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Development of Real-Time Monitoring System for an Off-Grid Photovoltaic System

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Abstract - In operating a photovoltaic system, it is required to employ hardware and software systems to monitor the parameter of the results of the solar panel conversion. Usually, monitoring the photovoltaic system is done by manual gauges and recording the measured results manually which would require a human hand. The present research designed and developed a real-time monitoring system for an off-grid photovoltaic system that could monitor the photovoltaic system performance automatically. The monitoring system design has 2 (two) subsystems. The first subsystem is a hardware system in the form of an electronic data logger system equipped with an SD card. This allowed data to be recorded on an SD card. The second sub-system is a software design developed using Microsoft in Visual Basic. The hardware and software were connected to monitor the photovoltaic results and recorded the obtained data in an SD card for further analysis.

1. Introduction

Solar energy is an inexhaustible source of energy that can be used as an alternative source of electricity. Solar energy can be converted into electrical energy using photovoltaic technology [1]. A solar cell or photovoltaic is a device that converts solar radiation energy into electrical energy. At present, solar panels have been widely applied, including in fishing vessels. However, the solar panel monitoring system on fishing vessels still uses a manual monitoring system so that the obtained data is not accurate and in its implementation, it requires direct measurements.

With current technological advances, this monitoring system has become easier to do with computers and software. There are many examples research which had been conducted related to monitoring system especially the ones using microcontroller. Rosiek and Batlles [2] used a microcontroller for meteorological station monitoring, Islam et al. [3] utilized it for health care monitoring, Mahmuddin et al. [4] also applied a microcontroller to monitor and control the charging process of a battery from a wind turbine. Related to solar monitoring, one of the research had been done by Mukaro and Carelse [5] who used it for solar radiation and environmental monitoring.

The present study designs and develops a monitoring system for an off-grid photovoltaic system so that it can be used in fishing vessels that are equipped with a solar system as well. The system has 2 (two) components which hardware system dan computer system. The hardware system consists of several sensors and a microcontroller. The microcontroller Arduino Uno was chosen as one of the

main components in the present study for its comprehensive features and simplicity in implementation [4]. Besides that, the present study also developed a computer program or software using Microsoft Visual Basic. This Visual Basic program can optimize the management of existing data so that a more accurate monitoring system application can be developed. With this monitoring system, continuous automatic recording of data can be done so that the obtained data is more precise and valid.

2. Literature Review

2.1. Monitoring System

According to Clayton and Petry [6], monitoring is a process of measuring, recording, collecting, processing, and communicating information to help decision making from program or project management. Therefore, in this study, the objective of a monitoring system is the process of measuring, recording, collecting, and remotely communicating data which are used to analyze the performance of the photovoltaic system in real-time. The monitored target is the measurement results of the sensors installed in each part of the photovoltaic system in the form of a voltage sensor, current sensor, temperature, and humidity sensor.

The supporting components of the solar panel monitoring system are as follows:

1)   Data logger

Data logging is the measurement and recording of electrical or physical quantities over a certain period of time. Data loggers are used in a variety of uses, including recording vehicle parameter data, environmental monitoring, and patient health monitoring. Common measurements include temperature, voltage, current, resistance, pressure, speed, and so on.

2)   Microcontroller

The commonly used microcontroller is Arduino which is a combination of hardware and software that is open source. The Arduino is an open-source, single-board microcontroller, derived from the wiring platform, designed for easy use of electronics in a variety of fields. The hardware has an Atmel AVR processor and the software has its own programming language which uses a simplified version of C++, making it easier to learn to program. This microcontroller has 14 digital input/output pins (6 PWM pins and 6 analog inputs), a 16 MHz crystal oscillator, a USB connection, and power supply connection, and a reset button [7]. Because of its open nature, anyone can download the Arduino hardware scheme and build it. Unlike most of the previous programmable circuit boards, the Arduino does not require a separate hardware device to load code onto the Arduino board. Finally, the Arduino provides a standard form factor that breaks down microcontroller functions into more accessible packages.

3)   Current sensor

The commonly current sensor is an ACS712 module, in the form of a current sensor IC that uses the hall effect principle. The advantage of this IC module is that it has high voltage isolation and is a current conductor with low resistance. This current sensor module produces a voltage that is directly proportional to the measured electric current, which is 185 mV/A. This condition allows for direct use of this module as a current sensor into the microcontroller.

4)   Voltage sensor

The open-circuit voltage (VOC) of the solar panel is 22 Vdc, while the microcontroller used in this design has an Analog to Digital Converter (ADC) which is capable of receiving a maximum voltage of 5 Vdc, so the solar panel voltage must be reduced and adjusted to the ADC capability.

5)   Light intensity sensor

The light sensor is a device used to convert light quantities into electrical quantities. One example of a light intensity sensor is the BH1750 sensor. This GY-302 digital light sensor module uses the

BH1750FVI light intensity sensor IC from ROHM Semiconductor which is sensitive to the light intensity around it (ambiance light).

6)   Temperature sensor

According to Utomo et al. [8], the LM35 temperature sensor is an electronic component that has a function to convert temperature into electrical quantities in the form of voltage. One example of a temperature sensor is the LM35. The LM35 has high accuracy and easy design when compared to other temperature sensors, the LM35 also has a low output impedance and high linearity so that it can be easily connected with special control circuits and does not require further adjustment. Although this sensor voltage can reach 30 volts, what is given to the sensor is 5 volts, so it can be used with a single power supply provided that the LM35 only requires a current of 60 μA, this means that the LM35 can generate heat (self-heating) from sensor which can cause a low reading error of less than 0.5 ºC at 25 ºC.

2.2. Microsoft Visual Basic

Microsoft Visual Basic 2010 is a programming language used to create graphical Windows applications (GUI-Graphical User Interface) to perform and complete certain tasks. Microsoft Visual Basic is event-driven programming (event-controlled programming) which means that the program waits until the user responds in the form of certain events (buttons are clicked, menus are selected, etc.) [9].

The advantages of using Microsoft Visual Basic 2010 according to Adi Kurniadi [9], include:
− Using a programming platform called developer studio, which has the same appearance and facilities as Visual C ++ and Visual J ++.
− It has a powerful compiler that can produce executable files faster and more efficiently.
− A wizard is a tool that makes it easy to create applications by automating certain tasks.
− The addition of new buttons that are more sophisticated and improve the rules of the Visual Basic Language structure.
− Faster and more reliable means of data access to create highly capable database applications.
− Visual Basic 2010 has several versions or editions tailored to the needs of the user.
− Visual Basic is accompanied by various tools to create database applications, Visual Basic database facilities which make it the best environment for developing client/server applications.
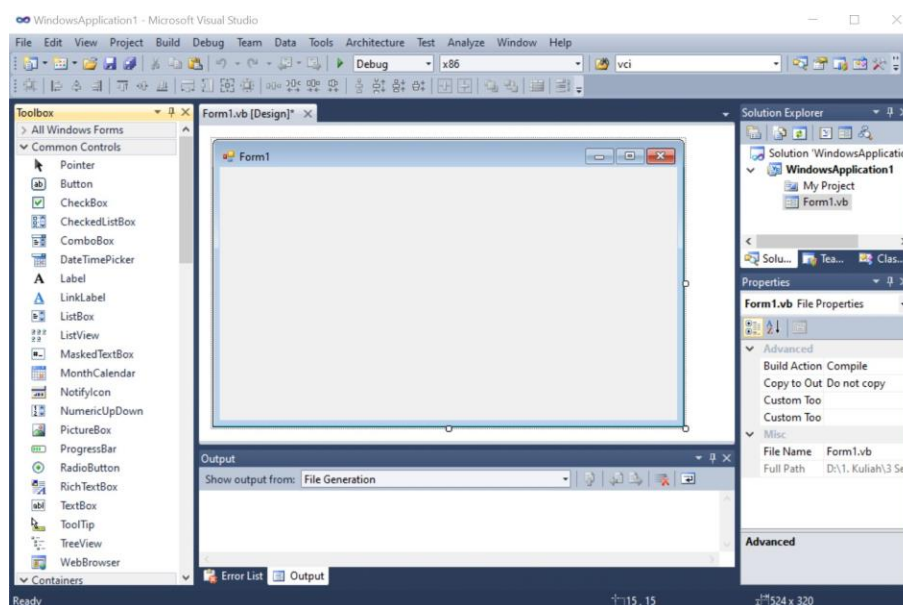
Figure 1. Microsoft Visual Basic IDE

The integrated development environment (IDE) and several main components of Microsoft Visual Basic are shown in Fig. 1. As shown in this figure, they are [10]:

1) Control Menu

    Control menu is a menu that is used primarily to manipulate the Visual Basic window. This means that the function of this menu is to resize, move or close the Visual Basic window.

2) Menu

    The Visual Basic menu contains all the commands that can be selected to perform a specific task. The contents of this menu are partly the same as windows programs in general.

3) Toolbar

    Contains a collection of buttons that are used to perform standard operations when clicked. To display the destination of the toolbar button, place the mouse on it. The information contained in a box will appear called a tooltip.

4) Form Window

    The form window is the main working area in creating Visual Basic application programs. This form is a place to place various kinds of interactive objects such as text, images, command buttons, and so on.

5) Toolbox

    The toolbox contains all the objects or controls needed to form an application program. Control is an object that will be a liaison (interface) between the application program and its user, and everything must be placed in the form window.

6) Project Explorer

    The project explorer window is a window that contains all the files in the Visual Basic application. Every application in Visual Basic is called a project, and each project can contain more than one file. In the project explorer, all files contained in the project application (project) are displayed such as forms, modules, classes, and so on.

7) Properties Window

    The properties window is a window that contains information about the objects contained in the Visual Basic application. Properties are properties of an object, such as its name, color, size, position, and so on.

8) Form Window Layout

    The form layout window is a window that describes the position of the form that is displayed on the monitor screen. The position of the form layout window is an indication of where the application will appear on the monitor screen when it is run.

9) Code Window

    The code window is one of the most important windows in Visual Basic. This window contains program codes which are instructions for Visual Basic applications. Each object in Visual Basic can be added with program codes to perform certain tasks.

3. Research Methodology

3.1. Research Location and Period

The main activities in research are hardware assembly and software design. The system testing was carried out at the Ocean System Laboratory, Marine Engineering Department, Faculty of Engineering, Hasanuddin University. This research was conducted for about 6 months.

3.2. Components

The specification and function of the main components used in the present study as well as their photos are shown in Table 1.

Table 1. Specification, function, and photos of the system main components

Components	Photos
1. Microcontroller The microcontroller used in this design is Arduino based on Arduino Uno. Arduino Uno is a microcontroller board based on the Atmega328. Arduino functions as a controller and reader of the calibration results produced by various sensors.	
2. Current sensor The current sensor is an electronic component that functions to detect the amount of electric current flowing. The current sensor used is in the form of the ACS712 model, in the form of a current sensor IC that uses the Hall effect principle.	
3. Voltage sensor A voltage sensor is a type of sensor that functions to measure electric voltage. This sensor is based on the principle of resistance pressure and can make the input voltage from the terminal reduce by 5 times the original voltage.	
4. Light sensor The BH1750 sensor is more accurate and easier to use using the diode or LDR version which only has a voltage output so that calculations are needed to get the light intensity.	
5. Temperature sensor The LM35DZ temperature sensor has high accuracy and ease of design when compared to other temperature sensors.	

6. Shield data logger

Shield data logger is a shield used to store data (data logging) on the SD Card, which is compatible with Arduino Uno, Duemilanove, Diecimila, Leonardo, Mega R3/Mega ADK.

7. Micro SD card

Micro SD card is memory commonly used in cellphones. Memory has a small size but has a large capacity. Micro SD card functions as a storage area for solar panel output data.

8. Charge Controller

The charge controller is a device that functions as a battery charging controller, regulates the direct current that is charged to the battery and taken from the batteryto the load. The charge controller can detect battery capacity. When the battery is fully charged, the charge controller will automatically cut off the electric current from the solar panels.

9. Battery

The battery functions is to store the electrical energy produced by the solar module before it is used to drive the load. The battery undergoes a cycle of store and discharge depending on the presence or absence of sunlight.

10. LCD 16 x 2

The used LCD is 16 x 2 LCD, which is one of the most popular displays used as an interface between the microcontroller and the user. 16 x 2 LCD viewer is used to view or monitor the state of the sensor or the running of the program.
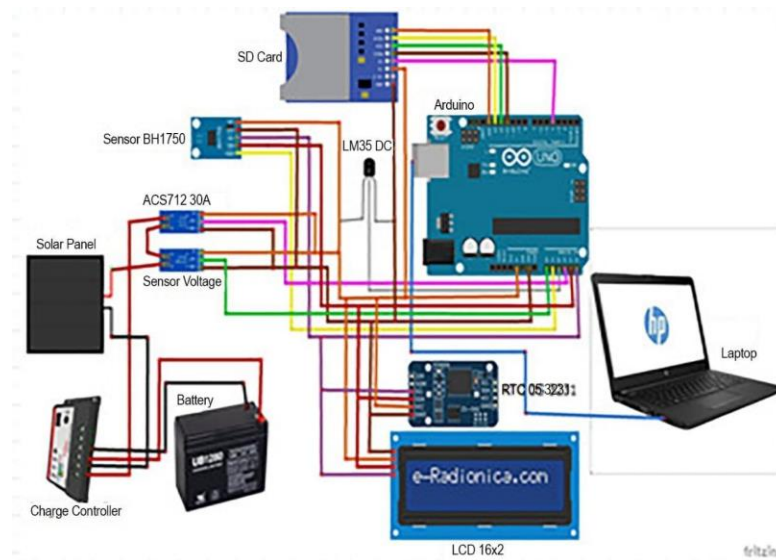
4. Results and Discussion

4.1. Hardware assembly

Sensors and components described in the previous section were connected and assembled. The sensors and components connections are shown in Fig. 2.

**Figure 2.** Hardware components and sensors connections

As shown in Fig. 2, the monitoring hardware system was equipped with a series of components which were a current sensor, a voltage sensor, a temperature sensor, an intensity sensor, a real-time clock (RTC), a 16 x 2 LCD, and an SD Card. SD Card functions to store the measured data from the various sensors. The voltage and current sensors are connected directly to the solar panel and then connected to the charge controller. The charge controller is then connected to the battery.

The charge controller has an indicator to display whether the solar panel and the battery have been properly connected or not. The LM35DZ temperature sensor and the BH1750 light sensor are placed directly on the surface of the solar panel. After that, the sensors are connected to the microcontroller Arduino according to the pins on the Arduino and the sensors. After all sensors are installed properly, the Arduino is connected to the laptop using a USB cable. In the laptop, the developed monitoring program is installed and connected to the microcontroller. The program will display the value of all measured variables from the sensors.

4.2. Monitoring program

The monitoring program or software was developed using Microsoft Visual Basic 2010. In the Visual Basic 2010 form, several tools are made that function to connect and disconnect Arduino with Visual Basic 2010 and display measured parameter data. The interface of the monitoring program is shown in Fig. 3.
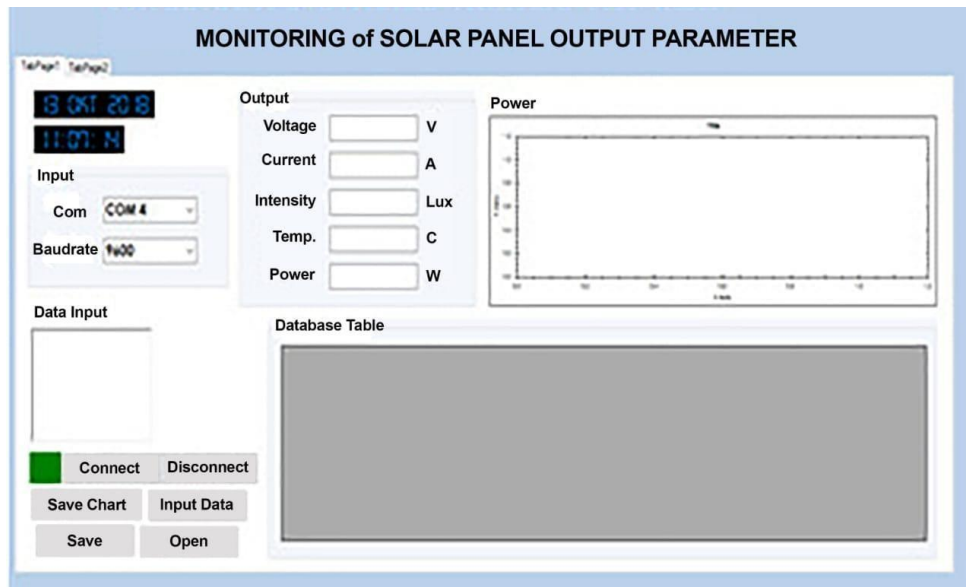
Figure 3. Monitoring program interface

The first step in using the monitoring program is the data initialization step. In this step, the user needs to confirm whether the shown data is in accordance with the desired data or not. After the first step, then the user presses the "connect" button to start the measurement process and take the measured data from the logger data or sensors. The obtained data are voltage (V), current (A), solar intensity (Lux), temperature (^{o}C), and power (W) in the "output section". The incoming data are also saved to a file automatically.

An example of data saved in a file is shown in Fig. 4.
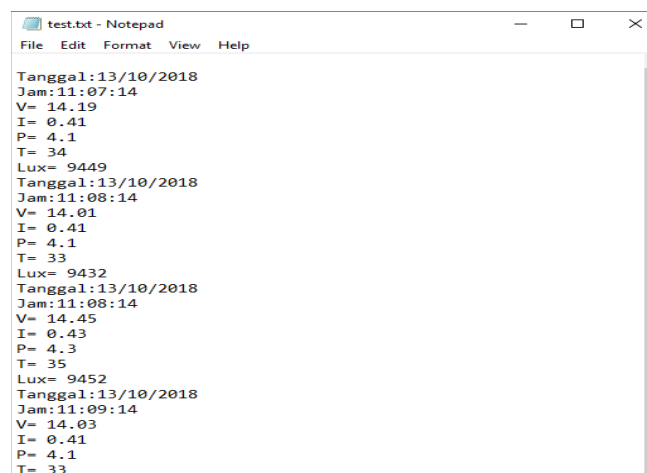
Figure 4. An example data files stored on the SD Card

From the picture above, it can be seen that the device is functioning properly and the data can be stored on the SD Card in text form. The data stored in the data logger is equipped with real-time, making it easier to analyze the data. The recorded data are also shown as a table in "database table" (Tabel Database) section. Data received from the system can also be immediately visualized in graphical form in terms of power in the "power" (daya) section. In the bottom-left part of the interface,

there are several buttons. When the user presses the "disconnect" button, the software stops measuring and retrieving data from the hardware system.

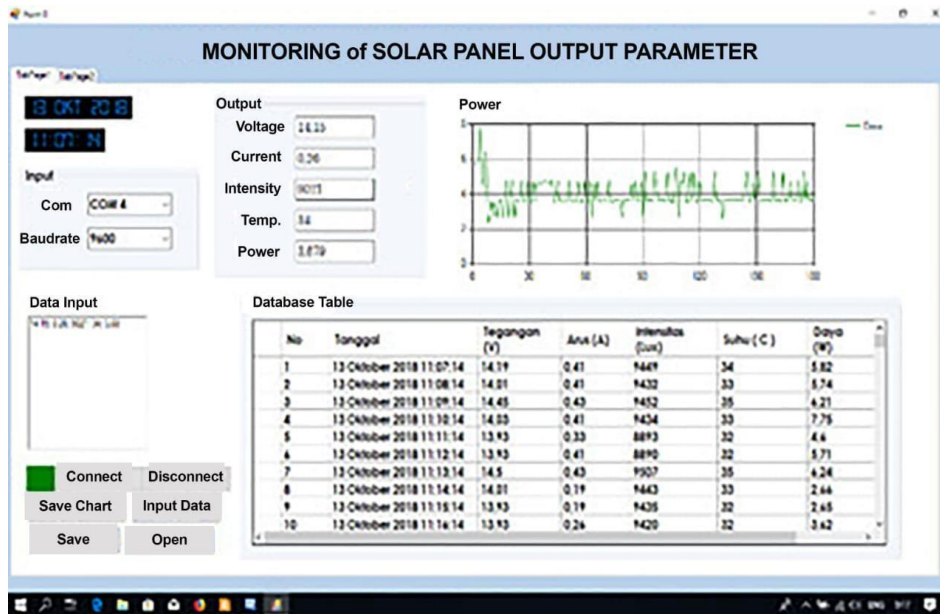An example of the interface when the software is running is shown in Fig. 5.

Figure 5. An example interface when the monitoring program is running

Data that has been received from the system is automatically stored in a file in an excel form. In addition, The data that have been received are separated into 5 (five) types of data, then plotted into a continuous graph as shown in Fig. 6. The graphs can also be stored by pressing "save Chart" button. In order to see these graphs, the user needs to press "open". The interface as shown in Fig. 6 is shown when the user presses this button.
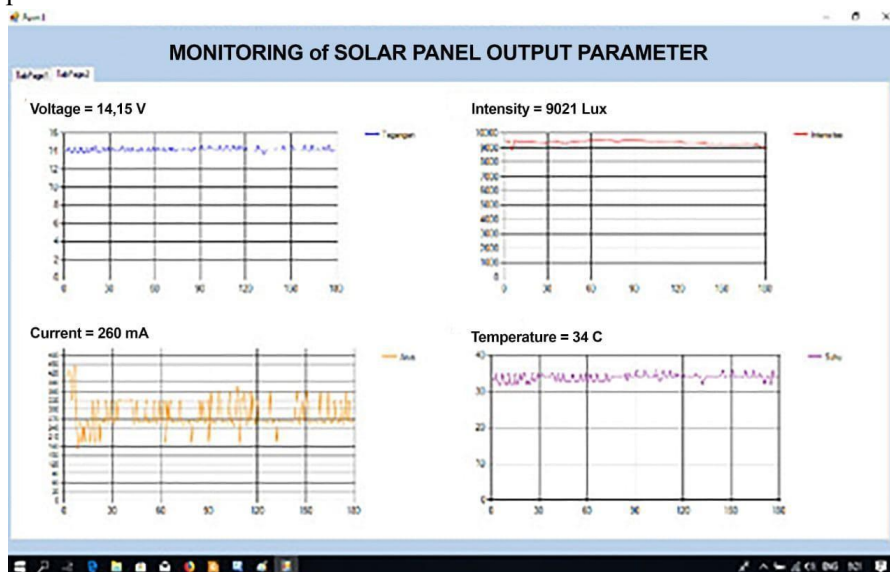

Figure 6. Additional graphs windows

As shown in Fig. 6, there are 4 (four) graphs that are shown when the button "open" is pressed which are voltage, intensity, current, and temperature. The average values of these variables are also shown above each graph.

The experiment and testing of the monitoring system showed the relationship between voltage, current, temperature, and solar panel power with intensity which had a similar fluctuating graph as shown in Fig. 6. It can be concluded that the sun's intensity also affects the performance of the solar panels in a straight proportion. The value of the sun's intensity determined the solar panel's conversion into voltage and current. The greater the intensity of the sun, the greater the voltage and current generated by the solar panels. This can explain that the changes in voltage and current that occurred are greatly influenced by the intensity of the sun.

5. Conclusion

The present research has developed a photovoltaic system monitoring for an off-grid system. The hardware system using a microcontroller Arduino Uno has been successfully implemented to monitor several variables produced from an off-grid photovoltaic system such as temperature, current, voltage, and power. Reading and measurement from monitoring program developed using Visual Basic can store the generated data every certain minute which would allow further analysis conveniently. The data can also be displayed in graphical form in the program interface making it easier to see and analyze data changes from sensors. The data tendency showed the accuracy of the developed system.

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