CONTROLLING UNMANNED SURFACE VEHICLE ROCKET USING GPS TRACKING METHOD

Unmanned surface vehicle (USV) is an unmanned vehicle that is operated on the surface for specific purposes. USV can be used in waters that cannot be traversed by boat with the crew, including environments with a high level of threat or an area that has been contaminated by nuclear, biological, or chemical. In addition, USV can also be used to survey shallow waters, to escort military weapons, the collection of environmental data, and coordinate with underwater vehicles (AUV). This research aims to design and create a simple USV rocket to maneuver on the water surface. The design phase of this study begins by describing a simple system for USV, then the selection of mechanical and electronic components, as well as making the program on the microcontroller Arduino Mega 2560. Further analyze the kinematics of motion USV and testing rockets thrust force and torque generated by the system USV named Electricducted fan (EDF). In this research, the rocket system dimensions are obtained with a size of 720 mm x 500 mm x 420 mm and a total weight of 3920 grams. The USV rocket is driven by motors Electricducted fan with 90 mm 1600 w, ESC 160 A, 6X Turnigy FHSS remote control, and a power source battery of 18.5 V Li-Po 5500 mAh much as two pieces. From the calculations, the maximum thrust force of 40.7 N with 1.41 Nm torque. It was found some kinematics parameters with angular acceleration and linear acceleration.

Keywords: Unmanned surface vehicle, control, Kinematics, GPS

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ABSTRACT
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In this research, the rocket system dimensions are obtained with a size of 720 mm x 500 mm x 420 mm and a total weight of 3920 grams. The USV rocket is driven by motors Electric ducted fan with 90 mm 1600 kv, ESC 160 A, 6X Turnigy FHSS remote control, and a power source battery of 18.5 V Li-Po 5500 mAh much as two pieces. From the calculations, the maximum thrust force of 40.7 N with 1.41 Nm torque. It was found some kinematics parameters with angular acceleration and linear acceleration.

Keywords: Unmanned surface vehicle, control, Kinematics, GPS
1. INTRODUCTION

Unmanned surface vehicle (USV) is an unmanned vehicle that is operated on the surface for specific purposes. USV can be used in waters that cannot be traversed by boat with the crew, including environments with a high level of threat or an area that has been contaminated by nuclear, biological, or chemical. In addition, USV can also be used to survey shallow waters, to escort military weapons, the collection of environmental data, and coordinate with under water vehicle (AUV). USV is also known as autonomous surface vehicle (ASV) or vehicle automatically because the surface using a global positioning system (GPS) in determining the direction of movement of the vehicle of interest (Manley 2008).

USV can be used in waters that cannot be traversed by boat with the crew, including environments with a high level of threat or an area that has been contaminated by nuclear, biological or chemical materials (Rujian 2010). And also another application of Unmanned Vehicle System could be found at (Syam 2016).

In addition, USV can also be used to survey shallow waters, to escort military weapons, the collection of environmental data, and coordinate with automated underwater vehicle (AUV). When compared with the AUV in the automation system, the accuracy USV much better than AUV because of the availability of global positioning system (GPS) (Naeem 2007).

Rocket technology has developed rapidly since the second world war with the goal of beginning to fight. Later in peacetime developed for the purpose of launching a satellite into orbit, atmospheric monitoring and research purposes other(Richard 1958). Rockets were mostly made to be able to fly in the air; therefore the authors designed a rocket unmanned surface vehicle (USV) that can move on the surface.

The objectives of this paper are as follows, designing and making rockets USV simple and effective. Then to determine the thrust produced by the motor during a simple maneuver. Finally, to analyze the kinematics of the rocket USV.

2. UNMANNED SURFACE VEHICLE

2.1 Frame Of Usv Surface
USV rocket systems generally same as the existing rocket systems, but USV system is much simpler. This is because only one fin can change the direction of motion of the rocket. The position of the rocket is in direct contact with water and equipped with cantilever hull catamaran-like ship models, causing the rocket USV difficult to move the roll and pitch motion but very good level of balance.

The rocket has two main hulls are symmetrical on the right and left sides. With this kind of double hull allows the rocket to move more balanced and relatively large size of the rocket and has a carrying capacity greater [Murphy 2011].
2.2 Rotation System of USV

USV rocket equation of motion in this research is using the reference system of the body axis. System body axis is the axis which refers to the vehicle body of the rocket. X axis along the longitudinal axis positive rockets forward, the Z axis in the plane of symmetry rocket upright and perpendicular to the X axis in a positive position to fly the flat bottom, and the Y axis perpendicular to the plane of symmetry and positive toward the right [Jorgensen 2011]

![Figure 1: The Roket with double hulls](image1)

![Figure 2: Rotation system of USV model [Jorgensen 2011]](image2)
And the inertia of tensor is diagonal matrix

$$ l = \begin{bmatrix} l_{xx} & 0 & 0 \\ 0 & l_{yy} & 0 \\ 0 & 0 & l_{zz} \end{bmatrix} \quad (3) $$

### 2.4 Thrust of USV Model

The forces acting on the rocket is gravity, thrust, and air friction. The forces acting on the rocket is gravity, thrust, and air friction. The Gravitation work at the center of gravity rocket and the direction on z-axis. At body frame, contribution of gravity \( F_{grav}^B \) as follow

$$ F_{grav}^B = \begin{bmatrix} m g \sin \theta \\ -m g \sin \phi \cos \theta \\ -m g \cos \phi \cos \theta \end{bmatrix} \quad (4) $$

Where \( g \) is acceleration of gravity.

The driving force is the total thrust produced by EDF and is always directed along the x-axis. When the rocket is moving then the constant of thrust parameter \( b \) (Ns²), and thrust \( F_{dr}^B \) could be shown below:

$$ F_{dr}^B = b \cdot \Omega^2 \quad (5) $$

There drag that occurs on a rocket USV when moving. This drag will affect the acceleration in the x and y on the body frame. While on the move, this drag can be obtained by equation (6) with \( \mu \) is constant (kg / s).

$$ F_{hom}^B = \begin{bmatrix} \mu u \\ -\mu v \\ 0 \end{bmatrix} \quad (6) $$

Then, the Water resistance is equivalent with velocity squared, where size and shape of the object can be used (7). With \( C \) is friction coefficient, dimensionless, \( A_i \) is the area affected by the barriers (m²) and \( p \) is density of air (kg/m³).

$$ F_{air}^B = \begin{bmatrix} \frac{1}{2} C A_x \rho u |u| \\ \frac{1}{2} C A_y \rho v |v| \\ \frac{1}{2} C A_z \rho w |w| \end{bmatrix} \quad (7) $$
Table 1. Reference of rocket parameters

<table>
<thead>
<tr>
<th>Parameters of system</th>
<th>x-axis</th>
<th>y-axis</th>
<th>z-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular Velocity</td>
<td>$p$</td>
<td>$q$</td>
<td>$r$</td>
</tr>
<tr>
<td>Linear Velocity</td>
<td>$u$</td>
<td>$v$</td>
<td>$w$</td>
</tr>
<tr>
<td>Aerodinamika Force</td>
<td>$x$</td>
<td>$y$</td>
<td>$z$</td>
</tr>
<tr>
<td>Moment of aerodynamic</td>
<td>$L$</td>
<td>$M$</td>
<td>$N$</td>
</tr>
<tr>
<td>Moment of Inertia</td>
<td>$I_{xx}$</td>
<td>$I_{yy}$</td>
<td>$I_{zz}$</td>
</tr>
<tr>
<td>Change of angle euler</td>
<td>$\phi$</td>
<td>$\theta$</td>
<td>$\psi$</td>
</tr>
</tbody>
</table>

2.3 Motion Equation of USV

By using the Newton-Euler's formula to describe the dynamics of the objects that are influenced by external forces and moments.

$$
\begin{bmatrix}
m I_{3x3} & 0_{3x3} \\
0_{3x3} & I
\end{bmatrix}
\begin{bmatrix}
\dot{x} \\
\dot{y}
\end{bmatrix}
+
\begin{bmatrix}
\omega^L \times m r^L \\
\omega^L \times I \omega^L
\end{bmatrix}
=
\begin{bmatrix}
F^B \\
T^B
\end{bmatrix}
$$

(1)

where,

- $M$ = mass (kg),
- $I$ = inertia of tensor (Nms$^2$),
- $v^B = [u \ v \ w]^T$; linear velocity of body (m/s),
- $\omega^B = [p \ q \ r]^T$; angular velocity of body (rad/s),
- $F^B$ = Force of rocket at the body frame (N),
- $T^B$ = moment of the rocket at body frame (Nm),
- $0_{3x3}$ = matrix 0 (null) with size 3x3
- $I_{3x3}$ = matrix identity, 3x3

Because the results of the cross product of vectors can be expressed in a skew-symmetric matrix multiplication as shown below

$$
a \times b =
\begin{bmatrix}
0 & -a_3 & a_2 \\
a_3 & 0 & -a_4 \\
-a_2 & a_4 & 0
\end{bmatrix}
\begin{bmatrix}
b_1 \\
b_2 \\
b_3
\end{bmatrix}
$$

(2)
2.5 Moment of USV Model

Moment is a force multiplied by the distance to the axis of rotation. At equation (8)-(12) is velocity of electric ducted fan (rad/s), velocity of electric ducted fan $\Omega$ (rad/s), the length of rocket $l$ and draft factor $d$ (Nms$^2$).

Moment of roll, By moving the control fins to produce a motion aileron roll.

$$\tau_{roll} = bl(\Omega^2) \quad (8)$$

By using the control fins to produce a motion elevator pitch, then momen of pitch is

$$\tau_{pitch} = bl \frac{\sqrt{3}}{2} (\Omega^2) \quad (9)$$

By using a fin rudder control to generate a yaw motion, it will be found the moment of yaw is.

$$\tau_{yaw} = d(\Omega^2) \quad (10)$$

The rotation of electric ducted fan (EDF) produce effects giroskopis of propeller is

$$\tau_{gyro} = \begin{bmatrix} -J_r \dot{\Omega}_r \\ J_r \dot{\phi} \Omega_r \\ 0 \end{bmatrix} \quad (11)$$

Then, inertia of rotation $J$, EDF (Nms$^2$) and angular velocity EDF, $\Omega$.

Counter of yaw torque is the difference of acceleration rotation of electric ducted fan can be obtained as folloes

$$\tau_{counter} = \begin{bmatrix} 0 \\ 0 \\ J_r \ddot{\Omega}_r \end{bmatrix} \quad (12)$$
3. RESEARCH METHOD

3.1 Design of work

Mechanics are made in the form of rocket USV is designed with the concept of a catamaran. The rocket mode has two main hull (hulls) are symmetrical on the right and left sides. Hull construction which thus enables the rocket to move (maneuver) is more balanced with the size of the relatively large rockets and has a greater carrying capacity.

The amount of cargo is required to estimate the length, width and height of the rocket that will be created. Rocket type of catamaran been selected for the purpose of making this rocket emphasizes the power factor load and stability compared maneuverability rocket rockets. The fins placed on the back of a rocket to propel the vehicle on the surface of the water. The motors used in electric motors drive system is ducted fan.

The design of rocket unmanned surface vehicle (USV) can be seen in Figure 4. Making the rocket hull using PVC pipe material is 3 inches so it is easy to be made. Rocket hull is made circular to minimize resistance when the rocket cruised above the water surface. Part of the upper frame made with aluminum material has a light weight yet sturdy, so do not make the weight of a vehicle to be heavy. USV has a total length of 72 cm, width 0.5 m and total height 0.42 m are included box components. Rocket with electronic charge has a weight of 3.92 kg, while the unladen weight of 1.6 kg electronics.

The vehicle using propeller made of aluminum with twelve pieces of leaf propeller diameter of 90 mm. Propeller greatly affect the speed of a rocket, because its function is to change the turning force of the motor into a propelling force [Tomas 2016].

![Figure 4. Design USV rocket](image)

3.2 Electronics System

Electronic system of USV consists of Arduino Mega 2560 as controller system, GPS device as coordinate system, Electronic Speed Control (ESC) as motor driver, motor electric ducted fan, motor servo for driving the vehicle, remote system KYL-1020U for sending data to operator. Technical description can be found below.
3.3 Interface of USV system; google earth

User interface can be shown at Figure 6. The user interface consists of Google Earth and Python. The data is processed by Python Software also describe roll, pitch and yaw, the direction of target, distance to the target and way point of the USV Rocket. Realtime position of the USV will be reported by google earth. Google Earth Software to display the position of the vehicle due to the use of a fairly easy and user friendly. Google Earth is also provided with a map of unpaid making it easy to access locations used. Vehicle location indicated by Placemark tool. Placemark position switch corresponding actual vehicle position (real time) to update the file *.kml containing Placemark position coordinates.

Figure 6. Display of interface system i.e. google earth and python soft (experimental place at lake of Hasanuddin University)
These waypoints are displayed using the path tool in Google Earth. In use, the user need only open a file *.kml using Google Earth and then run a python script that has been created. In order to communicate between Arduino with computers, a port on the python script must be adapted to the port is read on a computer device.

3.4 Experiment Procedure

It was using one EDF Motor, so that it is enough to test one motor for lifting experiment, for thrust and torque also.

a. Measurement of thrust USV Rocket

The resulting thrust force EDF and the motor comes in line with the direction of the force adopted. To know the major thrust is generated, the motor will be placed on a digital scale. EDF will be installed upside down such that the resulting thrust will push the motor down

![Figure 7. Thrust of electrical motor with propeller.](image)

b. Measurement of moment

To determine the motor torque generated when turning EDF. The motor will be mounted on an arm with a certain length. This arm will hit digital scales when the motor rotates.

4. RESULT AND DISCUSSION

4.1 Results of Experiment

There are four basic movements' rockets: throttle, roll, pitch, and yaw. Throttle movement control is done by changing the speed of EDF. Linear motion rockets (to fly along the surface) are controlled via the roll angle, pitch angle and yaw angle. To fly straight ahead, the third fin control in an upright position against the body of the rocket and motor rotation EDF raised, while for motion controlled through the ups and downs of rocket fins elevators. For the motion to turn left and right, the rocket is controlled by the rudder fin, whiles the rocket roll motion, and is controlled by aileron fins.
How to control the rocket USV is via electric ducted fan and fin movement. The electric ducted fan produces thrust forward by pressing the air to the rear. Because the source of the thrust is located outside the center of mass, differential thrust force changes can be used to rotate the rocket. Round of the motor also produces a reaction torque in the opposite direction to the direction of rotation. But two things happened because the likelihood is very small rocket hull USV has two buttresses on the right and left of the core components in direct contact with water. Therefore, the rocket USV only throttle and yaw motion can be controlled while the pitch and roll is considered zero (not moving).

1. Throttle Controller

The main control of the rocket is the throttle, where the throttle is used to control movement in the horizontal of the body. Because of the slope of the fins remain, then the direction of rotation of the thrust is fixed. The biggest task is to fight off the throttle friction...
with water. When adding or reducing the throttle, the rocket will move forward quickly or slowly. If a rocket in a tilted position then the thrust will propel rockets.

2. **Yaw Controller**

Yaw command is used to rotate the rocket along the z-axis. Yaw control is done by moving the rudder fin. When the rudder fin is moved to the left then the rocket will move to the left without having to add or reduce the thrust force generated from electric ducted fan. Then the total thrust has not changed and will only result in a round. The movement of the rocket flying through the air with the moving surface of the water is almost the same. But the movements of USV rocket not so complicated like a flying rocket. At USV rocket, EDF work easier because the total mass of the rocket is not dependent on the motor. USV rocket's ability to move the roll and pitch are also very small, because of the two hulls on both sides of the main components.

4.2 **Discussion of experimental work**

1. **Measurement of moment**

The thrust on the motor is influenced by angular velocity of electric ducted fan. If the angle of pitch of the propeller is fixed, then to raise/lower the thrust is to raise/lower the angular velocity of the propeller. This can be seen in Figure 17.

![Figure 17. The relationship between thrust $F_{th}$ (N) with Angular Velocity $\Omega$ (rad/s).](image)

Propeller has dimensions and mass large enough. So as to be able to provide high angular velocity, the motor requires power (watts) is quite large. This can be seen in Figure 18.
Figure 18. The relationship between thrust $F_d$ (N) and Power, $P$ (watt).

Figure 19. The result of coefficient of thrust $b$ (Ns$^2$).

2. Measurement of moment

Because the motor rotates the propeller, then the motor will produce a moment which is directed opposite to the direction of rotation of the propeller. Rockets generally use this moment to rotate the rocket body on the z axis. The larger the engine speed, the greater the torque generated. This can be seen in Figure 20.

Figure 20. The relationship between moment $\tau$ (Nm) and angular velocity $\Omega$ (rad/s).
Because of the size of power affect the rotation speed, if the power is higher then it will be given the greater torque generated. This can be seen in Figure 21

**Gambar 21.** The relationship between moment \( \tau \) (Nm) with Power \( P \) (watt).

**Figure 22.** The result of measurement of drag factor, \( d \) (Nm\(^2\)).

5. CONCLUSION

Based on experiment and analysis in the previous part, it can be conclude that the rocket is unmanned surface vehicle successed to build already implemented on the simple experiments. The rocket USV has 0.720 m long, 0.500m widths, tinggi 0.420 m tall, and weight 13,920 kg. This rocket was using electric ducted fan motor with size 90 mm. The maximum thrust force that can be generated motor at a maximum rotation 5396.82 rad / s is 40.7 N. moment which can be generated motor at maximum rotation is 1:41 Nm.

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REFERENCES


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