This slave microcontroller waits for serial command coming from the master microcontroller. These commands are the pan and tilt angle for the servos. The other slave microcontroller controls the three US -100 ultrasonic sensors constantly getting its distance reading. When the distance of the obstacle on any of the three sensors was below the threshold level, this microcontroller sends a low level signal on an output pin. This pin was connected to an interrupt pin of the master microcontroller. The master microcontroller therefore had an interrupt whenever a low level signal was present on this pin.

The master microcontroller performs numerous task.

These tasks were:
1. Communication with the WIFI serial module.
2. Controlling the two 6 A h-bridge motor controller.
3. Receives encoder counts from the two optical encoders.
4. Receives serial data from the digital compass.
5. Reads the output of the three axis accelerometer.
6. Executes the overall control loop for the control of the robot.

Fig. 9 shows the overall flow chart for the main controller loop of the master microcontroller firmware.

![Diagram](image-url)
The initial step in the main microcontroller code was the initialization routine. Here every piece of hardware interface was initialized, I/O pins data direction are set depending on the peripheral connected to it. Figure 10. is the flowchart for the initialization routine. The initialization is implemented on the setup() function of the main microcontroller code.

![Flowchart for the initialization routine](image)

The bulk of the main loop of the master controller’s firmware was a blocking wait loop. The program waits for serial data coming from the wifi serial module. The data coming from the wifi module were actually commands coming from the main graphical user interface. As mentioned previously, the graphical user interface processes commands entered by the user as relayed through the internet via Teamviewer. The commands received by the GUI were then encapsulated into a TCP packet which was then relayed to the serial wifi module. The serial wifi module then decapsulates the commands from the TCP packet into a stream of serial data. These serial data will now be the serial commands the main controller loop processes. Commands are formatted as a series of 4 bytes. The wait loop in the main loop waits for this and upon reception, the first byte then was used as an argument in a switch case block in the code. Different commands then are executed based on the decoded first byte. Likewise if a particular command needs a response from the robot, the said response was sent to the wifi serial module as a serial character stream. This serial stream was then converted to a TCP packet which will then be transmitted to the GUI client on the controlling PC. An example of this was the string “ready” which was transmitted every time a command was successfully executed by the robot.

III. TESTING AND EVALUATION

The main goal of this study was to develop a basic telepresence robot whose affectivity was dependent on how accurately it performs the tasks assigned by the controller. The study implements the objective method of evaluating the performance of the telerobot through a series of tasks that it has to complete at the shortest time possible, thus task completion time and reaction time to a remote stimuli were the metrics used. Task completion time was measured and averaged while the reaction time was measured by getting the time difference between the completion time in the local station and the time of completion as perceived in the remote station. Two tasks have been designed, one is the traversal of a square path and the other one is the traversal of a straight path.

The traversal of the square path employs the shared continuous means control. In this method a “command and wait strategy” was implemented by which the robot was sent commands one at a time. One command must be finished before another command was sent. The robot on the other hand monitors obstacles along the path, and once an obstacle was detected, it stops the present maneuver of the robot. The next step for the robot was then to wait for the next command and execute it. The path was traversed 10 times and the time of completion was recorded through Wireshark, an open source network sniffing software. The perceived time of completion was also measured on the controlling computer through Wireshark by looking at the timestamp on the TCP transmission of the last command coming from the remote machine. The testing area would be a tiled surface with an outline drawing of the path to be traversed. Two paths have been defined for testing, one is a square path with a side dimension of 1.2 m and the other is a straight line with a length of 1.6m.

In the experiment, the robot performs its usual startup routine whereby it connects to the controller station via internet. Skype and Teamviewer were run on both the robot and the controlling station. The robots controller GUI was then forwarded to the controller screen so that it can remotely control the robot. Skype provides the visual feedback to the controller PC so that it can effectively maneuver the robot. Once connection was established, the robot then traverses the paths. While the robot was traversing the paths, Wireshark monitors the wireless data packets leaving and entering the robot PC. These data packets are then sent remotely to the controller stations PC for monitoring. Wireshark in the controller station also monitor its wireless data packets particularly the timestamps on each TCP packet. Through the timestamps in the TCP packets, the time of completion and time delays was calculated and recorded. In calculating the time delay, the tasks starting time and ending time were extracted from the TCP stream trace and packet display list of the TCP transmission between the robot PC and the wifi module. Fig. 11 shows software modules and the data flow during the experiments.
IV. CONCLUSIONS AND RECOMMENDATIONS

The goal of the study was to develop a human sized tracked mobile robot suitable for telepresence applications. A mobile robot equipped with sensors and tele-presentation capabilities were developed. The robot was built from off the shelf components so that the overall cost of the system is as minimal as possible. The robot design process was implemented through the manufacture and testing of individual components. Core mobile robot movement and navigational programs were developed and tested. The effectiveness of the mobile robot as a test bed for tele-presentation were evaluated and analyzed by way of its real time response and time delay effects of the network. Iterative process of software creation, testing and debugging were done to come up with an optimized code suitable for both mobility and remote robot control. The physical hardware components of the robot were developed first through an iterative process of mixing and matching. Once the hardware components were developed, an iterative process of software development was implemented in order to fit the desired function of the robot. The mobility of the robot has been proven effective through a series of mobility test scenario where the robot has been controlled. The use of Skype has also been proven effective in sending the audio and video information between the robot and its controller. The use of Teamviewer as the controller medium for control signals deemed effective provided a good quality of service is expected from the internet connection. Overall, the design of the robot leads to a low cost system; as such materials were coming from off the shelf items.

A Series of time of task completion test and time of execution delay was conducted through the use of Wireshark network sniffing software. The researcher suggests therefore that more test be done on this aspects taking into account the different quality of service at different times of the day. As for the robot control, the researcher recommends further investigation by implementing control software that is not dependent on the commercial Teamviewer software. A pure client and server program for robot control is therefore recommended for further study.

As for mobile robot mobility, wheel slippage has been observed due to the nature of the wheels employed on the project. This resulted to severe errors on the optical encoder system which limits its effectiveness on smaller distances. Due to this, the researchers recommend the use of other means of robot locomotion such as wheels. Odometry using optical encoders deemed erroneous when large distances was traversed, thus the use of MicroElectroMechanical Modules (MEMS) such as accelerometers as position sensors are recommended.

REFERENCES


Intelligent Machine Vision for Automated Fence Intruder Detection Using Self-organizing Map

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Abstract – This paper presents an intelligent machine vision for automated fence intruder detection. A series of still captured images that contain fence events using Internet Protocol cameras was used as input data to the system. Two classifiers were used; the first is to classify human posture and the second one will classify intruder location. The system classifiers were implemented using Self-Organizing Map after the implementation of several image segmentation processes. The human posture classifier is in charge of classifying the detected subject’s posture patterns from subject’s silhouette. Moreover, the Intruder Localization Classifier is in charge of classifying the detected pattern’s location classifier will estimate the location of the intruder with respect to the fence using geometric feature from images as inputs. The system is capable of activating the alarm, display the actual image and depict the location of the intruder when an intruder is detected. In detecting intruder posture, the system’s success rate of 88%. Overall system accuracy for day-time intruder localization is 83% and an accuracy of 88% for night-time intruder localization.

Index Terms - Intelligent Machine Vision, Self-Organizing Map, and Image Segmentation, Classifier

I. INTRODUCTION

Anyone wants to have a safe home, properties or offices. The Self-Organizing Map Classifier for Vision Based Auto Intruder Detection embracing the method of Artificial Neural Network (ANN) will offer a remarkable result in defending the residence, stuffs or properties from thieves, intruders or burglars. Crime is increasing day by day, thus the demand of reliable, fast and accurate security system is rapidly increasing. It was stated that whether or not a person is a victim of crime, the mere thought of an unwanted visitor lurking around his house can make him cringe. Many home security systems have proven effective in preventing home burglaries. It was grouped differently depending on the usage of the system and on the technical features it offers. There are magnetic, electric circuit and motion detecting systems, infrared systems and wireless security systems. There are systems with security cameras, electric fences and guard dog perimeters. Some other systems can communicate via household electric wires called the X10 security systems and those operated remotely via the Internet.

Though the mention security system offer a remarkable result but, none of them has an ability to identify and analyze the current situation. It simply gives a warning when there is a disturbance on an emitted signal or on an established circuit. Usually this type of security system has high percentage of error or high false alarm rate.

Establishments like banks, airports, casinos, convenience stores, and military installation use surveillance cameras to monitor and record activities both inside and outside the building but not really effective in preventing break-ins. The recorded events can be firm evidence as enforcement in catching and prosecuting the burglar. The Hidden Cameras are an improvement, but still no power to stop a crime. Observing the visual display or video stream of surveillance cameras (i.e. Close-Circuit Television (CCTV) cameras) can be time consuming because the activity captured by each of the installed camera is shown in one monitor at the same time. If there are 9 cameras installed in a building, the person who is assigned to observe the situation surely have difficulties in watching the video stream at the same time, which also makes the system ineffective in preventing burglars. This type of system will be much vulnerable from intruders when the assigned person falls asleep.

Accordingly, the study focuses on the development of an intelligent machine vision fence intruder detection using Self-organizing map, aimed to identify the intrusion level within the set perimeter of a building or a residence, promising a reliable high detection rate and a low false alarm rate. It also aimed to make the job of the assigned person much easier in supervising the system’s visual display by providing simple but accurate visual display based on the intruder position. The system will trigger the alarm in case the assigned person falls asleep.

II. SYSTEM ARCHITECTURE

The system classifies the acquired still images from data acquisition unit as Not Intruder, Potential intruder, Intruder Level-1 (L-1), or Intruder Level-2, using two system’s classifiers: Human Pose Intruder Classifier and Intruder Localization Classifier after applying several image segmentation. The system will trigger the alarm and display the actual location and position of the intruder.

![Figure 1: General system architecture](image-url)
The designed details of Classifiers development is described in Figure 2.

Figure 2: Classifier development block diagram

Human data samples were taken randomly with varying distance based from the installed effective position of Internet Protocol Camera (IP Cam). Intruder Clothing color was also considered during data gathering. This was to anticipate the possible error caused by dress color. The study included only four clothing color: Blue, Green, Red, and Black. 160 images of human data samples were used experimentally per testing distance in both day time and night time. Sample images of human intruder are shown in Figure 3 and Figure 4.

Figure 3: Day-time human sample

Figure 4: Night-time human sample

All data or images that could possibly appear in testing area were all included during the data gathering of non-human data sample. It included different types of leaves and different types of animals such as dog, cat, horse, elephant, bird, butterfly, pig and etc. Non-human data come in different sizes, different angles, different shapes, and different positions. Basic geometrical shapes such as: circle, diamond, square, rectangle, triangle, ellipse, stars, and etc. were also included as non-human data sample.

Intruder localization data was subdivided into three: The Potential intruder data, The Level one (L-1) intruder and Level two (L-2) intruder. Potential intruder is an object classified as human and specifically located in a certain point of a fence, refer to Figure 5.

Figure 5: Relative intruder position (a) Potential Intruder, (b) L-1, (c) L-2

Unlike human recognition ability, computer recognition ability is pretty much limited to numbers. With this, the developed system viewed the input data in a form of still images, as a series of random numbers that represented each and every color, lines and shapes of the picture. Part of the system goal was to extract the human and the fence from the given data and make it available for further processing. Static method of object extraction was used to extract the fence from image. Fence was modeled using four line segments which depicted four corner points. Based from four corner points the system then calculated the image pixel at position \((x_i, y_i)\) that was known to be a part of fence model using the equation of a line:

\[
P_i(x) = \left(\frac{y_i - y_{i-1}}{x_i - x_{i-1}}\right) + x\, l_i (1)
\]

Where\( \text{slope} = \frac{(y_2 - y_1)}{(x_2 - x_1)} \)and the value of pixel y-coordinate \(P_i(y_i)\) was defined by the relation: \(y_{1_i} < P_i(y_i) < y_{2_i} \) using constant interval of 1.

Foreground extractor was to eliminate unwanted data and to extract the target object from the given image. Most likely Human intruder fell to the category of a moving object; it constantly changes its position throughout the time. Given a single video frame as input data, the value of image pixel was considered at position \((x, y)\)takenfor a certain period of time. This value was referred to as \(Z_{x,y}(t)\) and treated as a random process of variable \(G_i\).

\[
G_i = Z_{x,y}(t) (2)
\]

The current pixel value was modeled as a mixture of K Gaussian distribution. The weight of this value was determined by a distribution, \(\pi\)

\[
P(G_i) = \pi_0 N(G_i | \mu_0, \Sigma_0) + \pi_1 N(G_i | \mu_1, \Sigma_1) + \cdots + \pi_k N(G_i | \mu_k, \Sigma_k)
\]

Where\( \sum \pi_i = 1 \)

\[
P(G_i) = \sum_{i=0}^{k} \pi_i N (G_i | \mu_i, \Sigma_i) (3)
\]

where \(\pi_i\) is an estimated weight of the \(i^{th}\) Gaussian, and \(N\) is the evaluation of a standard Gaussian with mean \(\mu_i\), and covariance matrix \(\Sigma_i\):

\[
N(G_i | \mu, \Sigma) = \frac{1}{(2\pi)^{n/2}|\Sigma|^{1/2}} e^{-\frac{1}{2}(G-\mu)^T \Sigma^{-1} (G-\mu)} (4)
\]
Based on the calculated Gaussian value, individual pixel of an input data was being group into background pixel or foreground pixel. The background subtraction process was implemented.

Below was the procedural approach used in foreground detection:

1. For every N values taken from the pixel
2. Find the K Gaussians and weights that best fit to sample N values using Expectation Maximization (EM) algorithm
3. Find the Gaussian with the largest weight and store its mean as the value of the background image for that pixel.
4. Subtract the background image from the frame.

In the resulting difference image, any value larger than three standard deviations from the mean was considered foreground, and any other value was considered background.

Feature vector extraction and formulation was the final stage of eliminating unwanted data, refining and finalizing the target object using several image segmentation techniques. The technique used in this stage is depicted in Figure 6.

For each pixel in a video frame:
1. Subtract the background image from the frame.
2. Store its mean as the value of the background location:
3. Find the Gaussian with the largest weight and find the K Gaussians and weights that best fit to sample N values using Expectation Maximization (EM) algorithm.
4. Find the Gaussian with the largest weight and store the Gaussian with the largest weight and store its mean as the value of the background image for that pixel.
5. Subtract the background image from the frame.

Feature Vector was the data structure that contained all the unique details of the target object, needed in object classification. Feature Vector dimension was formulated using the equation 5 and equation 6.

Feature Vector Dimension ($a \times b$)

$$a = \text{image width x image height}$$

$$b = i(6)$$

Where: $a = \text{Number of data (pixel value in binary)}$ that represents the unique details of an object.

$i = \text{number of sample object}$

Furthermore, the Feature Vector dimension can be reduced by half of its size, using the distance formula from the equation of a line (Equation 7) to calculate the unique attribute of the object.

$$d_i = \text{data}_i - \text{ref}_i(7)$$

$$\text{data} = \{a_1, a_2, a_3, \ldots, a_n\}, \text{ where } a_i\text{ was the individual value represented the object details, shown in Figure 8 (f) (page 47) the red doted color pixels.}$$

$$\text{ref} = \{b_1, b_2, b_3, \ldots, b_n\}, \text{ where } b_i\text{ was the individual value taken from the point of reference, refer to Figure 3.18 (f) the blue doted color pixels.}$$

The number of raw $a$ from Feature Vector dimension ($a \times b$) was taken from the total number of object details $d_i$ from Equation 7.

Figure 8, illustrated the logical representation of object details reduction, from originally acquired image to process or converted image.

Three classifiers were used in the designed project development such as Human Pose Intruder Classifier, Day-time Intruder Localization Classifier and Night-time Intruder Localization Classifier.
The ability or accuracy of the Map to classify was adjusted experimentally by manipulating the parameter; number of epochs which defines the number of iterations used to train the system classifier; size of SOM defined the finite number of different classification type \( Q(y) \) of an input data; and number of data sample.

Furthermore, the focused of SOM was to convert high dimensional presentation into two dimensional presentations \([D(r) \times D(c)]\) by grouping the input data based on its likelihood. This understanding conveyed that a map with a dimension of \(20 \times 20\) will have \(400\) different types of data classifications, arranged according to its likelihood.

\[
Q(y) = D(r) \times D(c) \quad (8)
\]

The number of data sample can affect directly to the performance of the Classifiers, as mentioned above that classification variation of a classifier was modeled in the data sample details. In the field of Artificial Neural Network having a greater number of data samples used in network training depicted a better performance.

The development of Human Pose Intruder Classifier (HPIC) which designed to classify human pose in both daytime and nighttime used the following parameters during Map training:

- 10,000 training epochs
- Map dimension of \(10 \times 10\)
- 4,480 total no. of Human pose data sample
- 3200 total no. of Non-human data sample

Intruder Localization Classifier (ILC) was use to classify the input data that was labeled as positive human intruder pose by HPIC according to its level of intrusion such as Potential Intruder (PI), Level-1 (L-1) Intruder and Level-2 (L-2) Intruder.

There were two types of ILCs: Day-time ILCs and Night-time ILCs were developed separately using separate data samples. This was to address changing properties of input data during daytime and nighttime. The development of 2 ILC(s) used the following parameters during Map training:

- 30,000 training epochs
- Map dimension of \(10 \times 10\)

- 3,800 total number of Day-time and Night-time localization data sample. 1,400 in Level-1 and 1,400 in Level-2 data sample. 1000 total number of Day-time and Night-time localization potential intruder data sample.

The accuracy of newly created classifiers was tested using the data specified below:

For Human Pose Intruder Classifier:
5. 1000 samples for intruder human pose.
6. 1000 samples for non – human

For Intruder Localization Classifier:
Both daytime and nighttime
7. 100 samples per meter in level-1 intrusion, total of 700 samples
8. 100 samples per meter in level-1 intrusion, total of 700 samples
9. 100 samples per meter in level-1 intrusion, total of 700 samples

To test Intruder Localization Classifier accuracy, total of 2100 data samples were used. In Human Pose Intruder Classifier, 2000 total of samples were used to test its accuracy.

III TESTING RESULTS

Considering the constant change of light intensity and the image background stability, eliminating the unwanted data was never been easier. During noise reduction, the system could possibly hurt the desired object pixels The object detected was classified as human intruder only if it was positively identified as human and its localization belong to intruder localization. Furthermore, classifying the detected object was possible using only a single classifier, merging the object details as well as the object localization as object feature vector, but the time required to train the network was very expensive. Training period to develop a single classifier merging the object details and object localization did reached to approximately one month using 10 thousand epoch of network training. That was exhausting and time consuming network training. The downside of a single classifier was when there was an update for intruder sample that required re-training of network. The update would take another one month approximately. In contrast with the single classifier, by using two classifiers (HPIC and ILC) the network training period was effectively reduced to approximately 2.5 hours. Approximately 2 hours for HPI training using 10 thousand network training epochs. Approximately 0.5 hours for ILC training using 30 thousand training epochs.

![Figure 8: Object details extraction](image)

![Figure 9: Sample data hit (a) Not Human Pose (b) Human](image)
The data that were used in mapping were the same data that were used during map development. The result below was depicted according to its level as well as to its horizontal distance from the camera.

The intruder hit sample result depicted a clear boundary between three intruder level classifications. As expected, level 1 intruder classification would be closer to potential intruder level and level 2 intruders. Level 2 intruders and potential intruder level as shown in Figure 10 and 11, was isolated by a clear boundary distinction. The result implies that a potential intruder classification could hardly be identified as intruder level 2 and vice versa, but it could possibly be classified as intruder level 1. However, there were few occurrences of classification fluctuations as shown in Figure 10 (c), this was usually happened when the noise reduction process fails to preserved some important object details.

The first experiment was done using 1000 image for both human and not human data samples. Human sample was acquired using the same acquisition device used in actual experiments and all of the representations contain the pose of human intruder in different level and different distance. The data used to represent not human pose were taken from internet. The data were composed of different basic geometrical shapes and different animal shapes that were already in masked format. Human Pose classifier that was trained using 10 thousand epochs, painted a hit rate of 0.884 and a false rate of 0.116. Hit rate value ($\alpha$) depict a result of 0.8942857 and false hit rate of 0.105714286 ($\beta$) for Introduction Localization Classifier using 30 thousand epoch. Hit rate has a value ranges between 0 – 1 ($0<\alpha<1$). Value close to 1 means high hit ratings, 0.5 values was the neutral hit rating of the system, implies that system has accuracy of 50 percent (50%). Figure 13 presented the sample images that were false identified as not human and Figure 14 were the sample image of falsely identified as human from a set of not human data samples.

![Image](image1.png)

Figure 10: Night-time (a) L-1 (b) L-2 (c) Potential Intruder

Similar to Night-time hit sample results, level 2 intruder classification was expected to be the neighbor of intruder level 1 classification and intruder level 1 classification to potential intruder classification. Level 2 intruder could possibly be classified as intruder level 1 or vice versa. Additionally, intruder level rarely could be classified as potential level intruder, based from Figure 11, hit sample result.

![Image](image2.png)

Figure 11: Day-time (a) L-1 (b) L-2 (c) Potential Intruder

In intruder localization classification, potential identifier and level one intruder were the false classification possibly occurs, because of the location which was near to identical. The reason stated was also true to Level – 1 Intruders and Level – 2 Intruders. Classifier test result summary using 30 thousand epoch and 10x10 map dimension was shown in Table 1 using Human Pose Classifier, Table 2 for Intruder Localization Classifier – Night-time and Table 3 for Intruder Localization Classifier – Day-time.

<table>
<thead>
<tr>
<th>TABLE 1: HUMAN POSE INTRUDER CLASSIFIER</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Result</strong></td>
</tr>
<tr>
<td>Human samples</td>
</tr>
<tr>
<td>1000</td>
</tr>
</tbody>
</table>

Figure 12 and Figure 13 were the result sample during simulated experiment using 10 x 10 map dimension that trained 10 thousand times (10K epoch). To aid the deficiency of Human Pose Intruder Classifier, Intruder Localization Classifier was used to confirm the position of the identified human. In connection with this, mostly non – human objects have the position located below or distance from the fence and the human object usually located near or climbing in the fence.

In intruder localization classification, potential identifier and level one intruder were the false classification possibly occurs, because of the location which was near to identical. The reason stated was also true to Level – 1 Intruders and Level – 2 Intruders. Classifier test result summary using 30 thousand epoch and 10x10 map dimension was shown in Table 1 using Human Pose Classifier, Table 2 for Intruder Localization Classifier – Night-time and Table 3 for Intruder Localization Classifier – Day-time.
The experiment was using 10 intruder samples per meters as shown below. Given a single intruder the accuracy of the system was tested to detect the non-intruder level, the potential intruder level, the level-1 intruder level and the level-2 intruder level. As a result, the accuracy of the system was a little bit low for the intruders which have a horizontal distance: 2 meters and 4.5 meters, closer to the acquisition device. It was because the acquisition device could not have a clear view or good image representation of the given potential intruder level, due to the physical setup of the acquisition device, as shown in Figure 6. The system can only have a clear view to the intruder when the intruder starts to climb on the fence, and nearly the situation could be possibly identified as Level - 1 Intrusion.

Red line was the target system performance, blue curve was the approximation of the actual performance of the system, and green curve was the average system performance.

### Table 2: Intruder Localization Classifier – Night-Time

<table>
<thead>
<tr>
<th>Epoch</th>
<th>No. of ID</th>
<th>Positive</th>
<th>Negative</th>
<th>Hit Rate (a)</th>
<th>False Rate (b)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3K</td>
<td>1519</td>
<td>481</td>
<td>0.7595</td>
<td>0.2405</td>
<td>75.95</td>
<td></td>
</tr>
<tr>
<td>5K</td>
<td>1525</td>
<td>475</td>
<td>0.7625</td>
<td>0.2375</td>
<td>76.25</td>
<td></td>
</tr>
<tr>
<td>10K</td>
<td>1768</td>
<td>232</td>
<td>0.884</td>
<td>0.116</td>
<td>88.4</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: Using Intruder Localization Classifier – Used 700 Data Sample per Level

<table>
<thead>
<tr>
<th>Epoch</th>
<th>No. of ID</th>
<th>Positive</th>
<th>Negative</th>
<th>Hit Rate (a)</th>
<th>False Rate (b)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10K</td>
<td>1828</td>
<td>272</td>
<td>0.8704</td>
<td>0.1295</td>
<td>87.0476</td>
<td></td>
</tr>
<tr>
<td>30K</td>
<td>1806</td>
<td>294</td>
<td>0.86</td>
<td>0.14</td>
<td>86</td>
<td></td>
</tr>
</tbody>
</table>

The result in Table 1 depicted map accuracy with respect to the number of training epochs. The experiment evidently showed the result different from the three tested training epochs: 3k, 5k and 10k. The experiment result met the expectation that the greater the number of training epochs the better the classifier performance will be. For Table 3 and Table 2 the classifier was tested and trained using 10k training epochs and 30k training epochs. Based from the result, expectation was a little bit of. The accuracy of system classifier using 30K epochs was lower by one unit compared to the classifier with 10K training epochs, but the result does not show any significant difference in terms of classifier performance. The only difference was the training time used to develop the classifier, it took 25.55 minutes to train a classifier using 30K training epochs. It was 3 fold higher than the training time of a classifier using 10k training epochs.

The second experiment was done around 10:00 am to 2:00 pm. Because of Foreground Detection and Background Subtraction technique, the time of experiment conducted was not a much of a concerned of the said experiment, as long as the sun still up high, then still it’s good to go. Acquisition device was installed approximately 2.35 meter, measured from the ground and aiming to test the system accuracy using the distance of 2 meters, 4.5 meters, 5.5 meters, 7 meters, 8.5 meters, and 10.5 meters as the horizontal distance of the intruder from the camera. Recall, that the horizontal distance of the sample data (intruder) used to train both network (Human Pose Intruder and Intruder Localization Classifier) were taken using the specified distance from the camera: 3 to 2 meters, 4 meter, 6 meters, 7 meters, 9 meters, 10 meters, and 12 meters for Day-time data sample. The distance of used in the second experiment was a little bit off, this was done to test if the system still able to classify the object given the distance odd.

The experiment was using 10 intruder samples per meters as shown below. Given a single intruder the accuracy of the system was tested to detect the non-intruder level, the potential intruder level, the level-1 intruder level and the level-2 intruder level. As a result, the accuracy of the system was a little bit low for the intruders which have a horizontal distance: 2 meters and 4.5 meters, closer to the acquisition device. It was because; the acquisition device could not have a clear view or good image representation of the given potential intruder level, due to the physical setup of the acquisition device, as shown in Figure 6. The system can only have a clear view to the intruder when the intruder starts to climb on the fence, and nearly the situation could be possibly identified as Level – 1 Intrusion.

Red line was the target system performance, blue curve was the approximation of the actual performance of the system, and green curve was the average system performance.
distance from the camera up to 12 meter distance. As a result, the detector system did not positively identify the given sample as fence intruder, probably because of the system filter that filtered the location of non-intruder samples. The system was also tested using multiple intruders designated in random horizontal distance from the camera and climbed concurrently. As a result, the system still detected the intruder, if not all of them, at least the system detected the first climber or the intruders whose clearly emphasized from the perception of the acquisition device.

The third experiment was done around 10:00 pm to 1:00 am without the moon’s presence. With our without the presence of the moon during testing, the system can still be operational. Foreground Detection and Background subtraction technique was very much suitable in slight changes of image background illumination. The image background light, shown in Figure 4.21 was the light emitted by the acquisition device itself. The same with the first experiment acquisition device was installed or was setup 2.35 meters from the ground. Intruder horizontal distances used in third experiment were measure using the designated distances from the acquisition device: 2.5 meters, 5 meters, 7 meters, 9 meters, 10 meters and 11 meters. The designated distances were slightly different from the sample data used to train the network. The same reason with second experiment, the designated distances omitted purposely to test the classification accuracy of the system, which was one of the reason why SOM technique was developed.

This third experiment tested the system accuracy by providing 10 intruders sample per designated distances. Each of the intruders was identified on its potential level, on its level-one position and on its level-two position, with respect to the fence of interest. The same with experiment number one and experiment number two, the size of the map used was 10x10 that was train 10 thousand times for Human Pose Intruder Classifier and 30 thousand times for Intruder Localization Classifier.

The presented intruder sample in 6 different designated positions in both experiment 2 and experiment 3 were all detected by the system. Some Levels of intrusion were not identified or did not trigger the classifier due to the processing time or period required to detect or classify the intruder.

The system classified an intruder and gave a visual display approximately in less than 3 seconds. For intruder classification alone, the system classified the acquired image in less than 1.5 second. But since the system used wireless data transmission from acquisition unit to image classification unit and to monitoring unit, the time to complete single image classification reaches 3 seconds approximately, in both experiments 2 and 3.

However, the system accuracy in both experiment 2 and 3 was altered when the intruder or intruders climb faster than 1 second, since the time required in classifying single image was less than 1.5 seconds. Furthermore, when the intruder climbs the fence in less than 1 second, the system can still detect or can still classify the intruder in Level – 1 Intrusion category, given that the system did not detect the intruder in potential level position. However, if the said intruder was detected in potential level position, then there will be a big possibility that the intruder could not be detected anymore in Level-1 intrusion, but can still be detected in level 2 position.

III. CONCLUSIONS

In spite of all the factors that affected the system’s accuracy such as: sudden change of light illumination, movement of undesirable object, noises, and the speed of the intruders; the developed detector system had successfully detected the presented intruder samples that were located not beyond 12 meters horizontal distance from the location of the acquisition device. With the use of classifiers or identifiers developed using Self-Organizing Map, the detector system was able to identify the pose of the extracted object as well as the current position of the object with respect to the fence of interest. The developed intruder detector system was also able to provide a simple yet accurate visual presentation of the detected intruders and triggered the system alarm when the image was positive from intruder(s).

References

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Simulation and Experimental Works of Quadcopter Model for Simple Maneuver

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Abstract—This study aims to create a simulated and experimental of aircraft movements for multirotor quadcopter. The research method is theoretical and experimental methods. For theoretical method consists of calculating the dynamics and kinematics. While the experimental method consists of the aircraft testing and processing of GPS data recorded aircraft. The results showed that the acceleration acting on the aircraft is large enough that \( x^2 = 1.751 \text{ m/s}^2 \), \( y = 2.038 \text{ m/s}^2 \), and \( z = 1.6371 \text{ m/s}^2 \), (2) the value of the maximum error between the theoretical and the actual movement is \( e_x = 0.682 \text{ m}; e_y \) and \( e_z = 0.353 \text{ m} = 0.546 \text{ m} \). Theoretical movement pattern already resembles the actual movement.

Keywords: model simulation, quadcopter, dynamic control, kinematics control

I. INTRODUCTION

One type robots attract much attention is a mini unmanned aerial aircraft UAMVs (“Unmanned Mini Aerial Vehicles”), because of its ability to perform rescue tasks in hazardous locations and difficult to reach. This type of helicopter flying robot has the advantage over other flying vehicle that can maneuver in cramped areas and perform takeoff and vertical landing that it is called vertical take-off landing (VTOL).

Figure 1. Quadcopter with 4 rotors

Adapun penelitian ini akan membahas suatu jenis pesawat mini udara tanpa awak dengan tipe sayap berputar RUMAV (“Rotary-wing Unmanned Mini Aerial Vehicle”) yang dinamakan quadcopter. Shown at Figure 1, the quadcopter which is a flying robot that has four blades - independent rotor propeller mounted at each end of a cross frame.

Figure 2. Framework configuration of Quadcopter

To design a dynamic quadcopter model, first, defined two frames (coordinate axes) as shown in Figure 2, condition of an aircraft that explains the position and a vector velocity defined in a state of \( X_H \). Each vector consists of linear and angular position and linear velocity and angle.

If \( X_{LIN}^E \) is linear position vector consisting of the components in the direction of the \( x,y,z \) (\( x,y,z \)) and \( X_{ANG}^E \) angular position vector consisting of the components of the angular position \( x,y,z \) (\( \phi, \theta, \psi \)) then Quadcopter position vector \( X_H \) [1] is

II. DYNAMICS MODEL

In general, a quadcopter described simply as four rotors that are in a cross configuration. Vertical movement is obtained by adding or reducing the speed of the rotor with all the same value. This movement produces a vertical force \( U_1 \) (N) to the body frame which will be up or down the quadcopter. Roll motion is obtained by increasing or reducing the rotor speed of the left and at the same time reducing or increase the right rotor speed. Pitch motion is obtained in the same way on both the other motors.

Front and rear motors turn to the the anti-clockwise direction while the two other motor turn to the clockwise, so that the direction of the yaw motion/ anti-clockwise obtained if the front-rear speed propeller - increase/ decrease and the left and right speed of propeller decrease/ increase.
\[
X_H = \begin{bmatrix} X_{E}^{E} X_{ANG}^{E} \end{bmatrix}^T = \begin{bmatrix} x \ y \ z \ \phi \ \theta \ \psi \end{bmatrix}^T
\]  
\( (1) \)

If \( X_{E}^{E} \) is the linear velocity vector consisting of components of velocity of the \( x,y,z \) and \( X_{ANG}^{E} \) is the angular velocity vector consisting of the components of the angular velocity on the \( x, y, z \) \((p, q, r)\) then velocity vector,

\[
X_H = \begin{bmatrix} X_{E}^{E} X_{ANG}^{E} \end{bmatrix}^T = \begin{bmatrix} \dot{x} \dot{y} \dot{z} \ p \ q \ r \end{bmatrix}^T
\]  
\( (2) \)

Subscript E, B and H indicates that the variable relative to the frame-E, B-frame and H-frame.

It will be distinguished initial state vector and the state vector after acceleration in a given time \( t \), respectively noted \( X_{H0} \), \( X_{H0} \), \( X_{H0} \) dan \( X_{H0} \).

\[
X_{H0} = \begin{bmatrix} x_0 \ y_0 \ z_0 \ \phi_0 \ \theta_0 \ \psi_0 \end{bmatrix}^T
\]  
\( (3) \)

\[
X_{H0} = \begin{bmatrix} x_0 \ y_0 \ z_0 \ \phi_0 \ \theta_0 \ \psi_0 \end{bmatrix}^T
\]  
\( (4) \)

\[ \text{Figure 3. Freebody diagram of quadcopter with four rotors.} \]

Figure 3, shows the dynamics of the movement of a quadcopter. If the aircraft is given an acceleration of the aircraft will change its position and velocity. If \( \dot{X} \) is acceleration vector consisting of components \((\ddot{x}, \ddot{y}, \ddot{z}, \ddot{p}, \ddot{q}, \ddot{r})\), the new velocity vector at time \( t \) is obtained by the acceleration vector mengintegral quadcopter against \( t \). While the new position vector at time \( t \) is obtained by integration of the velocity vector respect to time \( t \).

Then, the equilibrium of the dynamics model of quadcopter will be shown in this part. Then it is important for analyzing the dynamic equilibrium in the plane so it will know the forces and moments that can work on the plane. Furthermore, of the forces and moments acting on the aircraft will be known acceleration occurs.

If the moment of inertia matrix \( M_H \), \( \dot{X}_H \) acceleration matrix, \( \dot{X}_H \), Sentripetal-Coriolis matrix \( CH \), velocities matrix \( \dot{X}_H \), GB gravitational vector and the action vector \( \Lambda \) of the general movement of an aircraft dynamics model of quadcopter can define in the following matrix form [1],[2]:

\[
M_H \dot{X}_H + C_H \cdot \dot{X}_H - G_H = \Lambda
\]  
\( (5) \)

If the action of the movement vector \( U_H \), OH propeller gyroscopic matrix and propeller angular velocity \( \Omega \), then the action vector is a general movement

\[
\Lambda = U_H + O_H \cdot \Omega
\]  
\( (6) \)

Both equation above can be written in the following form

\[
M_H \cdot \ddot{X}_H = -C_H \cdot \dot{X}_H + G_H + O_H \cdot \Omega + U_H
\]  
\( (7) \)

Subscript H indicates that the variable corresponding relative to the H frame.

If \( m \) [kg] is mass of quadcopter and \( I \) [N m s\(^2\)] is moment inertia matrix, the inertia system could be described as,

\[
M_H = \begin{bmatrix} m l_{3x3} & O_{3x3} \\ O_{3x3} & I \end{bmatrix}
\]  
\( (8) \)

It appears that MH is a diagonal matrix and \( a \) is a constant. Centripetal-Coriolis matrix,

\[
C_H = \begin{bmatrix} O_{3x3} & O_{3x3} \\ O_{3x3} & -S(l, \dot{X}_H) \end{bmatrix}
\]  
\( (9) \)

Gravitational vector,

\[
G_H = \begin{bmatrix} F_E^E \\ O_{3x1} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}
\]  
\( (10) \)

If JTP [N m s\(^2\)] is the total rotational moment of inertia of the propeller axis and \( \Omega \) [rad / s] is the angular velocity of the propeller whole, then the propeller gyroscopic matrix,

\[
O_H \cdot \Omega = J TP
\]  
\( (11) \)

If lift force factor \( b \) [N s\(^2\)] and \( d \) [N m s\(^2\)] is the drag factor, then the movement matrix can be shown below,
\[ \mathbf{E}_H = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ b & b & b & b \\ 0 & -b & 0 & b \\ -b & 0 & b & 0 \\ -d & d & -d & -d \end{bmatrix} \] (12)

If \( U_1 [N], U_2 [N \text{ m}], U_3 [N \text{ m}] \) and \( U_4 [N \text{ m}] \) are the lift force, roll torque, pitch torque and yaw torque respectively, then lift factor \( b [N \text{ m}^2] \) and the drag factor \( d [N \text{ m} \text{ s}^2] \) then action vector relative to frame-B,

\[ U_B = E_B \Omega^B = \begin{bmatrix} 0 \\ 0 \\ b (\Omega_1^2 + \Omega_2^2 + \Omega_3^2) \\ b (\Omega_2^2 - \Omega_3^2) \\ b (\Omega_3^2 - \Omega_1^2) \\ d (\Omega_2^2 + \Omega_3^2 - \Omega_1^2) \end{bmatrix} \] (13)

If \( R_\theta \) rotation matrix then relative action vector aksi relativ respect to frame-H,

\[ U_H = R_\theta O_{3x3} U_B = \begin{bmatrix} (c_\psi s_\phi + c_\phi s_\psi)U_1 \\ -c_\phi s_\psi + s_\phi c_\psi)U_1 \\ (c_\phi c_\psi)U_1 \\ U_2 \\ U_3 \\ U_4 \end{bmatrix} \] (14)

If \( c_k = \cos k, s_k = \sin k \) then matriks matrix,

\[ R_\psi = \begin{bmatrix} c_\psi c_\theta & -s_\psi s_\phi c_\theta + s_\phi s_\psi c_\theta & s_\phi c_\psi c_\theta + c_\phi s_\psi c_\theta \\ -s_\psi c_\phi c_\theta + c_\phi s_\psi c_\theta & c_\phi c_\psi c_\theta + s_\phi s_\psi c_\theta & s_\phi s_\phi c_\theta + c_\phi s_\psi c_\theta \\ s_\phi c_\theta & c_\phi c_\psi c_\theta - s_\phi s_\psi c_\theta & c_\phi s_\phi c_\theta - s_\phi s_\psi c_\theta \\ s_\psi c_\phi c_\theta & -c_\phi c_\psi c_\theta + s_\phi s_\psi c_\theta & -c_\phi s_\phi c_\theta + s_\phi s_\psi c_\theta \end{bmatrix} \] (15)

If \( t_\theta = \tan k \) then transfer matrix,

\[ T_\psi = \begin{bmatrix} 1 & s_\theta & c_\psi c_\theta \\ 0 & c_\psi & -s_\phi \\ 0 & s_\phi c_\theta & c_\phi c_\theta \end{bmatrix} \] (16)

Acceleration vector of quadcopter relative to frame-B could be described as,

\[ \ddot{X}_H = [\ddot{x} \ \ddot{y} \ \ddot{z} \ \dot{\phi} \ \dot{\psi} \ \dot{\theta}] = (- C_1 X_H + G_H + O_H \Omega + U_B) M_H \] (17)

In the simple equation is described as (17):

\[ \ddot{x} = (\sin \psi \sin \phi + \cos \psi \sin \theta \cos \phi) \frac{U_1}{m} \] 
\[ \ddot{y} = (-\cos \psi \sin \phi + \sin \psi \sin \theta \cos \phi) \frac{U_1}{m} \] 
\[ \ddot{z} = -g + (\cos \theta \cos \phi) \frac{U_1}{m} \] (18)

On equation (18) shows the mathematical model of quadcopter.

III. DYNAMICS MODEL OF QUADCOPTER

This section will be calculated dynamics of the movement of aircraft with specifications as shown in Table 1. The calculation process will be assisted with Matlab program.

<table>
<thead>
<tr>
<th>Tabel 1. Spesifikasi Pesawat</th>
<th>Deskripsi</th>
<th>Nilai</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>arm</td>
<td>240 mm</td>
</tr>
<tr>
<td>b</td>
<td>lift coefficient</td>
<td>72,081.10^16Ns²</td>
</tr>
<tr>
<td>d</td>
<td>drag coefficient</td>
<td>3,433.10^16Nms²</td>
</tr>
<tr>
<td>m</td>
<td>mass of quadcopter</td>
<td>1,576 kg</td>
</tr>
<tr>
<td>Ixx</td>
<td>body inertia moment for axis-x</td>
<td>15,293.10^16Nms²</td>
</tr>
<tr>
<td>Iyy</td>
<td>body inertia moment for axis-y</td>
<td>15,293.10^16Nms²</td>
</tr>
<tr>
<td>Izz</td>
<td>body inertia moment for axis-z</td>
<td>20,307.10^16Nms²</td>
</tr>
<tr>
<td>J tp</td>
<td>rotational moment inertia</td>
<td>0,103.10^16Nms²</td>
</tr>
</tbody>
</table>

An example of output program using matlab program:

| Vektor Aksi Pergerakan, U_H = | -0.0484 |
| Inertia Matrix of the System, M_H, | 1.5760 0.0000 0.0000 0.0000 0.0000 0.0000 |
| Sentripetal-Coriolis Matrix C_H (10^-4) | 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 |
| Gravitasional Vector G_H = | 0.0000 |
| Gyroscopic Propeller Matrix O_H (10^-4) | 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 |
```
0.1965 -0.1965 0.1965 -0.1965 
0.2208 -0.2208 0.2208 -0.2208
0.0000 -0.0000 0.0000 -0.0000
```

Angular velocities vector of each propeller,
\[ \Omega = \begin{bmatrix} 300.8505 \\ 302.9173 \end{bmatrix} \]

Angular velocities of quadcopter, \( D = -0.1017 \)

Acceleration Vector for aircraft,
\[ X_{DDot,H} = \begin{bmatrix} 0.0789 \\ 0.0886 \\ 6.7575 \\ -3.1632 \\ 2.8624 \\ -0.0252 \end{bmatrix} \]

**IV. QUADCOPTER SIMULATION**

This section will show a simulation of movement quadcopter both theoretically and experimentally. Movement of the experimental results obtained from the GPS data attached to Quadcopter. Furthermore, the results of calculations using the model dynamics and kinematics will be demonstrated in this section. For illustration, the movement in the x direction is planned to reach a distance of 5 m. As for the motion in the y direction is planned to reach a distance of 4.5 m. For motion in the z direction is planned and maintained at a height of 5 m.

In Figure 4, shows the graph of the trajectory of aircraft movement in three dimensions obtained from the calculation of dynamics and kinematics using matlab program.

In Figure 5, shows the graph plane distance (m) and time (s) in the x, y and z both theoretical and experiments using matlab program.
V. CONCLUSIONS

Acceleration due to the thrust plane is large enough that \( x^* = 1.7509 \, \text{m/s}^2, \ y^* = 2.0377 \, \text{m/s}^2 \) and \( z^* = 1.6371 \, \text{m/s}^2 \) for each mileage is \( x = 0.5565 \, \text{m}, \ y = 0.6307 \, \text{m} \) and \( z = 1.9700 \, \text{m} \). Thus indicating that the aircraft is quite agile in maneuvering.

Quadcopter movement simulation shown that the maximum error position between the theoretical and the actual movement is \( ex = 0.683 \, \text{m}; \ ey \) and \( ez = 0.353 \, \text{m} = 0.546 \, \text{m} \). Movement patterns and the theoretical value of the error is influenced by the control limit membership function of the fuzzy logic control design. Theoretical movement pattern similar to the actual movement.

REFERENCES


Design of Wheeled Mobile Robot with Tri-Star Wheel as Rescue Robot

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Abstract— This study aims to design, and analyze a mobile robot that can handle some of the obstacles, they are uneven surfaces, slopes, can also climb stairs. WMR in this study is Tri-star wheel that is containing three wheels for each set. On average surface only two wheels in contact with the surface, if there is an uneven surface or obstacle then the third wheel will rotate with the rotation center of the wheel in contact with the leading obstacle then only one wheel in contact with the surface. This study uses the C language program. Furthermore, the minimum thrust to be generated torque of the motor and transmission is 9.56 kg. The results obtained by calculation and analysis of DC motors used must have a torque greater than 14.67 kg.cm. Minimum thrust to be generated motor torque and the transmission is 9.56 kg. The experimental results give good results for robot to moving forward, backward, turn left, turn right and climbing the stairs.

Index Terms—WMR, tri-star, kinematics, dynamics model.

I. INTRODUCTION

Wheeled mobile robots (WMR) are generally used for flat areas or smooth trajectory, then the region with a significant height difference then the robot will stop or be programmed to turn look for another way. One of the unique and multifunctional robots are made to address the issues above are a robot with wheels arranged in a triangular shape, so there are three sets of wheels each wheel. This model is commonly called tri-star wheels.

On average surface only two wheels in contact with the ground, if there is an uneven surface or obstacle then the third wheel will rotate with the rotation center of the wheel in contact with the leading obstacle then only one wheel in contact with the surface. This kind of robot that uses wheels contacted to the ground, commonly used on uneven road surfaces. And also, these types of robots are very well used to climb the stairs.

Several previous studies which can be used as a reference, i.e. design rescue robot [1], and design wheel chair that can be climbing the stairs [2]. Meanwhile, this research aims to design and analyze the performance of a mobile robot using a tri-star wheels.

II. THE CONCEPT OF TRI-STAR

A. Stages of creating robot

In the Figure 1, shows stages of the manufacturing. There are three stages of manufacture of the robot, the first is planning. Including the selection of hardware and design, the next stage of manufacture. Including the manufacture of mechanical, electronic, and programs, and the last stage is the testing [3].

B. Wheeled Mobile Robot

Some types of wheels are often used on WMR among other types of Bi-wheel form of a pair of wheels that can be moved with a soft, very suitable for modeling, but still prone to the risk of slippage. Caterpillar type, form two pairs of wheels (each wheel connected to each other) with the appropriate characteristics of a straight movement, not to risk a skid, but cannot accurately model the turning movement. Type omnidirectional, has characteristics can move freely in all directions throughout the complex structure of the wheel, but still has the disadvantage of frame [4].

Figure 1. Design of robot

Figure 2. Wheel type that is often used in the WMR  
(a) Bi-Wheel; (b) Caterpillar; (c) omnidirectional
C. Electrical Motor

Wheel of WMR uses an electric motor. For high torque motors and torque motors larger then it is better to use a DC motor. The most important in the selection of a motor is the torque necessary. Note that, Figure 3 shows how the tri-star wheel work. Then, to calculate the minimum torque on the axis with the following equation [4]:

\[ T = \mu \times m \times g \]  \hspace{1cm} (1)

Friction Force \( F \), with radius of wheels \( R \) dan radius of axis is \( R_0 \),

\[ F = F_r \times \frac{R}{R_0} \]  \hspace{1cm} (2)

Torque at the axis can be shown,

\[ T_0 = -F \times R_0 = -\mu \times m \times g \times R \]  \hspace{1cm} (3)

Torque of motor is,

\[ T_m = \frac{\left( N \times h_g \right)}{N \times h_g} \times \text{untuk} \quad \left( = T_{\text{stall}} \right) \]  \hspace{1cm} (4)

where \( h_g \) is an efficiency of gears, \( T_{\text{stall}} \) is stall torque, it shown at specification of motor and \( N \) is gear ratio.

A. Kinematics of WMR

Technically, WMR robot has two main wheels are each driven by an independent drive, and the other that there is a wheel with one or two castor wheels. Those wheels are placed at the back of the robot that serves as a counterweight.

Figure 4 shows the architecture of the robot viewed from the top. If both drive wheels are spinning at the same speed, the robot will move straight direction, whereas if one of the wheel speeds is slower, then the robot will move with a curved trajectory toward the direction of one of the wheels that move more slowly [5].

For the wheel radius \( r \), and the rotation speed of the right wheel, and left respectively \( \omega_r \) and \( \omega_l \), then, the linear speed of the right and left wheels can be calculated by the following equation:

\[ v_r(t) = r \omega_r(t) \]  \hspace{1cm} (5)

\[ v_l(t) = r \omega_l(t) \]  \hspace{1cm} (6)

When the robot motion play when time \( t \) with the length of the radius \( R \) is measured from the center of rotation and the center point of the two wheels, the angular velocities can be calculated as:

\[ \omega(t) = \frac{v_r}{R} \]  \hspace{1cm} (7)

\[ \omega(t) = \frac{v_l}{R} \]  \hspace{1cm} (8)

Robot linear velocity \( v(t) \) and the angular veloci of the robot \( \omega(t) \) can be determined based on both the linear speed of the wheel. In detail, can be shown in matrix presented in equation below,

\[
\begin{bmatrix}
v(t)
\omega(t)
\end{bmatrix} =
\begin{bmatrix}
1 & 1
\frac{1}{2} & -\frac{1}{2}
\frac{1}{2} & \frac{1}{2}
\end{bmatrix}
\begin{bmatrix}
v_r(t)
v_l(t)
\end{bmatrix}
\]  \hspace{1cm} (9)

This equation shows the relation between the direct kinematics linear velocities of the wheels, and linear and angular velocities of the robot, while this equation below shows the opposite relationship.

\[
\begin{bmatrix}
v_r(t)
v_l(t)
\omega(t)
\end{bmatrix} =
\begin{bmatrix}
1 & \frac{1}{2} & -\frac{1}{2}
\frac{1}{2} & \frac{1}{2}
\frac{1}{2} & \frac{1}{2}
\end{bmatrix}
\begin{bmatrix}
v(t)
\omega(t)
\end{bmatrix}
\]  \hspace{1cm} (10)

Terms of absolute position control of the mobile robot is a robot knows the position and orientation of each moment. Furthermore, one solution is to calculate the distance the wheel every time. Mileage left wheel \( S_L \), the right wheel \( S_R \), and average distance \( S \) in successive time zones as follows:

\[ S_L(t) = v_L(t) \cdot t \]  \hspace{1cm} (11)

\[ S_R(t) = v_R(t) \cdot t \]  \hspace{1cm} (12)
Formula approach to orientation, position coordinates \( x \) and \( y \) coordinates respectively as follows.

\[
\begin{align*}
S(t) &= \frac{v_x(t) + v_y(t)}{2} \cdot t \\
\theta(t) &= \frac{S_x(t) - S_y(t)}{L} + \theta_0 \\
x(t) &= x_0 + S \cos \theta(t) \\
y(t) &= y_0 + S \sin \theta(t)
\end{align*}
\]

D. Tri-star model of WMR

Figure 5. Illustration the movement of Tri-Star Wheel uneven surface

Note, Figure 6 below, gears gear A is connected to the drive. B gears numbering three, connected by gears roda.Dan C is a liaison and steering. All three gears A, B and C are connected to the arm. There are two models of the movement of the WMR by tri-star wheel that is currently running on a flat foundation and up the stairs at the time.

Figure 6. (a) Model of gears of Tri-Star Wheel (b) Moving at flat surface

When moving on a flat surface then, there are two wheels in contact with the runway, each wheel just spins on its axis and each arm is not moving, see figure 6.B. Then, comparison of the angular velocity of the wheels of their gears are

\[
\begin{align*}
\frac{\omega_A}{\omega_C} &= \frac{n_C}{n_B} \\
\frac{\omega_C}{\omega_B} &= \frac{n_B}{n_A}
\end{align*}
\]

Velocity ratio (N) of this model is

\[
N = \frac{\omega_A}{\omega_B} = \frac{n_C}{n_A} \times \frac{n_B}{n_C} = \frac{n_B}{n_A}
\]

When climbing stairs, there is only one wheel in contact with the ground, and the other spinning wheels on the axle in contact with landasan, akibat rotation arm, see Figure 7.a. Kinematics equations under these conditions can be explained by using the method of complex numbers [7] as follows, note Figure 7.b.

\[
\begin{align*}
\bar{r}_2 &= r_2 e^{i\theta_2} = r_2 (\cos \theta_2 + i \sin \theta_2) \\
V_A &= \frac{d}{dt} (r_2 e^{i\theta_2}) \\
&= i\omega_2 r_2 e^{i\theta_2} \\
&= i\omega_2 r_2 \cos \theta_2 - i\omega_2 r_2 \sin \theta_2 \\
A_A &= \frac{d}{dt} (i\omega_2 r_2 e^{i\theta_2}) \\
&= i^2 \omega_2^2 r_2 e^{i\theta_2} - \omega_2^2 r_2 e^{i\theta_2} \\
&= i(\omega_2^2 r_2 \cos \theta_2 + i \sin \theta_2 - \omega_2^2 r_2 \cos \theta_2 + i \sin \theta_2) \\
&= \frac{\sum F}{mA_G} = mA_G (\cos \theta_{g2} + i \sin \theta_{g2})
\end{align*}
\]

For dynamic analysis of tri-star wheel by using complex numbers, the first step is to describe the free-body diagram. The second step is to create equilibrium equation based on free body diagrams. Furthermore, outlining all relevant vectors in the form of complex numbers.

Consider the free body diagram in Figure 7 the equilibrium equation is given as follows

\[
\begin{align*}
\sum F &= mA_G \\
\sum \bar{F} = m \bar{A}_G
\end{align*}
\]

Where the vectors described above as follows

\[
\begin{align*}
\bar{F} = F_x + iF_y \\
\bar{W} = We^{i\theta_2} = -i\bar{W} \\
\bar{A}_G &= mA_G (\cos \theta_{g2} + i \sin \theta_{g2})
\end{align*}
\]
Then the equilibrium equation can be rewritten

\[ F_x + iF_y - iW = mA_x (\cos \theta_{21} + i \sin \theta_{22}) \]  

(27)

Components described in the real and imaginary components, generating the equation below

\[ F_x = mA_x (\cos \theta_{21}) \]  

(28)

\[ F_y = mA_x (\sin \theta_{22}) + W \]  

(29)

Figure 8. Tri-star wheel in equilibrium position.

In order to balance the system, then \[ T = \vec{r} \times \vec{F} \], where

\[ \vec{r}_G = r_G e^{i\theta} = r_G (\cos \theta + i \sin \theta) \]  

(30)

It can be shown as,

\[ T = \begin{pmatrix} i & j & k \\ -F \cos \theta_G & -F \sin \theta_G & 0 \\ 0 & 0 & -F \sin \theta_G + W \end{pmatrix} \]

\[ T = |F| \cos \theta_G + |F| \sin \theta_G + W - |F| \cos \theta_G + r \sin \theta \]

(31)

III. ANALYSIS MODEL AND DISCUSSION

A. Result of Model Analysis

From this research generated several things, among others:

1) Wheeled Mobile Robot (WMR) with Tri-Star Wheels are made visible in the image 11. This robot consists of a frame, tri-star wheel just as seen in Figure 12, the motor and transmission torque amplifier (Figure 13), and electronic devices.

2) Kinematic analysis of results of Tri-Star Wheels with kinematics equations by the method of complex numbers, give the values of position, velocity and acceleration of each points on the tri-star wheel as follows: \(|r_A| = 0.18 \text{ m}, |r_B| = 0.09 \text{ m}, |V_A| = |V_B| = 0.195 \text{ m/s}, |A_A| = 0.098 \text{ m/s}^2, |A_B| = 0.216 \text{ m/s}^2, \text{ and } d |A_G| = 0.113 \text{ m/s}^2.

3) The results of the analysis of the dynamics of the wheel Tri-Star, is given in the graph in Figure 11. dynamic calculations to obtain the value of the torque to turn the wheels when climbing stairs.

In the Figure 10, WMR Robot Products Tri-Star has a length of 110 cm, width 75 cm and height 60 cm. And for the tri-star wheel has a small gap between the wheel axis 18 cm and smaller wheelbase to the center tri-star wheels 10 cm.

Figure 9. WMR Tri-Star

Figure 10. Tri-Star Wheels

Figure 11. Relation between angle and torque

WMR Tri-Star robot is controlled by an open loop control system, wherein the command signal is given via an infra-red remote control system that is subsequently processed in the microcontroller and then proceed to the next motor controllers.
motor will rotate according the applied voltage. Overall the controls are stored in a control box. From the observation, the command would be well received if the distance between the signal receiver remote with 1-10 meters.

From the test results, the performance of the robot WMR acquired Tri-Star is moving forward with a speed of 0.10 m / s, either moving backward with a speed of 0.10 m / s, turn left and right both with velocity 0.0024 rad / s, ladder that can be climbed up to a height of 20 cm and a width of at least 25 cm

IV. CONCLUSION

WMR robot by tri-star wheel can perform experiments for uneven surfaces. In addition, the tri-star robot successfully run straight, turn and climbs stairs. Meanwhile, the average of velocity of the Tri-star robot is 0.1 m / s. Furthermore, the controller of this system is done by open loop method using infrared control system.

ACKNOWLEDGMENT

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Application of Genetic Algorithm for Determining the Optimum Ship Route

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Abstract—Determining the most optimum route is a crucial factor in ship operation in terms of technical and economical points of view. In the present study, genetic algorithm (GA) is applied to determine the most optimum route of a ship with several destinations to visit. The problem and solution are considered to be similar with the travelling salesman problem (TSP). In GA implementation, the fitness of each individual is measured from the distance of its origin and final destination points. Moreover, several standard genetic operators are also implemented in the present study such as selection, mutation and crossover. An interactive program is developed with visual basic programming language to demonstrate and simulate the practicability and effectiveness of the method to solve the problem. Three cases are simulated in order to analyze the performance of the solution method which are simulations with varying number of population, probability crossover and mutation crossover. From the computation results, it can be shown that even though the average fitness of the population is fluctuating, the most optimum route still can be obtained.

Index Terms—Genetic algorithm, optimum ship route, travelling salesman problem, visual basic simulation.

I. INTRODUCTION

As fuel price increases, the ship sailing operation costs also get higher. This is not a favorable condition either for ship operators or for ship passengers in terms of ticket prices and sailing time. Therefore it is an important and crucial task to make the ship operation effective and efficient.

There are several ways to address the problem such as installing a fuel-efficient engine, utilizing cheap and renewable energies, designing ship hull forms with less resistance, etc. Another way to resolve the problem is to sail following the shortest route. As a result, the engine fuel and sailing time can be saved.

In the present study, the shortest route is assumed to be the most optimum route. It is also assumed that the ship needs to visit or reach several locations before the ship arriving at a final destination. The reason of the ship to visit or reach several locations can be to load/unload passengers and cargos at other ports or simply to avoid static obstacles such as anchoring ships, dangerous coral reefs, or bad weathers in certain area of the ocean.

In order to determine the most optimum route of a ship with several destinations, genetic algorithm is adopted as the main computation method in the present study. The method is one of popular methods in optimization research field. The flexibility of the method makes it convenient to be adopted in numerous research fields. For the purpose of finding the shortest path, it was also implemented by several researchers to the vehicles routing problem [1, 2, 3].

As described previously, in the present study, it is assumed that the ship has several destinations to visit. The ship needs to visit each destination location at least once. Therefore, the problem and solution method in the present study are similar to the travelling salesman problem (TSP). The implementation and solution of TSP with GA can also be found in Larranaga et al. [4] and Grefenstette et al. [5].

In order to define and solve the problem, ship sailing area is divided into a grid to make it easier to define the location and distance of the ship inside sailing area. The fitness of an individual is measured from the distance the ship sails starting from origin to the final destination points. In the present study, even though it is assumed that the origin point can be from any position inside the grid, it would be easy to extend the problem with fixed origin point.

Moreover, a computer program is developed to simulate the process of determining the most optimum route using Visual Basic programming language. With this program, the user can define the number and position of all locations that ship needs to visit. For this purpose, the user can determine them by manually clicking inside the grid or requesting the application to randomly determine certain numbers of locations to visit.

In order to demonstrate the applicability and performance of the solution method and program, simulations are performed by varying 3 (three) variables, which are:

- Case 1: varying initial population
- Case 2: varying crossover probability
- Case 3: varying mutation probability

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With these 3 cases, the effect of varying those variables to the computation results can be analyzed and discussed. Because of the flexibility of the solution method, the program simulation can be easily further developed and implemented to several other applications such as real time ship autopilot, remote underwater vehicle (RUV) obstacles avoidance, optimum ports development, etc.

II. GENETIC ALGORITHM

Genetic algorithm is one of popular methods used for optimization purpose. It is a method inspired by the evolution theory and uses the survival of the fittest strategy to find the optimal solution in a defined search space. It is an iteration process which starts by generating a certain number of random individuals. After that, genetic operators such as reproduction, crossover and mutation are applied to form the next generation which satisfies a certain fitness function. More detail explanation can be found in Coley [6] and Sivanandam and Deepa [7].

A. Outline of GA

Before starting the GA analysis, the chromosome representation of each individual or so-called encoding must be defined. There are some types of encoding such as binary encoding, integer encoding, permutation encoding, and tree encoding. In this study, integer encoding will be used. The integer will represent the number of locations that ships need to visit. Besides encoding, the genetic operators should also be defined. The following genetic operators are applied in this study.

- Selection (reproduction) is the process of choosing parents for mating. There are several methods which can be used in parents selection process for example roulette-wheel, tournament, stochastic universal damping, and truncation selections. The present study will adopt tournament selection.
- Crossover is used to interchange limited parts of parents. The parents will be decided to undergo crossover or not based on crossover probability \( P_C \).
- Mutation is used to flip the value of each chromosome of an individual. It is decided to apply mutation based on mutation probability \( P_M \).
- Elitism is copying the fittest member of previous population if the maximum fitness of the new population is lower than this fittest member.

The main flow of GA is shown in Fig. 1. In this figure, an initial population is generated as the first step. An individual in the population represents the distances of the ship route to sail. At this step, some random numbers are thrown for some number of genes which constitute a chromosome. After obtaining the values of each gene, the fitness of each individual is computed. The fitness is measured to determine the probability of an individual to be selected as parents which will be mated using genetic operators to obtain offsprings. These offsprings are then used to replace the old population and to be computed again to obtain their fitness. The process will continue for certain number of generations until the computation result converges. The computation is considered to be converged when there is no more increase in the best fitness for more than 100 generations.

B. Individual Representation

In order to solve the problem, several locations that ship needs to visit are represented by filled circles with certain numbers on them as shown in the figure below.

Each individual in the present problem is represented by a possible route that ship can sail. The chromosome of the individual is represented by the number of locations that the ship needs to visit. Therefore, each individual will have a chromosome consisting of random numbers of integer from 0 to the numbers of locations. 3 (three) examples of individuals with number of location equals to 10 are:

\[
\text{Individual 1} = 8 2 0 5 9 6 3 7 1 4 \\
\text{Individual 2} = 3 1 8 5 3 7 1 9 4 6 \\
\text{Individual 3} = 5 0 4 9 7 4 2 8 1 3
\]

The first integer of chromosome represents the origin point, the last integer represents the final destination point, and all other integers represent the locations or positions that need to be visited or reached at least once.

C. Fitness Definition

In order to evaluate the performance of an individual and convergence of the calculation, the fitness of the individual
needs to be defined. In this study, the fitness is defined to be the distance that ship needs to sail from origin to final destination. Therefore, lower value of fitness means shorter distance which represents higher fitness.

The fitness represents the probability of an individual to be chosen as parents for mating. Therefore an individual with higher fitness will have a bigger chance to be selected for mating. In implementation, the ship sailing area will be divided into grids, so the distance of two positions is measured from the number of grids which separate the two positions.

Because the fitness is measured by the distance of the grid, it can be determined using the following simple formula

\[
d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}
\]

where

- \((x_i, y_i)\) = ordinate of the first position
- \((x_j, y_j)\) = ordinate of the second position

III. SIMULATION PROGRAM

Simulation program is developed with Visual Basic programming language. The program consists of two windows with several controls on them. The first window shows the introduction about program and several input fields that needs to be filled by user which are number of population (PopSize), maximum generation (MaxGen), crossover probability (Pc), and mutation probability (Pm).

The start window of the program is shown in the following figure.

![Program start window](image)

Fig. 3. Program start window

Besides the introduction text and input fields, there are also 3 buttons. One button is to define the position labelled “Position Definition”, another one is to start the simulation labelled “Start Simulation” and third button is in the lower left corner of the window which is used to quit the program. In order to start the simulation, the user firstly needs to define the position by clicking “Position Definition” button. The program also shows a message below the “Positions Definition” button says “Positions not defined” when the user is still not defined the positions.

When the user clicks the “Positions Definition” button, the following window will be shown.

![Position definition window](image)

Fig. 4. Position definition window

The window shown in Fig. 4 consists of an empty panel, three buttons and an input text fields. In order to define the position, the user can directly click any point inside the panel or fill a certain number on input text field and then click “Random Position” button. The program will randomly place several positions on the panel. After the users defines the position, they can click button “OK” to quit or button “reset” to remove all the defined positions and start again the process from beginning.

After the positions definition processes are completed. The window can be closed so the program will return to the start window again. However, this time, the start window will inform the user that the positions have been defined by changing the message to be “positions defined”. At this stage, the simulation can be started by filling all input fields and then pressing “Start Simulation” button.

IV. RESULTS AND DISCUSSION

With the problem definition defined above, simulations are performed. The number of locations are randomly chosen to demonstrate the simulation as follows

![Example of random locations to demonstrate the program](image)

Fig. 5. Example of random locations to demonstrate the program.
As shown in the figure above, the number of positions are chosen to be 20. The positions are created randomly by clicking “Random Position” button.

In order to analyze the effect of genetic variables and performance of the method, 3 (three) cases are analyzed in the present study which are varying the number population, crossover probability and mutation probability.

1) Varying Number of Population

The first case is simulated by computing 4 different numbers of population which are 5, 20, 50 and 70. The crossover probability and mutation probability are fixed to be 75% and 30%, respectively. The number of maximum generation is chosen to be 1000 generation. The computation results are shown below

In Fig. 7, it can be observed that the average fitness is fluctuating in all 4 values of PopSize. This could mean that not all individuals in the population change to be the optimum ones. The results might be caused by the type of encoding used in the present study. The integer encoding limits the number of chromosome to be modified, hence limits the identities to be introduced in the population as well.

Moreover, from Fig. 7, it can also be observed that the average fitness of the population has the same trend with best fitness where higher value of PopSize will converge faster than lower one.

2) Crossover Probability effect

The second case is simulated by varying the crossover probability to be 50%, 80%, 90% and 100%. In this case, the number of population and mutation probability are fixed to be 50 and 30%, respectively. The computation results in terms of best fitness are shown in the following figure

From the figure above, a different trend with the previous case can be observed. In this case, the most optimum solution is obtained with crossover probability equals to 80% while higher crossover probability (Pc=90%) obtains the optimum solution slightly with more number of generations. Moreover, the highest crossover probability (Pc=100%) converges with optimal solution lower than results from other 3 values of Pc. The results show that in genetic algorithm, the higher crossover probability will not mean the best choice to use in the implementation. The best value of crossover probability will depend on the problem we are solving.

The average fitness of the population for 1000 generations of the second case are shown in the figure below
many number of positions, the simulation with $P_c=4\%$ converges slowest. The results could give us a suggestion that many individuals in the population which have poorer fitness even after many generations. The trend is different to all other cases previously. The results support the previous statement that the genetic operator of mutation has made the convergence of the solution method slower.

From all computations, the most optimum solution is found to be 51,344. However, there are several routes which have the same fitness value. One of the route is shown in the following figure.

![Fig. 12. One of the most optimum routes](image)

In the figure above, the optimum route has origin on position 9 while the final destination position is on 0. Moreover, by observing the route shown in Fig. 12, it can be suggested that the route is the optimal one. One reason of this judgment is because there is no arrow crossing other arrows.

Even though the demonstrated example seems to be simple with not so many number of positions, the simulation with large number of position can be performed with the program developed in the present study.

V. CONCLUSION

In the present study, genetic algorithm is applied to determine the most optimal route of a ship for sailing. The implemented method is also applied in a Visual Basic program. One example is demonstrated in the paper. From the
computation results, it can noted the genetic algorithm method is viable to be implemented in this problem. Moreover, it is also shown that even though the solution can be obtained, the average fitness of a population is still fluctuating which can be contributed to type of chromosome type of the individual. Another important point in the present study that mutation probability gives a negative effect to the convergence of the solution method.

REFERENCES


Fatigue Life Prediction In Journal Bearing

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Abstract— Failure of fatigue is damaged materials where caused frequent load. Fatigue owing to some factors, which is Stress concentration on fatigue, Stress life, Effect size and surface, and Change properties of surface. The fatigue failure of a material is dependent on the interaction of a large stress with a critical flow. In essence, fatigue is controlled by the weakest link of the material, with the probability of a weak link increasing with material volume. This phenomenon is evident in the fatigue test results of a material using specimens of varying diameters. From this research we can get effect of concentration stress on strength fatigue with S-N method. On this method only count fatigue life or endurance limit from Journal bearing housing. By Finite Element Analysis, it is not so easy to determine fatigue life. When we find the first yield point, it means this point is in the highest stress state. Then we can refer S-N curve. In this paper, the effect of bearing and housing elasticity on the stress field, which could result in surface fatigue in journal bearing, has been investigated. This condition is proved with occurred slip lines on surface of specimen. These slip lines are caused on some thousands stress cycles. Additional crack is happened immediately and finally long enough crack. So that formed unstable crack that caused fracture of brittleness or fracture of toughness because section of specimen cannot keep.

Index Terms— journal bearing, numerical, fatigue life

I. INTRODUCTION

While many parts may work well initially, they often fail in service due to fatigue failure caused by repeated cyclic loading. Characterizing the capability of a material to survive the many cycles a component may experience during its lifetime is the aim of fatigue analysis. In a general sense, Fatigue Analysis has three main methods, Strain Life, Stress Life, and Fracture Mechanics.

According to independent studies carried out by the Battelle group in 1982, between 80-90% of all structural failures occur through a fatigue mechanism and the estimated annual cost of fracture and fatigue to the US was 4.4% of GDP.

Furthermore the Battelle Study concluded that this could be reduced by 29% by application of current fatigue analysis technology.

In the past, fatigue analysis was largely the domain of the development engineer, who used measurements taken from prototype components to predict the fatigue behavior. This gave rise to the traditional “Build it, Test It, Fix It” approach to fatigue design. This approach is known to be very costly as an iterative design cycle is centered on the construction of real prototype components. This inhibits the ability to develop new concepts and reduces confidence in the final product due to a low statistical sample of tests. It is also common to find early products released with ‘known’ defects or product release dates being delayed whilst durability issues were addressed.

A more desirable approach is to conduct more testing based on computer simulations. Computational analysis can be performed relatively quickly and much earlier in the design cycle.

Confidence in the product is therefore improved because more usage scenarios can be simulated. It is not recommended, however, that these simulations completely replace prototype testing. It will always remain desirable to have prototype signoff tests to validate the analysis performed and improve our future modeling techniques. However, the number of prototype stages, and hence the total development time, can be reduced.

The following subsections are including: bearing in general, journal bearings, thrust bearing, other types of bearings, rotor-bearing system. Coupled thermomechanical non-linear finite element models have been developed to study 2D and 3D rolling, and rolling plus sliding contact problems. The various less or more realistic material constitutive models have been used to model behavior of bearing materials. The contact stress fatigue is considered as a primary wear mechanism. The damage process under contact loading such as, for example, is the cracking, spailing, and tribological reaction, can be study by the finite element method. We can study the mechanics of the sub-surface or near surface modes of rolling contact failure.

In this paper we overview the physical behavior responsible for fatigue stress from initiation to final component failure of journal bearing.

II. JOURNAL BEARING

The bearings are important enough to be studied because if the shaft’s orbit is not stable, or the bearing is not well designed, contact between the shaft and the bearing will appear.
The plain journal bearings are fully used in hydraulics due to their small size, low price, and its capability of carrying load.

The journal bearing appears in the finite element equations as a spring and damper. It appears at one node, linking the shaft to a rigid structure. It has 4 degrees of freedom.

![Fig 1. FE Equation of Journal Bearing](image)

The first thing we need to do is determine the static (mean) position of the shaft in the bearing.

![Fig 2. Static Bearing Calculation](image)

Two important parameters are obtained from the bearing test: (i) bearing yield ($S_{b, y}$) and (ii) bearing ultimate ($S_{b, ut}$) of the material; where bearing stress is defined with the following relation: $S_{b} = P/(Dt)$. The yield parameter is defined as the stress at a 2% permanent hole deformation, which is a definition comparable to the tensile yield. Bearing ultimate is defined as the first maximum load peak, which generally was the maximum stress reached.

For the material model, it is assumed that it behaves as an isotropic material with isotropic hardening. Uniaxial tensile test data are simplified into a trilinear behavior, consisting of (i) an elastic part, (ii) plastic part up to necking (15% plastic strain) with stiffness equal to 1467.67 MPa, which is followed by (iii) a description of the necking behavior.

Fatigue is defined as ‘Failure under a repeated or otherwise varying load which never reaches a level sufficient to cause failure in a single application.’ Fatigue cracks always develop as a result of cyclic plastic deformation in a localized area. This plastic deformation might arise through the presence of a small crack or pre-existing defect on the surface of a component, for both cases it is practically undetectable and unfeasible to model using traditional Finite Element techniques.

The fatigue life prediction follows the strain life approach used for notched geometries. Surface grooves are treated as microscopic notches, where elastic stresses and strains are converted to local plastic stresses and strains in the notch root. Different methods can be used for this conversion, depending on the stress state in the notch root and the applied loading. The most well-known approach is that due to Neuber which relates nominal elastic values to notch root stress and strain as $\varepsilon = K_{1} \varepsilon_{n} E = C$, where C is a constant and en is nominal elastic strain. Plane stress is assumed in this analysis, which can be shown not to be the case for a circumferentially notched bar. A method for general stress states is outlined later.

The fatigue strength of a welded component is defined as the stress range which fluctuating at constant amplitude causes failure of the component after a specified number of cycles (N). The stress range is the difference between the maximum and minimum points in the cycle. The number of cycles to failure is known as the endurance or fatigue life.

The expression linking N and $R^{m}$ can be plotted on a logarithmic scale as a straight line and is referred to as an S-N curve. The relationship holds for a wide range of endurance. It is limited at the low endurance end by static failure when the ultimate material strength is exceeded. At endurances exceeding about 5-10 million cycles the stress ranges are generally too small to permit propagation under constant amplitude loading. This limit is called the non-propagating Stress.

Finite element technique involves element-modeling discretion, which is defined through a displacement function of each node.

$$[F] = [k][D]$$  \hspace{1cm} (1)

**Handling Finite Element Analysis stress requires a good understanding of the stress-concentration effect, quantified as a factor $K_t$. The theoretical stress-concentration factor is based on a theoretical elastic, homogeneous, isotropic material and can be expressed as:**

$$K_{t} = \sigma_{\text{max}} / \sigma_{\text{nom}}$$  \hspace{1cm} (2)

**Handling FEA fatigue stresses correctly also requires good understanding of fatigue stress-concentration factor**

By Finite Element Analysis, it is not so easy to determine fatigue life. When we find the first yield point, it means this point is in the highest stress state. Then we can refer S-N curve.

**III. RESULT AND DISCUSSION**

From this research we can get effect of concentration stress or $K_t$ on strength fatigue with S-N method. On this method only count fatigue life or endurance limit from Journal Bearing. The lubricant was assumed to supply at ambient pressure via a full width line groove in the upstream groove. The Reynolds equation was solved using the Gauss-Seidel iterative method with over relaxation factor. The
boundary conditions required were at the bearing edges and at the lubricant supply line. The lubricant was assumed to capitated at ambient pressure. Thus; \( P_{\text{cavitation}} = P_{\text{atmofer}} = 0 \). For use with the Reynolds equation and full-width film applied, the following boundary conditions adapted were,

a) \( P = 0 \) at \( \phi = 0 \).

b) \( P = 0 \) at \( \phi = \pi/2 - \phi \), and \( P = 0 \) at \( \phi = 3\pi/2 - \phi \).

c) \( P = dP/dX = dP/dZ = 0 \) at \( \phi = \phi_2 = \pi + \alpha \).

d) \( P = 0 \) at \( z = \pm h/2 \).

![Fig 3. FEA Modelling for Journal Bearing](image)

From this research we can get effect of concentration stress or \( K_t \) on strength fatigue with S-N method. On this method only count fatigue life or endurance limit from Journal bearing.

![Fig 4. FStress Consentration for Journal Bearing](image)

<table>
<thead>
<tr>
<th>Stress (Mpa)</th>
<th>Fatigue life (cycle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13,872</td>
<td>48671</td>
</tr>
<tr>
<td>21,047</td>
<td>20518</td>
</tr>
<tr>
<td>27,728</td>
<td>15191</td>
</tr>
<tr>
<td>35,312</td>
<td>10513</td>
</tr>
<tr>
<td>40,128</td>
<td>5732</td>
</tr>
</tbody>
</table>

From the data we can draw S-N curve for journal bearing.

![Fig 5. Fatigue for Journal Bearing](image)

![Fig 6. S-N curve](image)

**IV. CONCLUSION**

A general approach to modelling the durability of Journal Bearing has been developed. The approach removes the requirement of rebuilding FEM models in order to capture the important stress raising features which significantly affect fatigue life predictions.

The method is ideally suited for predicting data for fatigue life calculations in Journal Bearing.

Example applications have been presented demonstrating some of the capabilities of the method. The most important point addressed in this work is that the method, which uses, can be implemented easily to predict fatigue life of journal bearing by Finite Element Analysis. Moreover, the algorithm provides robust and fast results because the proposed method avoids the extra computational burden for
preprocessing since only stress concentration of the components are used to predict the fatigue stress of the journal bearing. The proposed method can identify stress concentration, fatigue stress and calculate the fatigue life of the journal bearing.

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Development of 5-DOF Robot Arm Manipulator

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Abstract—This research is designed and made prototype articulated type robot arm with five degrees of freedom (5-DOF). Where the end-effector is a gripper is used that has two claws. This robot arm joint rotation has 5 pieces / revolute which serves to connect the links that one with the other link. Each joint is restricted 1 degrees of freedom. It aims to facilitate the mechanical and control system of the manipulator. As the actuator (driver) joint use stepper motors, which required the driver to control (control circuit) with input data in the form of computer commands communicated with the system working port. Parallel communication or control system of the manipulator is to adjust the angular position of each joint with computer program created with Visual Basic 6.0 language, which is working parallel to the driver circuit so that the driver circuit generates pulses to drive the stepper motor.

Index Terms—degree of freedom, robot arm, manipulator

I. INTRODUCTION

Products rapidly evolving field of technology today is robotics. The reason is because the robot can be designed to work on the process of working with high accuracy (quality) as well as having more job productivity (quantity) that can help increase the volume of production.

One of the advantages of the robot is able to be placed for the operations that are considered at risk (high-risk) to be done by humans, such as in the area of high temperature, hazardous chemicals, toxic gases, radioactive risks, including a mission in outer space. In addition, the robot is able to do continuous process repeatedly deemed too tedious to be done by humans. The work process includes a series of robot control system that enables a robot to take orders, run the program works, and produces both interrupt and process repeatedly. One of the robot controller is a computer that is often used. The robotics system is being developed not to replace the entire human role, but rather help people to more easily, quickly and comfortably in his work.

II. ROBOT COMPONENT

The main components of the robot arm generally has three important parts, namely manipulators, mechanical systems, and control systems.

Manipulator is a mechanical part that can be used to move, lift, and manipulate the work piece. Function depends on the type of robot end-effector mounted on the manipulator. End-effector can be a device welding, painting, machine tools or a gripper which has a movable jaw opens and closes. Gripper can be classified into 3 types:

- Unilateral action gripper; contact with the surface of the object. (Method: vacuum, magnetic and principles of adhesion)
- Bilateral action gripper; contact with the surface of the object 2. (Method: clamp)
- Multilateral action gripper; more than 2 contacts the surface of the object. For example, multijointed fingers (method: gripping).

Mechanical system illustrates how the shape of the robot hand and the type of components to be used.

Mechanical design is the principle that determines the skill/dexterity of a robot arm. 3 basic aspects that must be considered in designing a robot arm:

- The number of rods (link)
- Number of connections (joint linear / prismatic and revolute joint)
- The size and movement of each rod (degrees of freedom / DOF)

![Fig 1. Schematic Diagram of Robot Arm](image)

Robot arm control system in general is a microprocessor-based electronic circuit that functions as a regulator of all components in shaping the work function. The control system generally has three functions:

- Opening and closing movement of the manipulator components at the desired stage and specific point.
- Storing data in memory positions and phases.
- Allow the robot to be able to interface with a particular device.

Broadly speaking, the motion control system in robotics have structured parts, which include:

![Fig 2. Control System of Robot Arm](image)
Robots can be analyzed in two studies domain, namely the analysis of kinematic and dynamic analysis. Kinematic analysis related to robot movement regardless of inertial effects / inertia that occurs when the robot movement, while dynamic analysis related to the inertia effect of the physical structure of the robot is the result of the movement generated by the torque of the actuator when the robot is doing the movement.

Robotic systems in general consist of a system controller, electronic and mechanical robots.

![System Robot Arm](image)

Fig 3 System Robot Arm

G (s) is the controller mathematical equation is H (s) is the equation for a physical robotic systems including actuators and physical systems. Component ri is the reference input in the application can be either a reference position, velocity and acceleration. E is the error component and the component u is the output of the controller. The output y is a function of the expected motion of the robot is always equal to the reference (motion) which is defined in the input ri.

In a study of 3D movement known use of vector algebra and matrix algebra to simplify the analysis.

\[
\begin{bmatrix}
    p_x \\
    p_y \\
    p_z \\
\end{bmatrix} = R
\begin{bmatrix}
    u_x \\
    u_y \\
    u_z \\
\end{bmatrix}
\]

[1]

\[
\begin{bmatrix}
    p_x \\
    p_y \\
    p_z \\
\end{bmatrix} =
\begin{bmatrix}
    r_{11} & r_{12} & r_{13} & s_x \\
    r_{21} & r_{22} & r_{23} & s_y \\
    r_{31} & r_{32} & r_{33} & s_z \\
    0 & 0 & 0 & 1 \\
\end{bmatrix}
\begin{bmatrix}
    p_x \\
    p_y \\
    p_z \\
\end{bmatrix}
\]

[2]

Homogeneous transformation matrix (homogenous transformation matrix) is a combination of the rotation matrix and translation matrix. Homogeneous transformation matrix can be considered to consist of 4 submatrik, namely:

\[
T = \begin{bmatrix}
    \text{matrik rotasi} & \text{vektor posisi} \\
    \text{perspektif transformasi} & \text{skala} \\
\end{bmatrix}
\]

[3]

DH represents the only solid link depends on 4 parameters of the geometry of each link (for revolute or prismatic joint). These four parameters are defined as follows:

- θi is the angle of rotation on the axis Zi-1.
- αi is the angle of rotation on the axis Xi.
- The translation is on the axis Zi-1.
- ai is the translation in X-i axis.

For joint rotation, the parameters ai, αi, and is constant, while the θi parameters change when the link i moves (rotates) with based on link i-1.

Based on calculations of data for each link and gripper, obtained the effective length of the center of rotation of the joint (d & a) and the mass of the system at each link (m):

<table>
<thead>
<tr>
<th>d1</th>
<th>d2</th>
<th>d3</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 cm</td>
<td>30 mm</td>
<td>6.5 cm</td>
</tr>
<tr>
<td>a1</td>
<td>10 cm</td>
<td>100 mm</td>
</tr>
<tr>
<td>a2</td>
<td>10.9 cm</td>
<td>109 mm</td>
</tr>
<tr>
<td>13 cm</td>
<td>130 mm</td>
<td></td>
</tr>
</tbody>
</table>

m1 = 480 gram = 0.48 Kg
m2,3 = 304.7 gram = 0.3047 Kg
m3 = 91.9 gram = 0.0919 Kg
m3 + m4 (motor+bakul) = (94.1 + 160) gram = 254.1 gram = 0.2541 Kg
mprop + mprop (prop = (94.6 + 80) gram = 174.6 gram = 0.1746 Kg

Maximum distance of movement of the arm is not free because of the mechanical limitations on the arm, where the magnitude of the maximum angle (θ) achieved by each arm, namely: 01 = 900, 02 = 1200, 1500 = 03, 04 = 750, 05 = 900, 0 = 900.
The magnitude of the maximum displacement distance of each link:

\[ s_1 = \frac{\theta_1 \times 2 \pi R_1}{360} - \frac{90}{360} \times 2 \pi \times 35 = 54.078 \text{ mm} = 0.055 \text{ m} \]

In the same way it will be obtained:

If \( R_2 = 100 \text{ mm} \), then \( S_2 = 0.209 \text{ m} \)

If \( R_3 = 109 \text{ mm} \), then \( S_3 = 0.285 \text{ m} \)

If \( R_4 = 130 \text{ mm} \), then \( S_4 = 0.170 \text{ m} \)

If \( R_5 = 25 \text{ mm} \), then \( S_5 = 0.039 \text{ m} \)

The amount of energy the maximum movement of each link:

\[ E = F \times S = m \times g \times s \]

Table 1 Results of Measuring Voltage Power Supply

<table>
<thead>
<tr>
<th>Load condition</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Load</td>
<td>21.5 V</td>
</tr>
<tr>
<td>With load</td>
<td>20.5 V</td>
</tr>
</tbody>
</table>

Table 2 Results of Parallel Port Voltage Measurement

<table>
<thead>
<tr>
<th>Load condition</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logical “0” (low)</td>
<td>0 V</td>
</tr>
<tr>
<td>Logical “1” (high)</td>
<td>4.5 V</td>
</tr>
</tbody>
</table>

Table 3 Results of Measurement Circuit Voltage Driver

<table>
<thead>
<tr>
<th>condition</th>
<th>Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation</td>
<td>0 V</td>
</tr>
<tr>
<td>Cut Off</td>
<td>21 V</td>
</tr>
<tr>
<td>Voltage in</td>
<td>21.5 V</td>
</tr>
</tbody>
</table>

Analysis: From the results of stress measurements obtained parallel port voltage value logic 0 and logic 1 are the normal limits, i.e., logic 0 in the range 0 s / d 0.8 V and logic 1 in the range of 2.4 s / d 5 V. Therefore concluded parallel port can work well.

Voltage standard deviation value of less than 5%, so that the circuit can be concluded worked well.

Test Results: Form programs appear and function properly.

Analysis: Program under normal circumstances, because if it detected an error in the program after the Run, then the form and a visual basic program that has been made cannot be displayed.

IV. CONCLUSION

Based on the above can be taken several conclusions, among others:

• Program Visual Basic 6.0 is a language program that can be used to control the computer hardware whose function is to control the robotic arm.
• In the hardware design of a robot arm using the open-loop system (without feedback), so that no correction to the angle error is generated.
• Design of mechanical influence on the performance of the robot, such as limitation of motion, mass, arm length, and the interaction force on each joint. That of all that greatly affect the design of a robot arm control system program.

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Kinodynamic Motion Planning for an X4-Flyer Using a 2-Dimentional Harmonic Potential Field

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Abstract—In this research, we present a control method using kinodynamic motion planning based on a harmonic potential field (HPF) for an X4-Flyer moving in a 3-dimensional space. In the previous research, it was confirmed that a controller using two HPFs generated on the X-Y and X-Z planes was able to guide the X4-Flyer to the arbitrary target point in a 3-dimensional space. In this paper, the previous method is extended to the case where three HPFs generated on the X-Y, X-Z, and Y-Z planes are used, and it is verified that the X4-Flyer can move efficiently by using the proposed method through some simulations.

I. INTRODUCTION

Recently, there are many researches on the autonomous locomotion for an X4-Flyer[1]-[3]. An X4-Flyer is a vertical takeoff and landing (VTOL) aerial robot with four rotors, and it has received attention in recent years as search and rescue robots because of its highly maneuverability and hovering ability. In traditional motion planning, dynamic constraints and kinematic constraints are generally solved separately. In that case, dynamic constraints are mostly solved by designing the control input according to the result of kinematic constraints. There is “kinodynamic motion planning” that is aimed at solving these two constraints simultaneously, for designing the control input from the current state[4]. Kinodynamic motion planning can design the control input in one-step, and therefore it has an advantage of being able to decide the control input simply, compared to existing motion planning. There are many techniques for kinodynamic motion planning, and kinodynamic motion planning based on using “Harmonic potential field (HPF)” was proposed as one of them[5][6].

In this research, a control method is proposed for guiding an X4-Flyer to an arbitrary target point in a 3-dimensional space. The present controller guides an X4-Flyer by appropriately switching the HPF generated in a 2-dimensional plane. It was already confirmed in the previous research that a controller using two HPFs generated on the X-Y and X-Z planes can guide the X4-Flyer to the arbitrary target point in a 3-dimensional space. In this paper, the previous method is extended to the case where three HPFs generated on the X-Y, X-Z, and Y-Z planes are used. Moreover, it is verified by simulations that the X4-Flyer can move to the arbitrary target point efficiently by using the present method based on 2-dimensional HPFs.

II. KINODYNAMIC MOTION PLANNING FOR AN X4-FLYER

In the proposed method, kinodynamic motion planning is achieved by combining nonholonomic control input and the gradient which is calculated from the HPF. The system input $U = [U_1 U_2 U_3 U_4]^T$, which is constructed by nonholonomic control input $u_c$ and control input $\Delta u$ based on the gradient of the HPF, is as follows:

$$U = u_c + \Delta u. \quad (1)$$

Here, $U_1$ is a control input for acting on each translational motion, and $U_2$, $U_3$ and $U_4$ are control inputs for acting on roll angle $\phi$, pitch angle $\theta$ and yaw angle $\psi$ respectively. In the following subsections, we describe the control input based on nonholonomic control $u_c$ and the proposed control input $\Delta u$ based on the gradient of an HPF.

A. Nonholonomic Control Input

The control input $u_c = [u_{c1} u_{c2} u_{c3} u_{c4}]^T$ is added for z direction and three attitude angle and given as follows[7]:

$$\begin{align*}
   u_{c1} &= \frac{m \phi v}{\cos \phi \cos \theta} - \frac{mg}{\cos \phi \cos \theta} \\
   u_{c2} &= -k_1 (\phi - \phi_T) - k_2 \dot{\phi} \\
   u_{c3} &= -k_1 (\theta - \theta_T) - k_2 \dot{\theta} \\
   u_{c4} &= -k_1 (\psi - \psi_T) - k_3 \dot{\psi}.
\end{align*} \quad (2)$$

Here, $\dot{U}$ is:

$$\dot{U} = k_1 (z - z_T) + k_2 \dot{z}. \quad (3)$$

In these equation, $k_1$-$k_3$ are positive constant gains, and $z_T$ is an arbitrary altitude and $(\phi_T, \theta_T, \psi_T)$ are the desired angles.

B. Added Control Input

In this subsection, an added control input $\Delta u$ is described for the translational motion. Kinodynamic motion planning which is proposed in the previous research can only guide an X4-Flyer on the X-Y plane, because it uses an HPF generated in the X-Y plane. The proposed method can control the Z direction of an X4-Flyer by switching an HPF including the Z direction and an HPF in the X-Y plane.

For the control in the X-Y plane, the HPF on the X-Y plane including the current position of the X4-Flyer is used. At that time, using the gradient of the HPF on the X-Y plane, an added control input $\Delta u$ is designed by

$$\Delta u = \begin{cases} 
   -b_c \cdot \hat{x} - k_c \nabla V(x) - k_c \cdot F_C(x, \hat{x}) & \text{if } \sigma < \sqrt{(x-x_T)^2 + (y-y_T)^2} \\
   -b_{d1} \cdot h(x, \hat{x}) - k_c \nabla V(x) & \text{otherwise},
\end{cases} \quad (4)$$
\[ h(x, \dot{x}) = \left[ n^T \dot{x} n^+ \left( \frac{V(x)^T}{\|V(x)\|} \cdot \dot{x} \cdot \Phi(\nabla V(x)^T \dot{x}) \right) \frac{V(x)^T}{\|V(x)\|} \right], \]

\[ F_C(x, \dot{x}) = (x_T - x) \cdot \Phi(\sigma - |x_T - x|) \cdot \Phi(\dot{a}^T(x_T - x)). \]

where \( b_c, \ b_d, \ k_v \) and \( k_e \) denote a positive constant gain, \( h(x, \dot{x}) = [0 \ h(y, \dot{x}) \ h(x, \dot{x}) \ 0]^T, \ \dot{x} = [0 \ \dot{y} \ \dot{x}]^T, \ V(x) = [0 \ f_y \ f_x \ 0]^T, \) and \( F_C(x, \dot{x}) = [0 \ F_C(y, \dot{x}) \ F_C(x, \dot{x}) \ 0]^T. \) Note that, \( f_x \) and \( f_y \) mean the gradient of HPF parallel to the direction of \( x \)- and \( y \)-axis respectively.

For the \( Z \)-directional motion control, the HPF on the \( X-Z \) plane or the \( Y-Z \) plane including the current position of the X4-Flyer is used. In this control, the X4-Flyer moves in the \( Z \)-direction by subtracting the \( Z \)-directional gradient \( f_z \) calculated with the HPF from the current altitude \( z \) and regarding it as the target altitude \( z_T \) in Eq. (3), so it follows that

\[ \dot{U} = k_4 (z - (z - f_z)) + k_5 \ddot{z}. \]  

(5)

C. Switching of the HPFs

The proposed method uses 2-dimensional HPFs for guiding the X4-Flyer to an arbitrary target point in a 3-dimensional space. Only two HPFs generated on X-Y and X-Z planes are applied in the previous research, whereas three HPFs are used in this method. Fig. 1 shows a schema of generating the \( X \)-, \( Y \)-, and \( Z \)-directional gradients using three HPFs. In this method, the HPFs are generated on the X-Y, X-Z and Y-Z planes including the current position of the X4-Flyer as shown in Fig. 1. By giving the \( X \)-, \( Y \)-, and \( Z \)-directional gradients to the X4-Flyer, the controller guides the X4-Flyer in the 3-dimensional space. Here, the variables \( f_x, f_y, \) and \( f_z \) in Fig. 1 are \( X \)-, \( Y \)-, and \( Z \)-directional gradients, respectively.

As an illustration, consider the case where the X4-Flyer moves from the current position \( (x, y, z) = (45, 25, 10) \) to the target position \( (x_T, y_T, z_T) = (5, 5, 10) \) in the environment shown in Fig. 2. In this case, the HPF on the X-Y plane including the current altitude \( z = 10 \) (see Fig. 3 (a)), the HPF on the X-Z plane including the current \( y \)-position \( y = 25 \) (see Fig. 4 (a)), and the HPF on the Y-Z plane including the current \( x \)-position \( x = 45 \) (see Fig. 5 (a)) are generated. In order to generate the HPFs, \( (x_T, y_T) = (5, 5) \) is set as a target point in Fig. 3, \( (x_T, z_T) = (5, 10) \) is set as a target point in Fig. 4, and \( (y_T, z_T) = (5, 10) \) is set as a target point in Fig. 5. Then, by using the gradient of the current position generated as in Fig. 3 (b), Fig. 4 (b), and Fig. 5 (b), the controller guides the X4-Flyer toward the target point.

III. SIMULATIONS

In this section, it is confirmed that the proposed method can guide the X4-Flyer 3-dimensionally in the environment shown in Fig. 2, by simulations in MATLAB. Additionally, the proposed method is compared with the previous method to verify that the proposed method is more efficient than the previous one.
A. Conditions

In this simulation, it is assumed that the X4-Flyer moves from the initial position \((x, y, z) = (45, 25, 10)\) to the target position \((x_T, y_T, z_T) = (5, 5, 10)\) in the environment including an obstacle (shown in Fig. 2). The target attitude is always set as \((\phi_T, \theta_T, \psi_T) = (0, 0, 0)\), and the following equation is used as a dynamical model of the X4-Flyer[7]:

\[
\begin{align*}
\dot{x} &= (\cos \phi \sin \theta \cos \psi + \sin \phi \sin \psi \frac{1}{m} U_1 \\
\dot{y} &= (\cos \phi \sin \theta \sin \psi + \sin \phi \cos \psi \frac{1}{m} U_1 \\
\dot{z} &= -g + (\cos \phi \cos \theta) \frac{1}{m} U_1 \\
\dot{\phi} &= \dot{\theta} \dot{\psi} \left( \frac{I_z - I_y}{I_x} \right) - \frac{J_z}{I_x} \dot{\Omega} + \frac{I_z}{I_x} U_2 \\
\dot{\theta} &= \dot{\psi} \dot{\psi} \left( \frac{I_x - I_z}{I_y} \right) - \frac{J_x}{I_y} \dot{\Omega} + \frac{I_x}{I_y} U_3 \\
\dot{\psi} &= \dot{\phi} \dot{\psi} \left( \frac{I_y - I_x}{I_z} \right) + \frac{1}{I_z} U_4.
\end{align*}
\]

In this equation, let us define \(m\) [kg] as the mass of the X4-Flyer, \(l\) [m] as the length from the center of airframe to the center of rotor, \(g\) [m/s^2] as the gravity acceleration, \(I_x\), \(I_y\) and \(I_z\) [kg/m^2] as the inertial moment around each axis respectively, and \(J_r\) [kg/m^2] as the inertial moment of a rotor. Here, \(U_1\) is the control input for acting on each translational motion, and \(U_2\), \(U_3\) and \(U_4\) are the control inputs for acting on roll motion, pitch motion and yaw motion respectively. Then, \(\Omega\) and the system’s inputs \(U_1\), \(U_2\), \(U_3\) and \(U_4\) can be written by using the rotational speed \(\omega_i\) of the rotor \(i\) \((i=1,...,4)\), i.e.,

\[
\begin{align*}
U_1 &= b(\omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2) \\
U_2 &= b(\omega_2^2 - \omega_1^2) \\
U_3 &= b(\omega_3^2 - \omega_1^2) \\
U_4 &= d(\omega_2^2 + \omega_4^2 - \omega_1^2 - \omega_3^2) \\
\Omega &= \omega_2 + \omega_4 - \omega_1 - \omega_3.
\end{align*}
\]

Here \(b\) is the thrust coefficient and \(d\) is the drag coefficient. The parameters used for this simulation are shown in Table I, and they are obtained from the X4-Flyer developed in our laboratory (shown in Fig. 6). The gains are set as in Table II, from a rule of thumb.

B. Results

Figs. 7-10 show the simulation results. The solid red line drawn in Fig. 7 denotes the trajectory of the X4-Flyer when
using the proposed method, and the dotted blue line denotes the
trajectory when using the previous method. Fig. 8 shows the
change of the Euclidean distance between the current position
and the target position, and Fig. 9 and Fig. 10 show the
change of the attitude angles ($\phi$, $\theta$, $\psi$) when using the proposed
method and the previous method respectively.

C. Discussions

It is found from Fig. 7 that the X4-Flyer was able to
reach the target point from the initial state while avoiding
the obstacle in the 3-dimensional environment by using the
proposed method or the previous method. Moreover, the X4-
Flyer was able to move 3-dimensionally by using the gradient
of HPFs in spite of only using the 2-dimensional HPFs.
However, the trajectory when using the previous method takes
a long detour to upside of the obstacle. On the other hand,
the trajectory when using the proposed method takes a shorter
route from the side of the obstacle and it seems that an efficient
trajectory was chosen.

As shown in Fig. 8, the X4-Flyer was able to keep its
attitude on the target point after reaching the target point
even if which controller was used. However, the proposed
method was able to guide the X4-Flyer to the target point
about two times faster than the previous one. Small steady-state
errors remained after the X4-Flyer reached the target point,
irrespective of the control method adopted.

All the attitude angles of the X4-Flyer always fell within ±
0.04 [rad] as shown in Figs. 9 and 10. This result is acceptable
realistically, because the X4-Flyer assumed in this simulation
was able to easily cope with the oscillation of about ± 0.2
[rad]. From these results, it is confirmed that the proposed
method can choose a more efficient route and guide the X4-
Flyer to the target point faster than the previous method.

IV. Conclusions

In this paper, a method for guiding the X4-Flyer to an
arbitrary target point in a 3-dimensional space is proposed by
switching the HPFs, which are generated on 2-dimensional
planes. The usability of the proposed method was confirmed
in simulations by comparing it with the previous method.
In future works, we are going to implement the proposed
method to an actual machine, and make experiments in actual
environments.

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The Stabilization of Position and Attitude for a Blimp by a Switching Controller

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Abstract—In recent years, the development of unmanned air vehicles aiming at vegetation observation, information gathering of a disaster site, etc. is increasing. Among them, airships are attractive because of good energy efficiency and it is possible to be employed for a long time cruise. Especially, small airships called “blimp” have been developing to make the management easy. Although most of existing airships employ control methods by combining propellers and rudders, such a control approach has the problem that the maneuverability is deteriorated if their traveling speed is slow because the airflow received by rudders is weakened. In this research, “X4-Blimp” is proposed as a blimp controlled by only four propellers without any rudders, and it is controlled by a switching controller.

Index Terms—X4-Blimp, underactuated control, switching control.

I. INTRODUCTION

In recent years, unmanned aircrafts are expected to play an important role in observing vegetation and gathering information on disaster sites etc.[1] where it is hard for human to enter. Especially, airships that can float by its own buoyancy are attractive for good energy efficiency to travel for long time. However, a big airship requires a wide space and cost for maintenance. Thus, small airships which are called “blimp” have been developed, because it is easy to maintain and use it. Most of existing airships have propellers and rudders for controlling them. In this control method, the airframe is controlled by the rudders, using the airflow flowing on its surface. Such a method has a problem that if the traveling speed is slowed down, then the operability is deteriorated because of the weak airflow. Thus, it is desired to develop a blimp controlled without using rudders.

In this research, a controller method is proposed for an “X4-Blimp” where the airframe is controlled by only four propellers without any rudders. Since the X4-Blimp can control the positions and attitudes in three-dimensional space by regulating the output of the propellers, it can realize high operability, irrespective of its traveling speed. However, it is not easy to control the X4-Blimp, because it is an underactuated system. From an actual experiment, we have found that it was hard for a conventional X4-Blimp [2], in which the envelope is placed at the upper part of the airframe whereas the gondola is placed at the lower part of the airframe to fly downward.

II. OVERVIEW OF THE X4-BLIMP

A. Structure of the X4-Blimp

The X4-Blimp proposed in this research is composed of envelopes, a gondola and propellers as shown in Fig. 1. The envelopes is filled with helium gas to balance airframe mass with the buoyancy. The envelope form is a spheroid to decrease air resistance for traveling direction. The gondola includes batteries and controllers, and it is placed on the center of the airframe. The gondola form is a rectangular solid to maintain the space for the controllers etc. and simplify a calculation of the moment of inertia. The four propellers are attached on up, down, left and right sides of the gondola with the same distance from the center of the gondola. This airframe is designed symmetrically at a point C so as to be controlled easily.
B. Definition of the coordinates

A definition of coordinates is shown in Fig. 1, and the robot coordinate C is defined such that the origin is the center of the gondola, positive X-axis is set as the forward direction of the airframe, positive Y-axis is set as the right direction of the airframe, and Z-axis is set to be downward perpendicular to the airframe. Similarly, the world coordinate E is a right-handed coordinate where positive z-axis is set to be vertically downward. The center position of the gondola is represented by \( \eta = [\phi, \theta, \psi]^T \). A rotation matrix \( R \) to transform the robot coordinate to the world coordinate is derived as follows:

\[
R = \begin{bmatrix}
\cos \theta \cos \psi & -\cos \theta \sin \psi & \sin \theta \\
\sin \theta \cos \psi & \sin \theta \sin \psi & -\cos \theta \\
-\sin \psi & \cos \psi & 0
\end{bmatrix}
\]

where \( \cos A \) is \( \cos A \) and \( \sin A \) is \( \sin A \).

III. DERIVATION OF DYNAMICAL MODEL

A dynamical model of the X4-Blimp is derived by referring to X4-AUV studied in Watanabe et al. [2], the dynamical model of the X4-Blimp is derived as

\[
\begin{align*}
\dot{x} &= (\cos \theta \cos \psi u_1)/m \\
\dot{y} &= (\cos \theta \sin \psi u_1)/m \\
\dot{z} &= (-\sin \theta u_1)/m \\
\dot{\phi} &= \left(\dot{\psi}(I_1 - I_z) + u_2\right)/I_x \\
\dot{\theta} &= \left(\dot{\psi}I_2 + J_p\dot{\Omega} + l u_3\right)/I_y \\
\dot{\psi} &= \left(\dot{\theta}(I_2 - I_1) + J_p\dot{\theta} + I u_4\right)/I_z
\end{align*}
\]

where the mass of the airframe is \( m \), the moment of inertia for each axis is represented by \( I_x, I_y, \) and \( I_z \) respectively, the moment of inertia of the propellers is \( I_p \) and \( \Omega = \omega_2 + \omega_3 - \omega_1 - \omega_4 \). When four propellers are numbered from 1 to 4 in the clockwise from the upper propeller and the direction of rotational velocity of each propeller is positive if it is defined as clockwise. And the input \( u_1 \) of translational motion, the input \( u_2 \) of roll motion, the input \( u_3 \) of pitch motion and the input \( u_4 \) of yaw motion are represented by

\[
\begin{align*}
u_1 &= b(a_1^2 + a_2^2 + a_3^2 + a_4^2) \\
u_2 &= d(-a_1^2 - a_2^2 + a_3^2 + a_4^2) \\
u_3 &= b(a_1^2 - a_2^2) \\
u_4 &= b(a_1^2 - a_2^2)
\end{align*}
\]

where the thrust coefficient is \( b \) and the resistance coefficient is \( d \).

IV. DESIGN OF PARTIAL UNDERACTUATED CONTROLLERS

Since the system of the X4-Blimp represented by the dynamical model of Eq. (2) is an underactuated system with four inputs and 12 states, it is different to realize underactuated control. As shown in Fig. 2, two partial underactuated controllers for a model with 4 inputs 10 states are designed by combining a controller for a 2-input/4-state partial model with a controller for a 2-input/6-state partial model. The whole system is controlled by switching these two partial underactuated controllers. To perform a chained form transformation, the dynamic model is partially linearized such that

\[
\begin{align*}
\dot{x} &= \alpha_1 \\
\dot{y} &= \tan \psi \omega_1 \\
\dot{z} &= -\tan \theta \sec \psi \omega_1 \\
\dot{\phi} &= \omega_2 \\
\dot{\theta} &= \omega_3 \\
\dot{\psi} &= \omega_4
\end{align*}
\]

Then, the inputs are transformed as follows

\[
\begin{align*}
\omega_1 &= \cos \theta \cos \psi \omega_1/m \\
\omega_2 &= (\dot{\theta}I_1 - I_z)/I_x \\
\omega_3 &= (\dot{\psi}I_2 - J_p\dot{\Omega} + l u_3)/I_y \\
\omega_4 &= (\dot{\theta}(I_1 - I_2) + J_p\dot{\theta} + I u_4)/I_z
\end{align*}
\]

The partial underactuated controller 1 is designed from a 2-input/6-state partial model for \( x, \psi \) and \( y \), and from a 2-input/4-state partial model for \( \phi \) and \( \theta \). The partial underactuated controller 2 is designed from a 2-input/6-state partial model for \( x, \theta \) and \( z \), and from a 2-input/4-state partial model for \( \phi \) and \( \psi \). When a chained form transformation in [4] is applied, the 2-input/6-state partial model for \( x, \psi \) and \( y \) is denoted by

\[
\begin{align*}
\dot{z_1} &= h_1 = x \\
\dot{z_2} &= L_rh_2 = \dot{x} \\
\dot{z_3} &= L_1h_2 = \dot{\psi} \\
\dot{z_4} &= L_2h_2 = \dot{\psi}/\cos^2 \psi \\
\dot{z_5} &= \dot{h}_2 = y \\
\dot{z_6} &= \dot{h}_2 = y
\end{align*}
\]

Then, the inputs are transformed as follows

\[
\begin{align*}
\dot{v}_1 &= w_1 \\
\dot{v}_2 &= \frac{1}{\cos^2 \psi}w_4 + 2 \tan \psi \cos^2 \psi \psi^2
\end{align*}
\]

From the above results, a chained form is derived by

\[
\begin{align*}
\dot{x_1} &= v_1 \\
\dot{x_2} &= v_2 \\
\dot{x_3} &= z_2v_1
\end{align*}
\]

To apply a method in Xu and Ma [3] to Eq. (20), it is rewritten for state variables such as

\[
\begin{align*}
\dot{x_1} &= x_2, \quad \dot{x_2} = v_1 \\
\dot{x_3} &= x_4, \quad \dot{x_4} = v_2 \\
\dot{x_5} &= x_5, \quad \dot{x_6} = x_3v_1
\end{align*}
\]

Then the control input \( v_1 \) is denoted by

\[
\begin{align*}
v_1 = -s_1x_2 - s_2x_3
\end{align*}
\]

where \( s_2 > s_1 > 0 \). To control the underactuated system, a coordinate transformation is performed to design a controller based on a discontinuous model:
The Eq. (22) is rewritten as follows
\[
\begin{align*}
\dot{z}_1 &= z_2 \\
\dot{z}_2 &= -(s_1 + s_2)z_2 - s_1s_2z_1
\end{align*}
\] (23)
where \( Z_{3-6} = \{ z_3, z_4, z_5, z_6 \} \). Here, \( A_1, A_2(t) \) and \( B \) are denoted by
\[
A_1 = \begin{bmatrix}
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
1 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0
\end{bmatrix}, \quad A_2(t) = C
\] (24)
where \( C = \frac{z_2}{z_4} + s_1 \). The controllability of \([A_1, B]\) is confirmed. A controllable matrix is represented as \([B A_1 B A_2 B A_3 B]\). It is regular because \( s_1 > 0 \). Since \( A_1 + BL \) is controllable, the feedback gain \( L = [l_1, l_2, l_3, l_4] \) is calculated to make matrix \( A_1 + BL \) as the Hurwitz matrix by the pole placement method. The control input \( v_1 \) is denoted by
\[
v_1 = LZ_{3-6} + l_2z_3 + l_3z_4 + l_4z_5 + l_5z_6
\] (25)
Thus, since it can be stabilized to the origin, the control input for the chained form are derived as follows
\[
v_1 = -(s_1 + s_2)\dot{x} - s_1s_2x
\] (26)
In this way, the controller for 2-input/6-state partial model for \( x, \psi \) and \( y \) is designed. Next, the controller for the 2-input/6-state partial model for \( \phi \) and \( \theta \) is designed by a linear feedback such as
\[
w_2 = -k_1\phi - k_2\phi \quad (k_1, k_2 > 0)
\] (27)
\[
w_3 = -k_3\theta - k_4\theta \quad (k_3, k_4 > 0)
\] (28)
\[
w_4 = -k_5\psi - \theta
\] (29)
\[
w_5 = -k_6\psi \quad (k_6 > 0)
\] (30)
The partial underactuated controller 1 for a model with 4 input and 10 state is designed by combining the controllers for \( x, \psi \) and \( y \) with the controller for \( \phi \) and \( \theta \).

Similarly, the partial underactuated controller 2 is designed by combining the controller for the 2-input/6-state partial model for \( x, \theta \) and \( z \) with the controller for \( \phi \) and \( \psi \). The control inputs based on the chained form transformation is denoted by
\[
v_1 = -(s_1 + s_2)\dot{x} - s_1s_2x
\] (31)
\[
v_2 = \frac{l_1}{\cos\phi} \quad (\text{feedback})
\] (32)
In Fig. 3, a two-dimensional plane is represented by \( E_1 \) and \( E_2 \), and hysteresis like boundary lines \( \pi_1 \) and \( \pi_2 \) to separate the energy plane are represented respectively by
\[
\pi_1(E_1) = 1 - e^{\sqrt{E_1}}
\] (33)
\[
\pi_2(E_1) = 2\pi_1
\] (34)
In Fig. 3, the partial underactuated controller 1 is used on the region \( R_1 \), whereas the partial underactuated controller 2 is used on the region \( R_2 \). Considering an overlapped region, switching rules are decided as follows:

Rule 1:
If \( 0 < E_2 \leq \pi_1(E_1) \) then \( s_t = y \)

Rule 2
If \( \pi_1(E_1) < E_2 < \pi_2(E_1) \) and \( s_{t-1} = y \) then \( s_t = y \)

Rule 3:
If \( \pi_1(E_1) < E_2 < \pi_2(E_1) \) and \( s_{t-1} = z \) then \( s_t = z \)

Rule 4:
If \( \pi_2(E_1) < E_2 \) then \( s_t = z \)

Where \( s_t \) represents the controller used for each rule. When \( s_t = y \), the partial underactuated controller 1 is used, whereas when \( s_t = z \), the partial underactuated controller 2 is used. \( s_{t-1} \) represents the controller used before one-sampling time. According to this switching rule, the partial underactuated controller 2 is used to control the state \( z \). Similarly, the partial underactuated controller 1 is used to control the state \( y \). It should be noted that, in this switching rule, the chattering phenomena
VI. SIMULATION

This simulation is intended to verify that the state variables related to the position and attitude of the airframe converge to the origin by switching the two partial underactuated controllers using the switching rules created in previous section. The initial state of X4-Blimp is $q_0 = [-10.0, 0.5, 1.0, \pi/18, \pi/9, \pi/4]^T$, and the goal state is $q_r = [0, 0, 0, 0, 0, 0]^T$. The physical parameters used for simulation are shown in Table 1. The feedback gains $k_1 = 0.8, k_2 = 1.2, k_3 = 0.6, k_4 = 0.7, s_1 = 1/100, s_2 = 0.45, l_1 = -0.005, l_2 = -0.37, l_3 = -0.80$, and $l_4 = -35.1$ are for the partial underactuated controller 1, whereas the feedback gains $k_1 = 0.8, k_2 = 1.2, k_3 = 0.6, k_4 = 0.7, s_1 = 1/100, s_2 = 0.45, l_1 = -0.02, l_2 = -0.25, l_3 = -0.14$ and $l_4 = -10.08$ are for the partial underactuated controller 2.

It is found from Fig. 4 that the positions, i.e., the states $x$, $y$ and $z$ converge from the initial positions to the goal positions. Similarly, it is seen from Fig. 5 that all the attitudes $\phi$, $\theta$ and $\psi$ converge to the desired angles. Fig. 6 shows the energy trajectory, where it starts from the point S. It is found that the controller 2 was switched to the controller 1 at the point P and the energy finally converges to the origin at the point G. Switching of controllers occurs at the point P and the state variables are changed suddenly, if the energy trajectory exceeds the boundary line $\pi_2$. Thus, it is confirmed that the positions and attitudes of the X4-Blimp can be stabilized by switching the two partial underactuated controllers.

VII. CONCLUSION

In this paper, an underactuated controller has been proposed for stabilizing an X4-Blimp whose structure is symmetric at a point, where two partial underactuated controllers were designed from the derived dynamic model, and switching rules for switching two such controllers were constructed by applying the conventional logical rules based on hysteresis-like switching boundaries. The effectiveness of the proposed method was checked by simulations. For future work, we will apply this approach to a level flight for an X4 tail-sitter.

REFERENCES


New Waste Beverage Cans Identification Method

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Abstract— The primary emphasis of this work is on the development of a new waste beverage cans identification method for automated beverage cans sorting systems known as the SVS system. The method described involved window-based subdivision of the image into X-cells, construction of X-candidate template for N-cells, calculation of matching scores of reference templates for the N-cells image, and application of matching score to identify the grade of the object. The SVS system performance for correct beverage cans grade identification is 95.17% with estimated throughput of 21,600 objects per hour with a conveyor belt width of 18”. The weight of the throughput depends on the size and type of the objects.

Index Terms— Identification, SVS, beverage cans, sorting system

I. INTRODUCTION

Computer vision (CV) deals with extracting meaningful descriptions of physical objects from images (Ballard & Brown 1982, Brosnan & Da-WenSun 2003, and Kulkarni 2001). Due to low cost powerful solutions, the applications of CV have increased tremendously in diverse fields such as medical diagnostic imaging, food industry for quality evaluation, factory automation, robot vision, object identification, military reconnaissance, remote sensing, mineral exploration, cartography, and automated object grading and sorting. The aim of this motivation is to realize the necessity of the automated solid waste sorting system and justify the development of a smart vision sensing (SVS) system for automated recyclable waste beverage cans sorting using state-of-the-art of the CV.

The primary challenge in the recycling of beverage cans is to obtain raw material with the highest purity. In recycling, highly sorted stream facilitates high quality end product, and save processing chemicals and energy because various grades of beverage cans are subjected to different recycling processes. In addition, the amount of sludge and rejects generated in recycling processes is decreased for the utilization of sorted object in recycling as well as reduces the amount of energy needed to produce recycled cans. In this work, the type of a beverage cans is based on weight, color, usage, raw material or a combination of these factors.

Automated sorting systems are classified into mechanical and optical systems. Since 1932 to 2009, different mechanical and optical sorting methods have been developed to fill the demand of object sorting. Mechanical sorting cannot achieve commercially viable throughputs and accuracy. The popularity of optical sorting systems has increased because of inadequate throughput of mechanical sorting systems. The greatest advantages of optical sorting systems include the following: consistent and reliable production efficiency with a relatively high hit rate and purity; and low operational cost because of fewer manual workers on the production line.

The main objective of the research is to develop a smart vision sensing (SVS) system for automatic recyclable waste beverage cans sorting. More specifically, the aims is To select the best features and classifier for the smart vision sensing (SVS) system for automatic recyclable solid waste sorting.

II. THE SVS SYSTEM FOR SOLID WASTE SORTING

Figure 1 illustrates the block diagram of the proposed intelligent computer vision system for automatic sorting of recyclable beverage cans and a picture of the actual systems. The computer vision process consists of three parts: perception, cognition and action. The perception or image acquisition portion of this vision system consists of a commercially available webcam and a special lighting arrangement. The main responsibility of the action component of the vision system is to segregate waste beverage cans into different types based on the command of the cognition part of the vision system. Mechanical system are used to segregate and to pile different type of object according to their respective waste bins. In this research, we emphasize a beverage cans type identification system, which covers the perception and cognition components of the proposed system.

In this proposed system, 640×480 RGB images are captured from inspection zone on the conveyor belt by using Logitech QuickCam Pro 4000 Web Camera [46], [47]. The specifications of the webcam are CCD Optical sensor, color Camera, CCD Image Sensor Lens Construction support Manual Focus Adjustment, 4 pin USB Type A Interface for
In this experiment, it is observed that the performance of the vision system is extremely influenced by the lighting arrangement. For calibration and adjusting the lighting, three different lighting techniques namely front lighting-directional-bright field illumination, front lighting-directional- dark field illumination, and diffuse front lighting are considered in this research as shown in Figure 2. In both front lighting-directional-bright field illumination and diffuse front lighting, the images from the inspection zone show some reflection problems such that the object on the conveyor. Moreover, the reflection from the surface of the object is not uniform. It is important that the texture information of the objects is analyzed. Even one object of the same color in whole body showed different color combination in histogram analysis of the segmented portions of the image due to non-uniform lighting. In front lighting-directional-darkfield illumination, image from inspection zone is distinctive for texture analysis and the object surface is illuminated uniformly. Moreover, front lighting-directional-darkfield illumination is widely used in surface scratches or texture analysis (Pham D.T., & Alcock, R. J., 2003; Burke M.W., 1996), thus, this illumination technique is adopted for this experiment.

### III. FEATURE EXTRACTION

In the feature extraction phase, both color and gray scale images are considered. Brunner et al. (Brunner, C. C., Maristany, A. G., Butler, D.A., Leeuwen D.V., & Funck, J.W., 1992) converted the usual RGB color space into other potentially more useful color spaces, but they found that none provided any improvement over RGB. Thus, the RGB color space is considered in this research. For color images, each of the three color components – red, green and blue – are considered separately. For gray scale image, standard grayscale transformation is obtained from the original RGB image. Identification is primarily based on the dominating color level of the objects. In the feature selection process, special emphasis is placed on those features, which provides significant information regarding the dominant color level. Initially, seventeen first order features, such as mean, standard deviation, skewness, kurtosis, dispersion, lowest color level, highest color level, mode of the color level, entropy, energy, lower quartile, upper quartile, histogram tail length on dark side, histogram tail length on light side, median color level, range of the color level, and inter-quartile range, are extracted from the image using equations to determine the significant features in identification.

To calculate the first order features, the gray level histogram of the image is calculated first. The histogram, \( h(x) \), is a one dimensional array that represents the number of pixels in the image with a gray level of \( x \). The \( x \) parameter can take any value between 0 and \( Z - 1 \), where \( Z \) is the number of gray levels in the image. For color images, three histograms are calculated for the three color components: red, green and blue.

\[
\text{Mean, } \mu = \frac{\sum_{x} h(x)}{Z}
\]

\[
\text{Standard Deviation, } \sigma = \sqrt{\frac{\sum_{x} (h(x) - \mu)^2}{Z}}
\]

\[
\text{Skewness} = \frac{\sum_{x} (h(x) - \mu)^3}{Z \sigma^3}
\]

\[
\text{Kurtosis} = \frac{\sum_{x} (h(x) - \mu)^4}{Z \sigma^4}
\]

\[
\text{Dispersion} = \sum_{x} |h(x) - \mu|
\]

lowest color level, \( c = x \mid h(x) \neq 0 \)

where \( 0 \leq x < Z \)and \( h(i) = 0 \forall i:0 \leq i < x \)

highest color level, \( d = x \mid h(x) \neq 0 \)

where \( 0 \leq x < Z \)and \( h(i) = 0 \forall i:x < i < Z \)

\[
\text{Mode} = \max_{i} [h(i): \forall i:0 \leq i \leq Z, i \neq x]
\]

\[
\text{Entropy} = \frac{\sum_{x} h(x) \log_2(h(x))}{\text{pixelsp}}
\]

\[
\text{Energy} = \frac{\sum_{x} h(x)^2}{\text{pixelsp}}
\]

Where \( \text{pixelsp} \) is the total number of pixels used to calculate entropy.
IV. RESULT AND DISCUSSION

Since no databank was available for beverage cans identification system following our method of image extraction, we had to create a database of the objects. One of the tasks to be studied for the enrollment process is the color value of background that forms the ranges of different grades. It is obvious that the bigger the number of samples used, the more accurate range of color for respective grade of object will be created. 20 samples are considered sufficient to create accurate range of color for respective type of beverage cans. We have collected 3 photographs with resolution 100 dpi (dot per inch), 200 dpi, and 300 dpi for each of 160 objects.

In order to develop the proposed system, the software tools Matlab 7.4 for front-end application, Microsoft Access 2000 for backend database support, and MS Excel 2000 for data sheets and experimental results analysis are used.

The three types of waste beverage cans, Aluminum (ABC), Non-Aluminum (NAC) and Non-Recyclable (NRC), were considered in this experiment because of their dominating role in waste object with 1500 samples. Different templates were created for the same grade of object. Ten samples were considered to create an accurate feature vector for the reference template object grade.

In this section, a relative comparison is made based on the outcomes of the proposed method for ABC, NAC and NRC. The images P(a), Q(a) and R(a) represent the original images of ABC, NAC and NRC with background noise; in addition, the images P(b), Q(b) and R(b) represent the preprocessed images of ABC, NAC and NRC, respectively. The calculated first order features of the ABC, NAC and NRC are illustrated in Figure 3. The discriminating capabilities of the significant feature energy, mode, and histogram tail length on the dark side, histogram tail length on the light side, lower quartile, and upper quartile are illustrated in Figure 4.

The success rates of the object grade identification process for absolute distance metrics at different values of K are tabulated in Table 1. The correct identification rate is calculated based on the percentage of the number of objects that are classified into their respective object grades. Using the absolute distance metric with KNN, the results are 90% and 93% for k=3 and k=5, respectively.

![Figure 3 First order feature values](image3.png)

<table>
<thead>
<tr>
<th>Method</th>
<th>K Value</th>
<th>Name of the Distance Metrics</th>
<th>Correct Identification Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-nearest neighbor (KNN)</td>
<td>3</td>
<td>Absolute Distance</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Absolute Distance</td>
<td>93%</td>
</tr>
</tbody>
</table>

Finally, the best results of the SVS system is compared with the results published in literature other methods shown in Table 2. It is observed that the performance of the SVS system is the best among all existing systems. The template matching method showed the closest performance. The average maximum classification success rate of the template matching system is 94.67%, while the SVS system offered 95.17% classification success rate. In real time implementation, the SVS system is more effective and convenient than the template matching technique with regards to computational time and lighting consistency.

For instance, in template matching, significant time is allocated for preprocessing, while in the SVS system preprocessing is not required. Additionally, performance of the template matching method depends on lighting consistency during the enrollment and identification phases. With the SVS system, the lighting dependency has been alleviated because the system uses different reference templates for the same beverage cans types which are taken in different lighting conditions.

Thirdly, for template matching, a 5x5 template consists of 25 pixels; and for each pixel the RGB string length is 4 to 16. The RGB string length for 5x5 template is thus 100 to 400. As a consequence, there are 100 to 400 comparisons between one reference template and one cell image template, which makes the system inconvenient for real time implementation. For the SVS system, the template consists of only two values, namely mode and energy of the RGB components, which greatly improves the speed of the matching process.
TABLE 2. The results of the proposed method are compared with results published in literature.

<table>
<thead>
<tr>
<th>Name Industry Standard</th>
<th>Techniques Applied for Identification</th>
<th>Types of Sensor</th>
<th>Features</th>
<th>Classification Success Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial Neural Network</td>
<td>Template Matching, Template Matching</td>
<td>Logitech QuickCam 700x 4000 Web Camera, 700x 4000 Web Camera</td>
<td>RGB lighting, Energy</td>
<td>95.67%</td>
</tr>
<tr>
<td>SRS Systems</td>
<td>Not Mentioned</td>
<td>NIR, Color sensors, and light sensors</td>
<td>Materials, size, color, texture, and laser source</td>
<td>80%</td>
</tr>
<tr>
<td>Artificial Neural Network</td>
<td>Artificial Neural Network, Fuzzy Inference System Algorithm</td>
<td>Logitech QuickCam 700x 4000 Web Camera</td>
<td>Color, and Energy of the RGB Components</td>
<td>95.17%</td>
</tr>
</tbody>
</table>

V. CONCLUSION

The primary emphasis of this work is on the development of a new waste beverage cans identification method for automated beverage cans sorting systems known as the SVS system.

Another important idea that has been implemented is the adaptability to new subcategories of the primary Object grades. The wide range of subcategories of object grades is used to train the system to recognize new subcategories, and as a result the system is scalable and able to provide robust decisions for object identification tasks. Besides, the method was trained with many reference templates using different lighting conditions, which overcame the need to maintain lighting consistency during enrollment and identification phases.

The most important point addressed in this work is that the method, which uses computer vision, can be implemented easily to sort multiple types of beverage cans. Moreover, the algorithm provides robust and fast results because the proposed method avoids the extra computational burden for preprocessing since only two features, mode and energy, of the RGB components are used to identify the dominating color value of the object image. The proposed method can identify three major beverage cans types, ABC, NAC and NRC.

REFERENCES

Experimental Test of the Thermoelectric Performance on the Dispenser Cooler

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Abstract—This study aims to find out of the cooling performance of thermoelectric coolers with single, double series, and double parallel circuit. The experiment was conducted in the Cooling and Heating laboratory of Mechanical Engineering Department, Hasanuddin University, Makassar. The data taken were hot side temperature, cold side temperature, water temperature, and ambient temperature. Data analysis was carried out on water temperature, temperature difference, absorbed heat, and COP with some variations of thermoelectric circuit and DC electric voltage in 360-minute period. The result reveal that the best module was the double thermoelectric arranged with a series circuit in the voltage of 10 V. This could be seen after 360 minutes with cold water temperature of 12°C, temperature difference of 28°C, absorbed heat of 19.52810 and COP of 1.25268.

Keywords: thermoelectric cooler, water temperature, DC electric voltage.

I. INTRODUCTION

The national need for energy is increasing along with the growth of national economy that needs the efforts to ensure the continuous availability of energy in sufficient quantity and quality at a reasonable price level. With the decreasing amount of energy derived from fossil, humans are trying to find new sources of alternative energy. One of the solutions that can be used to generate energy and is environmentally friendly is by using thermoelectric.

The selection of the thermoelectric module specification is based on the heat load, the temperature difference and the electrical parameters used. Thermoelectric cooler has several advantages including no noise, easy maintenance, environmentally friendly and does not require a lot of additional components. In addition, another benefit of thermoelectric cooler as the engine is able to reduce air pollution and Ozone Depleting Substances (ODSs) because it no longer uses Hydrochlorofluorocarbons (HCFCs) and Chlorofluorocarbons (CFCs) known as Ozone Depleting Substances (ODSs) [1].

Thermoelectric first discovered in 1821 by the German scientist Thomas Johann Seebeck. He connected copper and iron in a circuit. Between the two metals are then placed compass needle. When the metal is heated, it turns the compass needle move. Later known, it happens because electricity that occurs in metals cause the magnetic field. This magnetic field that moves a compass needle. This phenomenon known as the Seebeck effect [2].

Seebeck's discovery inspires Jean Charles Athanase Peltier to examine the opposite of the phenomenon. He flowed the electric discharge on two metal pieces glued together in a series. When electrical power is applied, the heat absorption occurs at the junction of the two metals and heat release in another connection. This heat release and absorption revert each other when the current is reverted. The discovery which occurred in 1934 then known as the Peltier effect [3]. Seebeck and Peltier effect is then the basic for the development of thermoelectric technology.

Simple mode of cooling is by using a thermoelectric device. However, due to the limits of thermoelectric materials performance, one degree of the thermoelectric cooler machine can only be operated with a small temperature range. If the temperature ratio between the heatsink and cooling is large, then the coolant engine with one degree of thermoelectric will lose its effectiveness. Thus, the application of thermoelectric with two or more levels are combined in the coolant engine is an important method to improve the performance of thermoelectric [4].

II. THEORETICAL FOUNDATION

A thermoelectric device works by converting heat energy directly into electricity (thermoelectric generators), or otherwise, the electricity generating cold (thermoelectric coolers). Thermoelectric module composed by semiconductor material arrangement (usually Bismuth Telluride) which uses three principles of thermodynamics, known as Seebeck effect, Peltier and Thomson. Its construction consists of a pair of P-type semiconductor material and N-type which forms thermocouple like a sandwich between two thin ceramic wafers [5].

Thermoelectric cooler (TEC), which is a semiconductor circuit by utilizing the Peltier effect has been used as a cooling device on some mini cooling system. In which cooling has become a necessity in modern society that has been proven to improve the quality in terms of taste and hygiene of food and beverages [6].

Generally, thermoelectric module, has a measurement of 40mmx40mm or smaller and has less than 4 mm thick. Age of a thermoelectric module in accordance with the industry standard is about 100,000-200,000 hours and more than 20 years when used as a coolant, and by the number and voltage which is appropriate with the characteristics of each module [5].
Test using thermoelectric cooler module is the application of the Peltier effect to move heat. Thermoelectric cooler which is used consists of a number of pairs of P-type and N-type semiconductor connected in series and parallel thermal electricity. Heat which is pumped directly can be changed by changing the pole which is flowed by DC electricity. The thermoelectric semiconductor material composed of N-type made from a mixture of bismuth-telluride-selenium (BiTeSe) and P type made from a mixture of bismuth-antimony-telluride (BiTeSb). The use of bismuth telluride on thermoelectric cooler based on some studies that suggest that bismuth telluride is a material that has the best performance even though it has limitations on the heat temperature [7].

In this study we want to know the performance of cooler using single, double series, and double parallel assembled thermoelectric cooler.

In analyzing the performance of thermoelectric modules can be observed in Figure 1, the heat transfer occurs from the heat load to the cold side of the thermoelectric module can be determined from the amount of heat that is pumped by the Peltier effect, heat moves from the hot side to the cold side because the thermal conductivity of thermoelectric materials, and partly of the total Joule heating effect generated by the electric current to thermal resistance [8].

**Heat pumped by the Peltier effect**

Heat which is pumped by the Peltier effect \( q_p \) is the electrical energy which is supplied and can be known by determining the value of the Seebeck coefficient (\( \alpha \)), the cold side temperature (\( T_c \)), and the electric current supplied to the thermoelectric (I).

\[
q_p = \alpha \cdot T_c \cdot I \\
(1)
\]

**Heat transfer because of thermal conductivity**

The amount of heat move due to thermal conductivity \( q_k \) is influenced by the magnitude of the thermal conductivity (\( K \)) and the value of the temperature difference (\( \Delta T \)).

\[
q_k = K \cdot \Delta T \\
(2)
\]

**Joule heating effect generated by the electric current**

Joule heating effect \( q_J \) is the heat loss that occurs as a result of electrical current which can be determined from the value of the square of the electric current (I) and electrical resistance (R) and assumed to be divided toward the cold side and hot side.

\[
q_J = \frac{I^2 \cdot R}{2} \\
(3)
\]

**Heat absorbed at the cold side of the thermoelectric module**

\[
q_c = \alpha \cdot T_c \cdot I - K \cdot \Delta T - \frac{I^2 \cdot R}{2} \\
(4)
\]

**Heat released at the hot side of the thermoelectric module**

\[
q_h = \alpha \cdot T_c \cdot I - K \cdot \Delta T + \frac{I^2 \cdot R}{2} \\
(5)
\]

As described above, to determine the absorbed calorific value \( q_c \) and the released heat \( q_h \) on thermoelectric can be written in equation (4) and (5), where the first term is given electrical energy, the second term is the heat energy transmitted by conduction, and the third term is the loss of heat due to electrical current.

Based on the type of thermoelectric modules used, TEC1-12706, number of connection elements (N) is 127 so that the thermoelectric module is twice of the number of connection elements (2N).

Seebeck coefficient value element (\( \alpha_m \)), thermal conductivity element (\( K_m \)), and the thermal resistance elements (\( \rho \)) usually can be seen from the data vendors or from the corresponding equations form a thermoelectric material, in this case the material used is Bismuth Telluride.

**Seebeck coefficient**

Value of the Seebeck coefficient (\( \alpha \)) is determined by the value of the Seebeck coefficient element \( \alpha_m \) and the number of elements on the thermoelectric modules.

\[
\alpha = 2 \cdot \alpha_m \cdot N \\
(6)
\]

**Seebeck coefficient of the element**

\[
\alpha_m = \alpha_0 + \alpha_1 \cdot T_{393} + \alpha_2 \cdot T_{393}^2 \\
(7)
\]

\( \alpha_0 = 2.2224 \times 10^{-5}; \alpha_1 = 9306 \times 10^{-7}; \alpha_2 = -9905 \times 10^{-10} \)

**Thermal conductivity**

The amount of the thermal conductivity (\( K \)) is determined by the thermal conductivity of the element (\( K_m \)), the geometry factor (\( G \)), and the number of elements on the thermoelectric modules.

\[
K = 2 \cdot K_m \cdot N \cdot G \\
(8)
\]

**The thermal conductivity of elements**

\[
K_m = K_0 + K_1 \cdot T_{393} + K_2 \cdot T_{393}^2 \\
(9)
\]

\( K_0 = 6.2605 \times 10^{-2}; K_1 = -2777 \times 10^{-4}; K_2 = 4.131 \times 10^{-7} \)

**Electrical resistivity**

The amount of electrical resistance (\( R \)) is determined by electrical resistance elements (\( \rho \)), the geometry factor (\( G \)), and the number of elements on the thermoelectric modules.

\[
R = \frac{2 \cdot \rho \cdot N}{G} \\
(10)
\]
Resistance of electric element

\[ \rho = \rho_0 + \rho_1 T_{sve} + \rho_2 T_{sve}^2 \]  
(11)

\[ \rho_0 = 5.112 \times 10^{-5}; \rho_1 = 1.634 \times 10^{-6}; \rho_2 = 6.279 \times 10^9 \]

By substituting equation number (6), (8), (10) into equation number (4) can be obtained calorific value which is absorbed at the cold side of the thermoelectric module:

\[ \dot{q}_c = 2N \left[ \sigma_m \cdot \ln \frac{T_c}{K_m} \cdot \Delta T \cdot G - \frac{T_c}{2G} \right] \]  
(12)

By substituting equation number (6), (8), (10) to equation number (5) can be obtained calorific value which is released on the hot side of the thermoelectric module:

\[ \dot{q}_h = 2N \left[ \sigma_m \cdot \ln \frac{T_c}{K_m} \cdot \Delta T \cdot G + \frac{T_c}{2G} \right] \]  
(13)

The electric power supplied to the thermoelectric module

The amount of electrical power supplied to the thermoelectric module influenced the size of the electric current (I) and the amount of the electrical resistance (R).

\[ P_{in} = I^2 \cdot R \]  
(14)

Energy equilibrium

According to the working principle of thermoelectric based on Peltier effect, heat is absorbed from the cold side by qc and the heat released to the environment by qh. The difference between the two is the amount of electrical power required or \( P_{in} \) so that the thermoelectric energy equilibrium can be written in the following equation:

\[ \dot{q}_h = \dot{q}_c + P_{in} \]  
(15)

Figure of merit

Figure of merit (Z) is the default for determining the efficiency of thermoelectric materials. If the value of Z increases the capability of thermoelectric materials also increased. Figure of merit value varies depending on the needs of the thermoelectric material temperature [7].

\[ Z = \frac{\sigma_m^2}{\rho \cdot K_m} \]  
(16)

Coefficient of Performance (COP)

COP is a measure of the efficiency of a thermoelectric cooler that can be seen from the comparison of the amount of heat absorbed at the cold side \( (\dot{q}_c) \) to the amount of incoming power \( (P_{in}) \) [5].

\[ COP = \frac{\dot{q}_c}{P_{in}} \]  
(17)

Average calor absorbed at the cold side of the thermoelectric module up to 360 minutes

Average calor can be determined by determining the total heat absorbed at the cold side \( (\Sigma \dot{q}_c) \) the amount of heat absorption occurs \( (\Sigma n) \).

\[ \dot{q}_c = \frac{\Sigma \dot{q}_c}{\Sigma n} \]  
(18)

Heat absorbed from the water

Heat absorbed from the water can be determined by determining the value of the mass of water \( (m) \), specific heat of water \( (Cp) \), and the difference between water temperature \( (\Delta T_{air}) \) and time difference \( (\Delta t) \).

\[ \dot{q}_w = \frac{m \cdot Cp \cdot \Delta T_{air}}{\Delta t} \]  
(19)

Average calor absorbed from the water up to 360 minutes

Average calor can be determined by determining the total heat absorbed from water \( (\Sigma \dot{q}_w) \) against the amount of absorption of heat occurs \( (\Sigma n) \).

\[ \bar{q}_w = \frac{\Sigma \dot{q}_w}{\Sigma n} \]  
(20)

III. RESEARCH METHODOLOGY

The research method used is the experimental method. Thermoelectric performance testing carried out by variation of the DC power supply given, which is 8 V, 10 V, 12 V and variation of module by using single module, multiple series module, and multiple parallel module with a 360-minute long test as shown in Figure 1 and Figure 2 .

Data collection was performed by measuring the cold side, hot side, water temperature, and ambient temperature using a thermocouple and a temperature controller. Determination of the value of the element geometry factor \( (G) \) is using the AZTEC software; version 3.1 [10]. Data processing done by calculating the calorific value absorbed, heat removed, the electrical power used, figures of merit, and COP.

Single Thermoelectric Testing Installation

![Single Thermoelectric Testing Installation](image)

I. MODEL ANALYSIS AND DISCUSSION

From the results of data collection and the calculation in the research, the thermoelectric performances are:

The temperature of the hot side of the thermoelectric module

In the initial conditions before supplying the voltage, the hot side temperature is at room temperature and after supplying the voltage, the hot side temperature will increase until it reaches a certain temperature. It shows that in
thermoelectric, hot side temperature will increase by the addition of voltage.

Double Thermoelectric Testing Installation

![Figure 3. Double Thermoelectric Testing Installation](image)

The temperature of the cold side of the thermoelectric module

At first, the cold side temperature is at room temperature and then decreases until it reaches a certain temperature. Cold side temperatures will continue to drop to constant conditions. In single thermoelectric, giving 8 V and 10 V of voltage can reach temperatures lower than 12 V. At double thermoelectric with series circuit, the voltage of 10 V can reach the lowest cold side temperatures among the three variations of voltage. In double thermoelectric arranged in parallel, the voltage of 8 V can reach the lowest cold side temperatures among the three variations of voltage.

Different temperature of thermoelectric module

In the initial condition, the temperature difference value is zero because the temperature of the hot side and the cold side is at the same temperature. In a single thermoelectric, the greater the applied voltage, the value of the temperature difference will be even greater. Likewise on double thermoelectric series, the greater the applied voltage, the value of the temperature difference will increase. But for parallel thermoelectric double, on the voltage of 12 V the value of the temperature difference is low because the value of Th and Tc tend to be constant and not increased since the beginning of cooling.

The temperature of the cooled water

At the beginning of cooling, water temperature is around 29°C and then will continue to decrease until a certain temperature. In single thermoelectric, giving the voltage of 8 V and 10 V can reach lower water temperature than giving the voltage of 12 V. The addition of voltion to the double thermoelectric which is assembled series can accelerate the decrease in water temperature. In parallel double circuit with the voltage of 12 V can be seen that very little heat is absorbed from the water. This is because the temperature reaches 56°C heat and heat can not be released properly into the air so that the side of the thermoelectric cooler can only reach temperatures of 29°C and the water temperature can reach 28°C only.

Heat absorbed at the cold side of the thermoelectric module

The calculation of the absorbed heat associated with the amount of the electric current generated from a given DC voltage. The amount of electric current is influenced from the resistance or thermoelectric module. The greater the voltage, the electric current generated is also getting bigger and the greater the electrical resistance, the current generated will be smaller. Determination of the electrical resistance depends on the number of constituent elements of the thermoelectric module [4]. For double thermoelectric, the number of elements of the module is two times of the number of elements of single module. However, the resistance is also affected from the series type. For double thermoelectric series, the resistance and the variables that influenced the electric current is twice bigger than that of a single thermoelectric. While for the double parallel thermoelectric, the amount of resistance and the variables associated with the electric current is half of a single thermoelectric. This can be proved by calculating the energy balance which can be seen in appendix of calculation table, where the amount of heat released (q_C) is the amount of electric power required (Pin) and the amount of heat absorbed at the cold side (q_C) [10].

In Figure 3 it can be seen the increase in the value of the absorbed heat affected from the increase in the electrical voltage to each circuit. For voltage of 8V, the highest qc value is indicated by a series of parallel double that is equal to 17.44189 W. For voltage of 10V, the highest qc value indicated by a single sequence that is equal to 20.61895 W. For a voltage of 12 V, the highest qc values indicated by a single sequence that is equal to 24.71738 W. I suggests that the increase in the value of the absorbed heat is proportion to the increase of the applied voltage but depends on the variation of the thermoelectric circuit.

![Figure 4. Graph of electrical voltage to the heat absorbed at the cold side on 360 minutes](image)

The electric power supplied to the thermoelectric module

Figure 4 is a graph of relation between voltage electricity to the electrical power supplied and variations of sequence at 360 minutes. From the graph it can be seen that the greater the voltage applied to each circuit, electrical power used is also greater. When compared to the third variation of the thermoelectric circuit, double circuit series shows the value of the lowest power. This shows a double thermoelectric series is a series that consumes the least power among the three variations of the circuit.
Figure 5. Graph of electricity voltage to the electrical power supplied with the circuit variation on 360 minutes.

COP value is a measure of the efficiency of a thermoelectric cooler that can be seen from the comparison of the amount of heat absorbed at the cold side (q_c) to the amount of incoming power (P_in). Now, thermoelectric cooling still has low COP value that it can not compete with vapor compression cooling system [9].

Figure 6. Graphs of the relationship of voltage applied to the COP on 360 minutes

Figure 5 is a graph of the relationship between the COP to the applied voltage and variation of circuit on 360 minutes. The amount of COP influenced by heat absorbed at the cold side and the amount of electrical power used. For voltage of 8V, the highest COP values shown in multiple series, by 1.5268. For voltage of 10V, the highest COP values shown in multiple series circuit is equal to 1.25268. For voltage of 12V, the highest COP value is shown in a series of multiple series that is equal to 1.09192. It shows that voltage variation given, double series circuit showed the highest COP value compared to other circuit variations.

From the three variations of the thermoelectric circuit, best known performance is a thermoelectric module which is arranged in double circuit with the voltage of 10 V as it can achieve the lowest water temperature, the lowest power consumption, and best cooling speed.

II. CONCLUSION

From the calculation results and discussion can be concluded as follows:

1. After analyzing the performance of single thermoelectric, best known performance generated by giving voltage of 8 V.

2. After analyzing the performance of double thermoelectric with series assembled, the best performance is produced by giving voltage of 10 V.

3. After analyzing the performance of double thermoelectric with parallel circuit, best performance generated by giving voltage of 8 V.

4. Of the three variations of the circuit, the best performance is the double thermoelectric modules with series assembled on voltage of 10 V.

Symbol

C_p = Specific heat of water [J/kgK]
G = The geometry factor [cm]
I = Electric current [A]
K = Thermal conductivity [W/K]
K_m = Thermal conductivity of elements [W/cmK]
m = Mass of water [kg]
N = Number of elements on the thermoelectric
P_m = Electric power [W]
q_c = Heat absorbed at the cold side of the thermoelectric [W]
q_h = Heat released at the hot side of the thermoelectric [W]
q_w = Heat absorbed from the water [W]
R = Electrical resistance [Ω]
T_c = Cold side temperature [K]
V = Electrical voltage [V]
Z = Figure of merit [K’]
α = Seebeck coefficient [V/K]
α_m = Seebeck coefficient of the element [V/K]
ρ = Resistance of electric element [Ωcm]
ΔT = Temperature difference [K]
ΔT_w = Temperature difference of water [K]
Δt = Time difference [s]

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Potential Coir Fibre Composite for Small Wind Turbine Blade Application

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Abstract— Natural fibers have been developed as reinforcement of composite to shift synthetic fibers. One of potential natural fibers developed is coir fiber. This paper aims to describe potential coir fiber as reinforcement of composite for small wind turbine blade application. The research shows that mechanical properties (tensile, impact, shear, flexural and compression strengths) of coir fiber composite have really similar to wood properties for small wind turbine blade material, but inferior to glass fiber composite properties. The effect of weathering was also evaluated to coir fiber composite in this paper.

Index Terms— Coir fibers, composites, wind turbine blade.

I. INTRODUCTION

Natural fibers have been applied in composite materials. Related to this, natural fibers have beneficial properties over synthetic fibers like high specific strength and modulus, low density, low cost and abundant in many countries [1, 2, 3]. Some natural fibers used as reinforcement composite are coir, flax, jute, and ramie fibers.

Coir fiber is a natural fiber which has been used for reinforcement of composite. Coir fiber composite has been developed in India and Brazil. Some researches of mechanical properties of coir fiber composite were done. Flexural strength was obtained for coir fiber/polyester composite really similar to the conventional materials [4]. Meanwhile, impact strength of coir fiber composites is higher than jute and kenaf composites. Alkali treatment of coir fiber increases its bonding with polyester matrix. Coir fiber composites show tensile strength improves when fibers is soaked in 2% alkali prior to mixing polyester and flexural strength improves when 5% alkali [5]. This result was supported by another researcher that states tensile strength of coir fiber composites increased when fibers are soaked with alkali prior to binding with matrix. This is because good adhesive between fibers and matrix after alkali treatment [6]. Tensile, impact and flexural strengths of coir/epoxy composites were evaluated with the average values of 17.86 MPa, 11.49 kJ/m² and 31.08 MPa respectively. These values have lower than glass reinforced composite laminate [7]. The tensile strength of coir reinforced composites was also tested and found lower its value. But, their impact strength was found higher which have potential for application in automotive that require impact resistance [8]. The impact strength of coir fiber composites was also reported that its value is higher than other natural fiber composites [9].

Coir fiber composite have been developed to some applications like automotive and structure. In this paper, the potential application of this composite was presented for small wind turbine blade and it was also evaluated effect of weathering time to the mechanical properties.

Using of fiber composites in wind turbine blade was applied with glass fiber as reinforcement [10]. Glass fiber composite for small wind blade have been applied and compared to flax fiber composite. Flax fiber as natural fiber can replace possibly glass fiber for reinforcement composite [11]. The designed small blades will be subjected to load when operation, therefore they need good strength, stiffness and tip deflection.

For application in wind blade, weathering will affect to the materials of wind blade. Some literatures explained the effect of weathering to the natural fiber composites. Kenaf high density polyethylene (K-HDPE) composite has been tested for durable behavior towards weather effect. The result shows that composite obtained brittleness proportional to the amount of weathering time [12]. Then, outdoor weathering affected tensile and moduli of the banana/phenol formaldehyde composite, and alkali treatment of fiber can improve tensile strength if exposure to outdoor weathering [13]. Mechanical properties (including impact, tensile and shear strengths) of coir/epoxy composites were influenced by weathering when composites were placed in outdoor for 10 days, 20 days and 30 days [14] [15]. These effect can be seen in Table 1 where we were published.

<table>
<thead>
<tr>
<th>Specimens Treatment Time</th>
<th>Tensile Strength (MPa)</th>
<th>Shear Strength (MPa)</th>
<th>Impact Strength (kJ/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without treatment (WT)</td>
<td>17.56</td>
<td>14.57</td>
<td>384.99</td>
</tr>
<tr>
<td>10 days</td>
<td>17.37</td>
<td>14.42</td>
<td>328.13</td>
</tr>
<tr>
<td>20 days</td>
<td>16.38</td>
<td>13.83</td>
<td>307.22</td>
</tr>
<tr>
<td>30 days</td>
<td>16.40</td>
<td>13.63</td>
<td>296.00</td>
</tr>
</tbody>
</table>

Table 1. The Effect of Weathering Time on Impact, Tensile and Shear Strength of Coir Fiber Composites
II. METHODOLOGY

Coir fibers were extracted from the husk of coconut shell. Prior to mixing with matrix, fibers were soaked in 5% NaOH and water during 24 hours. Epoxy resin was used as matrix. Coir fiber composites were made with 17% volume fraction of fiber by pressing molding for 24 hours. Molded composite is shown in Fig.1. Then, specimens were divided into two types including without treatment (WT) and treatment to weathering. Specimens with treatment time to the environmental effect (outdoor weathering) were 10 days, 20 days and 30 days. Mechanical properties of coir fiber composites were tested in this paper including compression and flexural strength with specimens as shown in Fig. 1 and Fig.2. Flexural testing used three point bending and compression used compressive testing. For impact, tensile and shear strength have been published [14],[15].

![Fig 1. Molded coir fiber composite](image)

III. RESULTS AND DISCUSSION

Coir fiber composites were tested the mechanical properties including compression, flexural, tensile, shear and impact strength. These properties can be seen in Table 2. Impact, tensile and shear strength results were published previously. In this paper, flexural and compression strengths of coir fiber composite were described. Flexural and compression strengths were presented in Table 2 with values of 44.89 MPa and 26.27 MPa respectively.

TABLE 2. MECHANICAL PROPERTIES OF COIR FIBER COMPOSITES

<table>
<thead>
<tr>
<th>Properties</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength (MPa)</td>
<td>17.56 [15]</td>
</tr>
<tr>
<td>Shear strength (MPa)</td>
<td>14.57 [15]</td>
</tr>
<tr>
<td>Impact strength (kJ/m²)</td>
<td>384.99 [14]</td>
</tr>
<tr>
<td>Flexural strength (MPa)</td>
<td>44.89</td>
</tr>
<tr>
<td>Compression strength (MPa)</td>
<td>26.27</td>
</tr>
</tbody>
</table>

From mechanical properties of coir fiber composite as explained before, it can be seen that for application of small wind turbine blade can be compared with other composites and wood in Table 2. Mechanical properties of wood for small wind turbine blade have similar to the coir fiber composites. This indicated that coir reinforced composites have potential for using of wind blade material. But, mechanical properties of coir fiber composite are lower than glass fiber composite. For development of application in wind turbine blade therefore coir fiber composites need hybridization to other fibers for improving strength and stiffness.

TABLE 2. MECHANICAL PROPERTIES OF GLASS FIBER COMPOSITES AND WOOD

<table>
<thead>
<tr>
<th>Materials</th>
<th>Tensile Stre. (MPa)</th>
<th>Shear Stre. (MPa)</th>
<th>Flex. Stre. (MPa)</th>
<th>Compr Stre. (MPa)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFRP</td>
<td>826</td>
<td>90.9</td>
<td>14.04</td>
<td></td>
<td>[11][16]</td>
</tr>
<tr>
<td>Laminated veneer lumber</td>
<td>19.1</td>
<td>28.7</td>
<td></td>
<td></td>
<td>[17]</td>
</tr>
<tr>
<td>Timberstron wood</td>
<td>5.1</td>
<td></td>
<td></td>
<td></td>
<td>[17]</td>
</tr>
</tbody>
</table>

Related to weathering time effect, the relationship between compression strength and treatment time of specimens is demonstrated in Fig.1. Compression strength was not change significantly on the treatment (weathering) time. When testing of coBut, flexural strength decreased when specimens were exposed during 20 days and 30 days (Fig.2). The decreasing of flexural strength are about 9.71% for 20 days and 20.4% for 30 days.
days. The possible cause of decreasing its strength was due to solar radiation and high humidity.

![Graph showing Compression Strength vs. Specimen Treatment Time]

**Fig 1.** Relation between compression strength and specimen treatment time

![Graph showing Flexural Strength vs. Specimen Treatment Time]

**Fig 2.** Relation between flexural strength and specimen treatment time

### IV. SUMMARY

Coir fiber composite is one of natural fiber composites having potential for small wind turbine blade application because their mechanical properties were found competitive with wood properties for wind blade materials. Although, it has inferior to glass fiber composites. Related to treatment (weathering) time of specimens, mechanical properties of coir fiber composites were tend to decreasing but it is not significant.

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A new development of thermosiphon solar hot water with parallel-serpentine tube configuration

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Abstract—The new configuration of the heat pipe copper absorber fluid in solar water heater (SHW) has been developed in an aluminium collector box that aims to improve the efficiency and especially the outlet temperature of the fluid prior to entering the stainless steel hot water. Parallel-serpentine pipe configuration is used in this study in which 5/8" copper tube installing on the inlet header and header outlet of parallel configuration. The header outlet is connected with 3/8" serpentine configuration tube before entering water tank. Meanwhile collector panels mounted on a north-facing slope of 20° to get a lot of sunlight. From the observations show that the temperature of the water out of the collector is around 90°C with thermosiphon SHW efficiency of approximately 25%.

Key words: solar hot water, parallel-serpentine, tube configuration

I. INTRODUCTION

Solar hot water (SHW) is cheaper application of solar collector energy use than air ones. This can be seen a plenty of water heater technology are manufactured with various models according to customer needs. Recently, one obstacle water heating technology products available in the market is the selling price that is not affordable all society levels. Therefore this study is aimed at producing water heating collectors that are less expensive, easy installed and environmentally friendly.

Thermosiphon solar hot water collectors become interesting topic for research and even more manufactured with various modification leading to increasing efficiency. Mostly, tubes configuration of current SHW are parallel and/or serpentine laying out independently. Both configurations have advantages and disadvantages for certain solar radiation hours in one day. For instance, parallel tube configuration is more useful form midday till afternoon, whereas serpentine ones is between morning and midday for water solar heating. Therefore, Mustofa dkk. [1] and Mustofa et al., [2] has been designed and made a prototype of a hybrid model both serpentine and parallel tube configuration in one single collector box leading to minimizing the disadvantages fo SHW. Thermosiphon principle is applied for collector plate heat with fluid absorber within flat plate and sinusoidal wave configuration and with serpentine-parallel fluid tubes above the plates. The water output temperature in pipe parallel is high enough till about 80°C, while water temperature in the reservoir averaged less 50°C. The reservoir water temperature is not enough last long due to insulating ability of fiberglass reservoir material. In other words, it is needed to be modified the tank material and tubes configuration.

Thus, this research has focus on modification of some collectors materials such as fiberglass reservoir to be stainless steel, wood collector box becomes aluminium ones. In addition, to accelerate the circulation of hot fluid entered into the reservoir, the configuration of the serpentine-parallel tubes is reversed into a parallel-serpentine in serial connecting. Water flows from the reservoir made by stainless steel to firstly parallel tube configuration and then serpentine within hot fluid back into the tank in means of natural convection (thermosiphon) [3]. That happens due to the water mass difference within solar collector box that is exposed to north at 20° slope angle. The slope angle (β) is defined as the angle between the plane of the collector and the horizontal. The azimuth angle (γ) is defined as the displacement angle between the projection on a horizontal plane of the normal to the collector surface and due north. The incidence angle, θ, is the angle between the direct radiation on a surface and the normal to that surface. For maximum direct radiation, the incidence angle should be a minimum [4]. Fig. 1 shows these angles.

Figure 1. Major angles in solar applications
II. COLLECTOR DESIGN

As can be seen from Figure 2, collector box is mainly made from aluminium with dimensions 128 x 78 x 10 cm comprising copper tubes on flat and wave sinusoidal plates. The tube and plates were painted by double Arclic Lacquer Black Metallic leads to increasing heat absorption from the Sun. There are two differences tube diameters for parallel configuration. For parallel configuration tubes, they are 3/8” and 5/8”. Header parallel tube is 5/8” and the rest of tubes dimension is 3/8” including serpentine configuration. Insulator sponge 3 cm thick is under the flat and wave sinusoidal plates.

For stainless steel tank is located above the collector in which cool and hot water are circulating through the tubes. The tank size itself is 80 x 30 cm with copper taps on two sides as for output and input water circulating.

Based on those design, instantaneous equations associated with collector performance are given as follows:

\[ \eta = \frac{Q_u}{IA} \]  \hspace{1cm} (1)

While \( Q_u \) is divided by 2 correspondences formula,

\[ Q_{par} = A_{par}S - UA_{par}(T_{par} - T_a) \] \hspace{1cm} (2a)  
\[ Q_{ser} = A_{ser}S - UA_{ser}(T_{ser} - T_u) \] \hspace{1cm} (2b)

For serpentine configuration, where \( T_s \) is ambient temperature and \( S \) is energy from the Sun that can be absorbed by collector.

The useful gain given collector to fluid:

\[ q_u = mC_p \Delta T \]  \hspace{1cm} (3)

Which \( m \) is equal

\[ m = \rho A_{(par-ser)}/2V \] \hspace{1cm} (3a)  
\[ \Delta T = (T_{outser} - T_{inpar}) \] \hspace{1cm} (3b)

Thus, the instantaneous efficiency for each tube configuration is belows:

\[ \eta_{par} = \frac{mC_p (T_{outpar} - T_{inpar})}{IA_{par}} \] \hspace{1cm} (4a)

\[ \eta_{ser} = \frac{mC_p (T_{outser} - T_{inser})}{IA_{ser}} \] \hspace{1cm} (4b)

So, the total efficiency for parallel-serpentine solar hot water is accumulate of \( \eta_{par} + \eta_{ser} \) \hspace{1cm} (5)

III. METHOD

The research begins with searching solar hot water collector materials and some tube configurations topics, their advantages and disadvantages. Mustofa et al., [2] used serpentine-parallel in \( \frac{1}{2} \)” of the tubes diameter. It takes 3 till 4 hours to reach maximum hot fluid in the tank, while high temperature within the reservoir is not long lasting. Therefore, research method is started by turning the configuration to parallel-serpentine with 3/8 and 5/8” tubes diameter and so on. Testing has been done with 2 mass flow rate (0.035 and 0.189 ltr/s) on clear weather condition. Data collected from 9.30am till 3pm each 30 minutes both fluid temperatures and solar intensity. The intensity was recorded with Solarimeter Tenmars as shown in Figure 3, while fluid temperature is noted by thermocouple digitals in Figure 4.

For ambient temperature is measured by mercury thermometer. All testing had been conducted at outdoor Mechanical Engineering laboratory in Tadulako University. Data are tabulated and calculated based on formulas from (1) to (5).

Figure 2. Prototype SHW parallel-serpentine configuration

For equator line like in Palu, Central Sulawesi, the slope angle is less influence on solar intensity. Thus, 20° is accepted.
IV. RESULT AND DISCUSSION

A. Solar Intensity

Based on data collected by solar radiation of 18 locations in Indonesia, the solar radiation in Indonesia can be classified as follows: for the western and eastern Indonesia with the distribution of radiation in the Western Regions of Indonesia (KBI) about 4.5 kWh/m²/day with monthly variation of approximately 10%, and in Eastern Indonesia (KTI) approximately 5.1 kWh/m²/day with approximately 9% of the monthly variation (EMR 2008). Continued the measurement data from 1991 to 1994, the Central Sulawesi categorized as the third largest in Indonesia after the District. Sumbawa (5,747 Wh/m²) and Jayapura (5,720 Wh/m²) in terms of the intensity of solar radiation, which amounted to 5,512 Wh/m² [5] & [6]. This data, in fact, support for developing SHW in Palu as indicated in Figure 4.

From Figure 5 shows that the average solar intensity increased significantly from 11.00 to 11.30 and stable a couple of hours. Means that solar energy for heating water collector is quite high and effective in mid day till afternoon.

B. Collector Efficiency

The test procedure and efficiency calculation specified in equation (5) with 2 mass flow rates, namely 0.189 and 0.035 (kg/s).

The graph indicates that collector efficiency for 0.189 kg/s mass flow rates is higher than that of 0.035 kg/s. However, the rate of 0.035 is more stable in low efficiecy than that 0.189 kg/s.

C. Water Outlet Temperature For Parallel-Serpentine

Figure 7 depicts that water outlet temperature (T_{outletPar}) in parallel tube heat absorber is lower than that of serpentine ones (T_{outletSer}). The highest temperature of serpentine is about 90°C. This temperature will heat water in the tank. As a result,

V. CONCLUSION

SHW for parallel-serpentine tubes configuration with single cover glazing has been designed and made it. After that, testing set-up for passive collector (natural convection) has been done for 2 mass flow rates. It indicates that the higher mass flow rate, the better of water outlet temperature. This means that hot water in the tank/reservoir will be soon hot. Proven that parallel-serpentine is better than of serpentine-parallel tubes configuration [1] &[2] in terms of outer temperature prior to entering the tank. Future research is needed to apply an active collector (forced convection).

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NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_{par}</td>
<td>parallel collector area</td>
<td>m²</td>
</tr>
<tr>
<td>A_{ser}</td>
<td>serpentine collector area</td>
<td>m²</td>
</tr>
<tr>
<td>C_p</td>
<td>water specific heat</td>
<td>J/kg°C</td>
</tr>
<tr>
<td>I</td>
<td>solar intensity</td>
<td>W/m²</td>
</tr>
<tr>
<td>Q_u</td>
<td>useful heat gain from collector</td>
<td>W</td>
</tr>
<tr>
<td>m</td>
<td>mass flow rate</td>
<td>kg/s</td>
</tr>
<tr>
<td>U</td>
<td>collector heat losses coefficient</td>
<td>W/m³K</td>
</tr>
</tbody>
</table>
REFERENCES


Optimal Design of V-shaped Absorber Plate to the Performance of Solar Water Heater

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Abstract—Solar energy is known as an environmentally friendly energy source and wide range of applications. This energy is utilized in various applications such as domestic and industrial water heating, refrigeration, cooking, power production and water pumping etc. The present study analyzes absorptivity of flat-plate absorber and various V-shaped absorber plates. Analytical investigation of absorptivity of the various V-shaped absorber plates and comparison with that of the flat-plate absorber was carried out. The result shows that V-shaped absorber plate with angle of $\beta = 21^\circ$ (V-shaped dimension of $t = 4$ cm and $l = 4$ cm) has a better absorptivity compared with that of the flat-plate absorber and others V-shaped absorber plates. Improving the absorptivity of absorber plate enhances thermal performance of solar water heater. Utilization of V-shaped absorber plate will increase the efficiency of solar water heater due to increasing its absorptivity of absorber plate.

Key words—Solar water heater, V-shaped absorber plate, Efficiency

I. INTRODUCTION

Solar energy is a renewable energy source with wide range of applications such as domestic and industrial water heating, refrigeration, cooking, power production and water pumping etc. Utilization of solar water heaters is increasing in the world due to their simplicity and reliability. Thermosyphon solar water heating system is now widely used in domestic as well as industrial sector due to its ease of operation and simple maintenance. Solar water heating system proves to be an effective technology for converting solar energy into thermal energy. Development of various system components that includes the collector, storage tank and heat exchanger is interest subject to enhance thermal performance of solar water heater. Several investigations have been reported to address these issues. Collector efficiency of air solar heater has been investigated [1]. Effect of glass cover of the solar water heater collector has been reported in [2]. Ayompe and Duffy [3] have investigated the thermal performance of solar water heating system with 4 m² flat-plate collectors in Dublin, Ireland. The results show that solar fraction was 32.2 %, collector efficiency was 45.6 % and system efficiency was 37.8%. Optical analysis, experimental study and cost analysis of the stationary V-through solar water heater system have been studied by Chong et al. [4]. They proposed a stationary V-through solar water heater with the maximum solar concentration ratio of 1.8 suns to improve the thermal efficiency. Various techniques to enhance the thermal efficiency in solar water heater have been reviewed by Jaisankar et al. [5]. Solar water heating system is an effective technology to convert solar energy into thermal energy. The efficiency of solar thermal conversion is around 70% when compared to solar electrical direct conversion system which has an efficiency of only 17%. Summary on the development of various system components that includes the collector, storage tank and heat exchanger are discussed in [6].

The present work analyzes absorptivity of flat-plate absorber and various V-shaped absorber plates. Absorptivity of flat-plate absorber and V-shaped absorber plates with various angle $\beta$ and dimensions were investigated.

II. SOLAR WATER HEATER

Thermosyphon solar water heaters which its components includes the collector, storage tank and heat exchanger are characterized by converting solar energy into thermal energy. The system performance is affected by absorber plate and its design, selective coating, thermal insulation, tilt angle of the collector and working fluid. The schematic layout of a typical thermosyphon solar water heater is shown in Fig. 1.

![Fig. 1. The schematic layout of a typical thermosyphon solar water heater](image-url)
Design and thermal properties of the absorber plate contribute to the performance of solar collector. The cross sectional view of a solar water heater with flat-plate absorber is shown in Fig. 2 (a) and V-shaped absorber plate is shown in Fig. 2 (b).

a) Flat-plate absorber

b) V-shaped absorber plate

Fig. 2. The cross sectional view of a solar water heater

III. ABSORPTANCE OF V-SHAPED ABSORBER PLATE

Two types of absorber plates which are flat-plate and V-shaped plate are investigated to study the absorptivity of the plates. Increasing the absorptivity of the absorber plate lead to enhance the collector efficiency. The solar energy is converted to usefull energy by absorbed it in the absorber plate and transferred it to working fluid. Various types of V-shaped absorber plates are V-shaped plate with angle of $\beta = 21^\circ$ ($t = 4$ cm), $32^\circ$ ($t = 4$ cm), $41^\circ$ ($t = 4$ cm), $27^\circ$ ($t = 3$ cm), $40^\circ$ ($t = 3$ cm), $49^\circ$ ($t = 3$ cm). Analytical method is applied to calculate the absorptivity of absorber plates. Cross-sectional view of ray-tracing result of flat-plate absorber and V-shaped absorber plates are shown in Appendix B.

Solar radiations with incident angle of $\theta = 0^\circ$, $30^\circ$, $60^\circ$ reach the surface of absorber plates. Solar radiations reach the absorber plate perpendicular ($\theta = 0^\circ$) in the daytime, with $\theta = 60^\circ$ in the morning and afternoon. Absorptivity of absorber plate is calculated by absorbed solar radiation in the plate based on its incident angle. The absorber plates are assumed as a black surface. In the case of V-shaped plate, solar radiation is reflected by several times. Solar radiation is absorbed by the plate in each reflection based on its incident angle. Absorptance of black flat-plate with various incident angles is shown in Appendix A [7]. Absorptivity of flat-plate absorber and V-shaped absorber plates are shown in table I.

TABLE I. ABSORPTIVITY OF FLAT-PLATE ABSORBER AND V-SHAPED ABSORBER PLATES

<table>
<thead>
<tr>
<th>No.</th>
<th>Absorber plate orientation</th>
<th>Angle of incident ($\theta$)</th>
<th>Absorptivity ($\alpha$)</th>
<th>Average absorptivity ($\alpha_{\text{average}}$)</th>
<th>V-shaped dimension ($t$ and $l$), cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Flat-plate absorber</td>
<td>0</td>
<td>0.965</td>
<td>0.936</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>0.951</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>0.894</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>V-shaped $\beta = 41^\circ$</td>
<td>0</td>
<td>0.985</td>
<td>0.971</td>
<td>4 and 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>0.968</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>0.961</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>V-shaped $\beta = 32^\circ$</td>
<td>0</td>
<td>0.980</td>
<td>0.973</td>
<td>4 and 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>0.974</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>0.963</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>V-shaped $\beta = 21^\circ$</td>
<td>0</td>
<td>0.970</td>
<td>0.975</td>
<td>4 and 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>0.973</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>0.981</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>V-shaped $\beta = 49^\circ$</td>
<td>0</td>
<td>0.966</td>
<td>0.965</td>
<td>3 and 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>0.966</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>0.963</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>V-shaped $\beta = 40^\circ$</td>
<td>0</td>
<td>0.979</td>
<td>0.968</td>
<td>3 and 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>0.960</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>0.966</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>V-shaped $\beta = 27^\circ$</td>
<td>0</td>
<td>0.970</td>
<td>0.970</td>
<td>3 and 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>0.968</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>60</td>
<td>0.970</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3 shows absorptivity of flat-plate absorber and various V-shaped absorber plates. Absorptivity of the flat-plate absorber decreases in increasing the incident angle. However, absorptivity of V-shaped absorber plates changes slightly with increasing the incident angle. This fact indicates that V-shaped absorber plates provide a better absorptivity compared with the flat-plate absorber. Several reflections of the solar radiation on the V-shaped absorber plates increase its absorptivity.

![Absorptivity of flat-plate absorber and various V-shaped absorber plates](image1)

**Fig. 3. Absorptivity of flat-plate absorber and various V-shaped absorber plates**

![Average absorptivity of absorber plates](image2)

**Fig. 4. Average absorptivity of absorber plates**

Based on the average absorptivity of V-shaped absorber plates, optimal design is found in the V-shaped absorber plate with angle of $\beta = 21^\circ$ (V-shaped dimension of $t = 4$ cm and $l = 4$ cm) as shown in the Fig. 4. Applying the V-shaped absorber plate in the solar water heating system will increase its performance due to increasing the absorptivity of its absorber plate.

IV. CONCLUSIONS

Analytical investigations of absorptivity of various V-shaped absorber plates and comparison with that of flat-plate absorber have been carried out. The result shows that the V-shaped absorber plate with angle of $\beta = 21^\circ$ has a better absorptivity compared with that of the flat-plate absorber and others V-shaped absorber plates. Utilization of V-shaped absorber plate will increase the efficiency of solar water heater.

ACKNOWLEDGMENT

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REFERENCES


### Appendix A

**Table 4** Variation with Incident Angle of Transmittance for Single and Double Glazing and Absorptance for Flat-Black Paint

<table>
<thead>
<tr>
<th>Incident Angle, Deg</th>
<th>Transmittance</th>
<th>Absorptance for Flat-Black Paint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single Glazing</td>
<td>Double Glazing</td>
</tr>
<tr>
<td>0</td>
<td>0.87</td>
<td>0.77</td>
</tr>
<tr>
<td>10</td>
<td>0.87</td>
<td>0.77</td>
</tr>
<tr>
<td>20</td>
<td>0.87</td>
<td>0.77</td>
</tr>
<tr>
<td>30</td>
<td>0.87</td>
<td>0.76</td>
</tr>
<tr>
<td>40</td>
<td>0.86</td>
<td>0.75</td>
</tr>
<tr>
<td>50</td>
<td>0.84</td>
<td>0.73</td>
</tr>
<tr>
<td>60</td>
<td>0.79</td>
<td>0.67</td>
</tr>
<tr>
<td>70</td>
<td>0.68</td>
<td>0.53</td>
</tr>
<tr>
<td>80</td>
<td>0.42</td>
<td>0.25</td>
</tr>
<tr>
<td>90</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Appendix B
Cross-sectional view of ray-tracing result of plat and V-shaped absorber plate

Flat-plate absorber

Angle of Incident $= 0^\circ$

Angle of Incident $= 30^\circ$

Angle of Incident $= 60^\circ$
V-shaped absorber plate

Angle of Incident = 0°

Angle of Incident = 30°

Angle of Incident = 60°
Angle of Incident = 0°

Angle of Incident = 30°

Angle of Incident = 60°
Angle of Incident = 0°

Angle of Incident = 30°

Angle of Incident = 60°