ENERGY USAGE MONITORING SYSTEM FOR ENVIRONMENTAL MOBILE STATION

S. Sendari[1], Y. Rahmawati[1], F.M. Ramadhan[1], F. Alqodri[1], T. Tibyani[2], T. Matsumoto[3], A. Fujiyama[3] and I. Rachman[3]

[1]Faculty of Engineering,
Universitas Negeri Malang, Malang 65145, Indonesia.

[2]Faculty of Computer Science,
Universitas Brawijaya, Malang 65145, Indonesia.

[3]Faculty of Environment,
The University of Kitakyushu, Kitakyushu 808-0135, Japan.

Corresponding Author's Email: [1]siti.sendari.ft@um.ac.id

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ABSTRACT: This paper designed an energy usage monitoring system for the environmental mobile station (EMS). The system worked through several sensor modules that were attached to the EMS to monitor the environmental condition, i.e., carbon monoxide (CO) level, carbon dioxide (CO2) level, methane (CH4) level, temperature, humidity, wind direction, and wind velocity. The EMS used solar power energy; hence all sensor modules drained the solar power energy. Since the EMS sustainability depended on the energy from solar power and the modules' consumption, it was urgent to monitor its usage to measure the battery energy availability following the environmental conditions, such as sunny or cloudy. The harvesting energy of the solar power system was estimated using the irradiation sensor, while the energy consumption should also be monitored to gauge the drain. The result showed that the energy usage monitoring system could measure the energy availability with irradiance values ranging from 500-1000 w/m and produced the harvesting value of solar power around 14 W.

KEYWORDS: *Energy Usage; Monitoring System; Solar Power; Environmental Mobile Station*

1.0 INTRODUCTION

Monitoring the environment is essential to collect its conditions, which could affect human health [1]. One developed technology is the Environmental Mobile Station (EMS) [2]. Air pollution is taken into account since it is not only impacting climate change but also affecting public and individual health [3]. Some sensor modules are attached to the EMS to measure environmental conditions. The EMS has to move from one point to another in an outdoor setting, far from electricity sources. Renewable energy systems are mainly designed to harvest energy [2]. Solar power has been widely used because it is environmentally friendly. Therefore, EMS could use a solar power energy system to supply the entire load. The important thing is to maintain the availability of the energy supply from solar power [3].

Mostly, the EMS is installed in a car that supplies the power energy from the car's electricity. However, the driver could be in danger if the car is driven in a harmful environment. A remote EMS could be a solution to measure the environmental conditions from a safe distance. Thus, the EMS should work well with power energy as an aspect to be considered. This research aimed to calculate the produced energy by solar power systems to maintain EMS electrical. This method is challenging to implement due to the dynamically-changed weather [4]. The EMS was added with an energy usage monitoring system to overcome this problem.

The proposed system measures the energy produced by the solar power system and calculates the energy usage by the EMS. This system was developed similarly to the conventional EMS, which is not equipped with an energy usage monitoring system. This system measured energy production from the solar power system and consumed energy by the EMS. Therefore, the EMS can be terminated if the energy is not enough. This system works in real-time by using the internet of things (IoT) to collect, analyze, and interpret data measurement as information [5].

2.0 METHODOLOGY

The required energy by the EMS highly depends on the solar power system. The Power output harvested by solar power is calculated as follows

$$\mathrm{P} = \mathrm{V}\left[\mathrm{I}_{SC} - I_{SC}\exp\left(\frac{q(V - V_{oc}}{KT}\right)\right] \tag{1}$$

in which P is the output power, V is the voltage, while V_{OC} is the voltage of an open circuit, I_{SC} is the short circuit current, K is Boltzmann's constant, T is the standard temperature, and q is the electron charge.

Meanwhile, the load characteristics determine a critical and unavoidable role. The essential condition for the operation of EMS is determined as follows

$$V_{L(\min)} < V < V_{L(\max)} \tag{2}$$

Therefore, energy harvesting and utilization should be monitored continuously to avoid damage to the environmental mobile stations when the energy is drained. Figure 1 illustrates the flowchart of the proposed monitoring system.

2.1 Development of Energy Usage Monitoring System

The station is developed to measure carbon monoxide (CO) level, carbon dioxide (CO2) level, methane (CH4) level, temperature, humidity, wind velocity, and wind direction. The measurement uses several sensors installed in the system, such as an MQ-7 sensor, MH-Z19 sensor, TGS2600 sensor, DS18B20 sensor, DHT22 sensor, wind direction sensor and wind velocity sensor. The station needs energy availability to work continuously.

The proposed system measures the energy availability in the station's batteries, solar irradiance, current, and voltage values. Therefore, this station can be terminated if the energy is not enough. The irradiance sensor evaluates the data using the pyranometer method [6], which measures the value in w/m^2. In this paper, an irradiance sensor was developed with a mini 0.3W solar power, a ds18b20 temperature sensor [7], and INA219 current module [8]. The irradiance data is calibrated based on the values at the irradiance sensor [9], which was compared to the Lutron Solar Power Meter values.

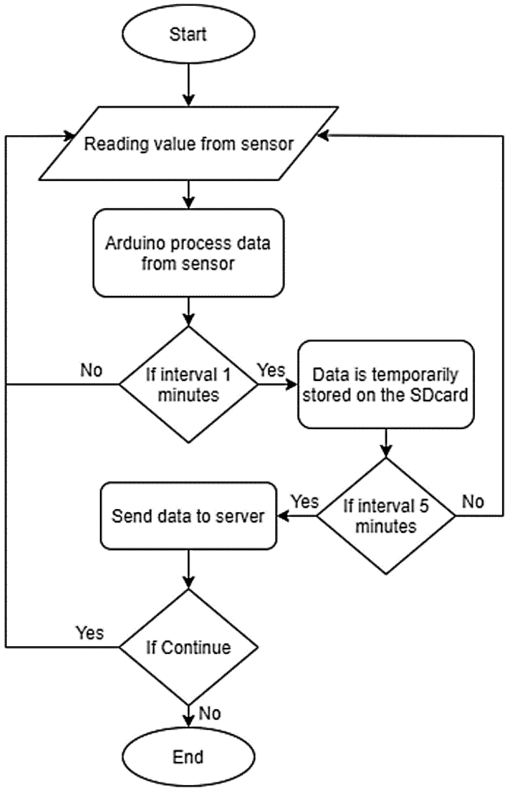

Figure 1: Flowchart of the proposed monitoring system

The EMS was also equipped with three ACS712 current sensors [10]. The first current sensor was installed at the solar power system's input to measure the current flowing at the 30 Wp solar panels. This solar panel produced a maximum current (Imax) of 1.3A. The second current sensor was mounted to the 40 Ah battery of the solar power system. The third current sensor was mounted to the load of the solar power system, which measured the total current consumed by the environmental monitoring system. Also, two types of voltage sensors were installed in the environmental mobile station. The first was HVSR25 to measure the voltage on the solar power system. The second type, INA219, measures the voltage on the battery and load. The measurement data was processed by Arduino Mega Pro microcontroller as the Central Processing Unit (CPU) and was also displayed using Nextion Human Machine Interface (HMI). All these modules worked as the load of the energy usage monitoring system.

Since the EMS worked far from the WiFi network, the proposed system sent the data to the server using General Packet Radio Service (GPRS) communication module, i.e., SIM800L. This module has high-speed data transfer and can maintain stable communication [13]. The data was sent to the communication system via the nRF24 radio module, which can transmit data up to 2.4 GHz [14]. The communication system was developed using ESP32 to communicate with the server. Figure 2 shows the block diagram of the proposed system. This system was original and has been tried out at the Department of Electrical Engineering, Universitas Negeri Malang.

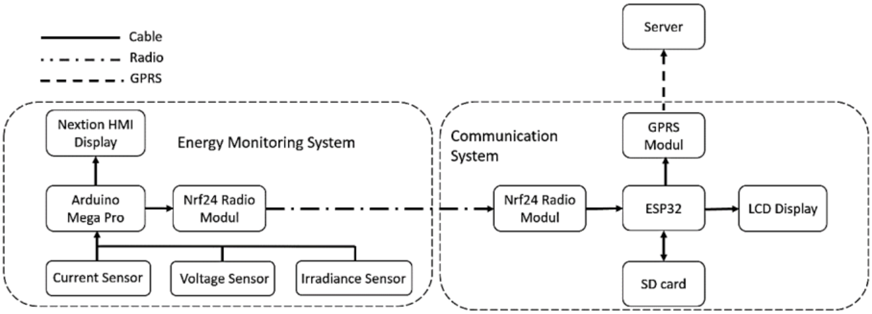

Figure 2: Block diagram of the proposed energy usage monitoring system

2.2 Calibration Process

The calibration process was carried out to verify values that were measured by sensors and compared to the instrumentation tools. A similar procedure was performed on voltage, current, and irradiance values using two measuring instruments: UNI-T UT210E Clamp Meter and Lutron Solar Power Meter. A linear regression formula was used to calibrate the measurement data [11]. The result is presented in Table 1, and the calibration process example is shown in Figure 3. The y represents the calibrated value, while the x represents the sensor value. The equations in Table 1 were applied to the CPU to adjust the sensor values following the standard values of instrumentation tools.

Table 1: Equation data of each sensor

Sensor	Equation
Irradiance	y = 0.0143x + 81.871
Solar power current	y = 0.8820x + 0.0210
Solar power voltage	y = 0.9876x + 0.0983
Battery current	y = 0.9720x + 0.0090
Battery voltage	y = 0.9830x + 0.1900
Load current	y = 1.0027x + 0.0185
Load voltage	y = 0.9862x + 0.0440

(a) (b)

Figure 3: Calibration process (a) measurement using a standard tool, and (b) measurement of the developed system

2.3 Evaluation of Data Communication

Data communication evaluation is a process to verify whether the transferred data is received correctly or not. The data processed by Arduino Mega Pro was sent through radio communication nRF24 to ESP32. Data measurement from the sensor was float data type with four bits for each, as shown in Table 2. Since there were ten variable numbers, the total length was 40 bits. This length exceeded the maximum transmission capacity of nRF24 radio communication, which is 32 bits. Therefore, it was necessary to divide the data length into two sessions. The first session sent 16 bits of data length into four variables: 1) irradiance, 2) solar power current, 3) solar power voltage, and 4) solar power energy. The second session sent 24 bits data length consisting of six variables: 1) battery current, 2) battery voltage, 3) state of charge, 4) load current, 5) load voltage, and 6) load energy.

Table 2: Data measurement format

Variable	Data type	Unit
Irradiance	float	W/m^2
Solar power current	float	A
Solar power voltage	float	V
Solar power Energy	float	W
Battery current	float	A
Battery voltage	float	V
State of Charge (SoC)	float	%
Load current	float	A
Load voltage	float	V
Load energy	float	W

The data communication from Arduino Mega Pro to ESP32 was carried out as a method shown in Figure 4. First, Arduino Mega Pro sent the data from the first session. When the data length was detected at 16 bits, ESP32 would acknowledge the data to the Arduino Mega Pro. After the first session met a success, the second session began with

Arduino Mega Pro sending data to ESP32. Next, ESP32 sent acknowledgment data again to Arduino Mega Pro after detecting a data length of 24 bits, as shown in Figure 5. Once the two sessions performed their work correctly, the data transfer between Arduino and ESP32 was declared successful.

The communication system gathered the received data every minute and was temporarily stored in the internal memory. After five minutes, the stored data was sent to the server through a GPRS connection using TCP/IP protocols in the context of IoT [12]. Finally, the data was displayed on web monitoring to monitor them through the internet connection.

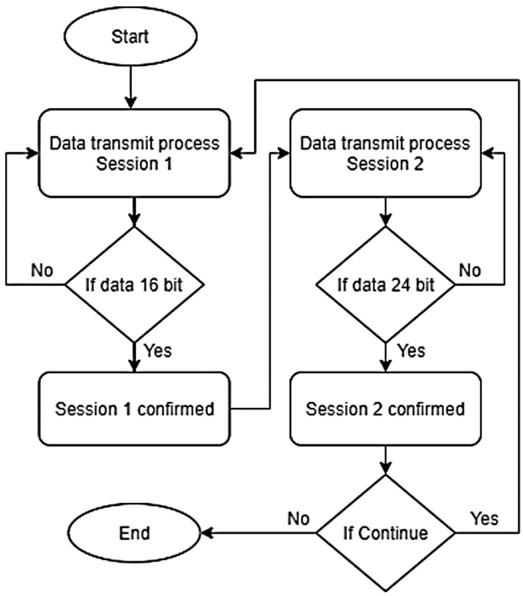

Figure 4: Data communication from Arduino Mega Pro to ESP32

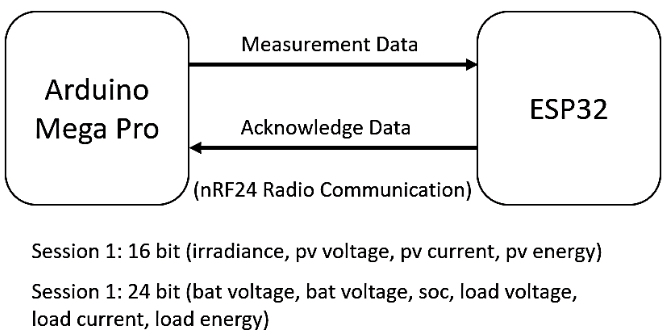

Figure 5: Data communication method

3.0 RESULTS AND DISCUSSION

This section presents the results of developing the system utilization implementation on the environmental mobile station.

3.1 Results of Developing Monitoring Energy Usage

The monitoring hardware in this study can be seen in Figure 6. The hardware consisted of three parts: 1) a Nextion display, 2) an irradiance sensor, and 3) a terminal connection. Figure 7 illustrates the display's four menus: 1) solar power monitor, 2) load monitor, 3) battery monitor, and 4) irradiance monitor. The monitor showed the real-time voltage, current, and energy levels measured by sensors and were updated every 100ms. The irradiance sensor measured the solar irradiance level, which was connected directly to the hardware and installed beside the solar panel. Terminal connection of the energy usage monitoring system was used to connect Arduino Mega Pro to the solar panel, battery, and loads. Voltage and current sensors were installed in the system box and should be connected to the measured parts.

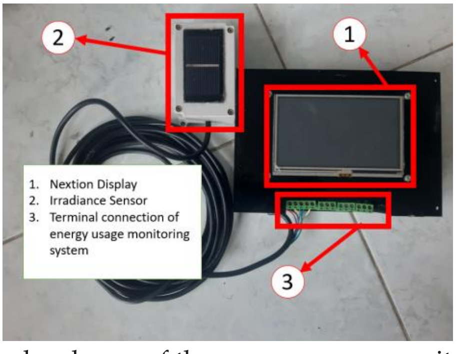

Figure 6: The hardware of the energy usage monitoring system

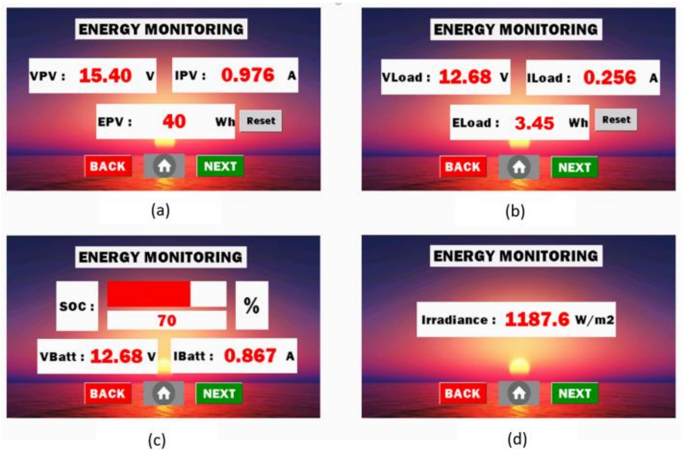

Figure 7: Display of monitoring menus (a) solar power monitor, b) load monitor, c) battery monitor, and d) irradiance monitor

This study's energy usage monitoring system was tried in March 2020, from 7:59 until 17:18 in Malang City, Indonesia. The try-out data consisted of the measurement data of solar power (Power PV) production and irradiance data, as displayed in Figure 8. The energy availability data in batteries is presented in Figure 9, and the load consumption data from EMS is illustrated in Figure 10.

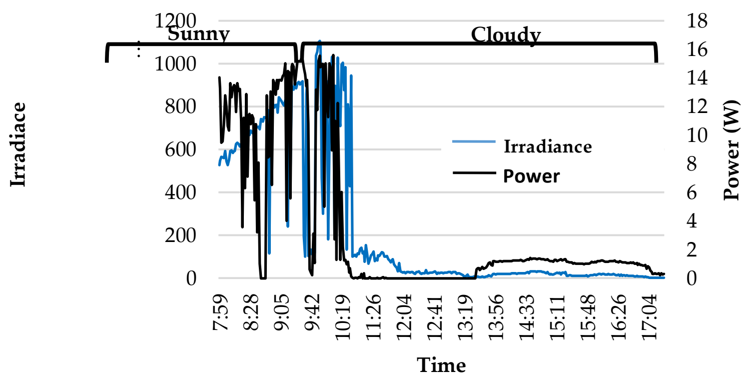

Figure 8: Sample data of solar power production

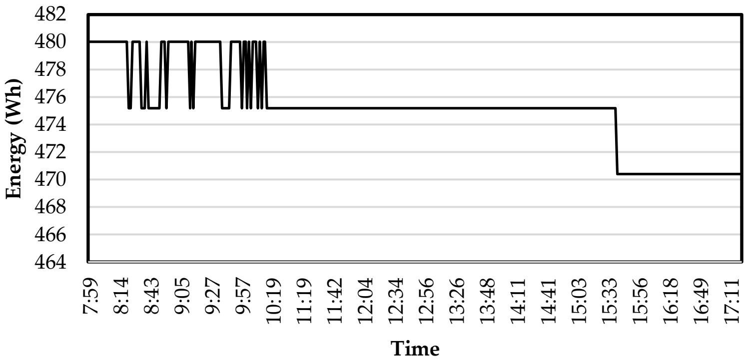

Figure 9: Battery energy availability

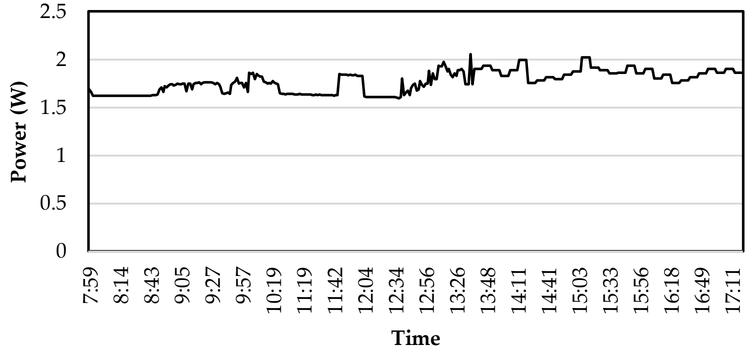

Figure 10: Load consumption

3.2 Analysis of Energy Usage Monitoring System

Regarding the data in Figure 8, the value of solar power production ranges around 14 W, while the irradiance values range from 500-1000 w/m2. The data shows several surges due to overcast on the solar panel. It was raining around 10:12, which dropped the irradiance values to zero and decreased the values of solar power production. Therefore, the amount of produced energy by solar power depends on the weather condition, as stated in [13].

Regarding the results presented in Figure 9, the energy availability in the battery can be explained as follows. The battery is at full capacity with a peak value of 480 Wh, or equal to the State of Charge (SoC) of 100% before 10:12. When solar irradiance has high intensity, the solar power system can produce abundant energy for charging the battery. As the solar irradiance dropped after 10:12, the energy value of the battery could not be maintained since the solar power could not harvest energy appropriately. Typically, the energy harvesting should be greater or equal to the load consumed [14].

During the charging and discharging process, the load of the environmental monitoring system still worked despite the overcast. The load consumption is shown in Figure 10. The maximum load consumption is about 2W. Therefore, the energy consumption of the load affected the battery's capacity, and the battery voltage value went down during the discharging process. All the data has proven that this monitoring system could measure environmental conditions. It was confirmed that energy usage could also be monitored to evaluate energy availability when the EMS is working. The proposed system could estimate energy availability to obtain the desired utility within various environmental conditions [15].

4.0 CONCLUSION

The proposed energy usage monitoring system was used to measure the available energy for the EMS. Here, the proposed system measured the battery's energy and directly monitored the data at the station and through the web server. This system was equipped with a solar power system as the energy source harvested by solar panels and consumed by the load. The results showed that the energy usage monitoring system could measure the energy availability representing the energy profile of the EMS. When the irradiance values ranged from 500-1000 w/m, it produced the harvesting value of solar power within the range of around 14 W. This study found that the energy management system could be monitored through solar power production, energy usage in battery, and load consumption of the EMS.

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