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Low-cost IOT based Energy Monitoring System (EMOSY)

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ABSTRACT

Energy monitoring system becomes an important subject to provide information of electricity usage for the users. Due to advances in electronics and computing, many technologic solutions are now available. These solutions are very important tool to a sustainable future. Hence, this paper presents the digitization of a low-cost small-scale energy monitoring systems based on IoT. The proposed energy monitoring system known as EMOSY is designed to eliminates the high-cost energy meter. EMOSY is a portable and practical system which can be used without modification of internal or external connection of appliances. EMOSY is developed by using a voltage detector circuit concept by amplifying the existence of electrostatic. This electrostatic reading sends to the database through Wi-Fi module ESP8266 integrated with Arduino NodeMCU. The web page is designed using Adobe Dreamweaver with HTML and PHP coding. In the proposed system, the user able to monitor the energy usage of each appliance and estimated billing time to time. Based on the result, the energy monitoring system successfully can detect the existence of electrostatic, and the webpage database can display the energy usage extended to the estimated electricity bill. The monitoring system is found to be useful to the residential, commercial, and industrial to monitor energy patterns, which is essential to facilitate energy conservation measures for minimizing energy usage.

Keywords: — IOT energy monitoring, Arduino, Electronic sensor, Energy meter, Energy management

1. INTRODUCTION

In recent times, the increase in electricity consumption has increased significantly and therefore required a significant increase in energy supply in the coming decades due to the growing population and economic development. Energy monitoring is a tool that helps you understand and visualize your energy consumption. Unmonitored energy leads to a supply and demand deficit [1]. With the rapid development of information technology, especially the Internet of Things (IOT), it is now possible to create a more effective energy monitoring system by providing real-time energy consumption data. Internet of Things or IoT is a concept where equipment, machines, sensors and devices are connected via the Internet or any network. Using the Internet of Things, information between devices is collected and transmitted to humans through the network, making people's lives easier and smarter in many aspects. It has been applied in many fields such as industry, agriculture, transportation, medical care system and home automation. IoT applications have recently been integrated into smart energy, smart grids and smart cities [1]. In order to support smart energy applications, a small device for monitoring the energy usage of the Internet of Things needs to be developed.

Smart meters are usually installed on the main switch board (MSB) of residential, commercial, and industrial to monitor power consumption. After installing the smart meter, the energy consumption of the building can be easily monitored by the person in charge, but the cost of the smart meter is very high. In addition to the price of equipment, data collection has also become

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critical, where data collection only displays average data for the entire building, rather than average data for each specific area or electrical equipment. Therefore, in order to overcome these limitations, researchers focus on developing small energy monitoring equipment with the concept of the Internet of Things at the lowest cost.

An enormous amount of work has been carried out in the development of a smart meter monitoring system. The automation of measurements of electronic meters named AMR (Automated Meter Reading) [2-4], advanced metering infrastructure (AMI), or smart energy meter with real-time energy information report was introduced in many developed countries with implementation at the household level. The AMR is a concept that allows devices to be accessed remotely and capture electronic data provided by meters installed at the customer units. The data can be captured either using unidirectional mode or bidirectional mode [5]. The difference between smart meters from traditional energy meter devices is by their communication ability. The advances of energy monitoring help consumers see their real-time usage, eventually encouraging them to use less energy to save money [6-8]. In addition, studies have suggested that more energy can be saved or decreased at the household level with real-time energy consumption feedback compared to conventional indirect feedback like monthly bills [9-11]. However, those smart meters are usually high cost and require a large communication medium infrastructure; hence, these might not be efficient and affordable in many developing countries.

Cheddadi et al. [12] proposed a cost-effective open source IoT solution that uses ESP322 microcontrollers and low-cost sensors to monitor solar photovoltaic systems. The proposed design has basically been found in low-cost edge sensing methods, open-source software and processing technologies. A. Baruah et al. [13] Developed a real-time power monitoring system (PMS) that can measure energy consumption in the home. The proposed method is an upgraded version of the traditional system, where the NodeMCU is connected to the LED of the existing meter. The recorded readings are uploaded to the cloud and stored in Google Sheets. The recorded data is transmitted to the cloud through the Wi-Fi module on the NodeMCU in the real-time clock (RTC) module every hour. By using PMS, consumers can monitor their energy usage through mobile applications. For users who do not have an internet connection, the system provides a GPRS/LTE connection as an alternative way to monitor their power consumption. Similar work has also used Arduino as the microcontroller in the monitoring device to reduce the human error of charging electricity bills [14].

Various studies have been published examining the impact of energy usage for the entire building or any particular area. There are limited studies on the monitoring energy usage at the appliances used. Researchers [15-16] focus on developing the energy consumption at measuring plug or appliances. The monitoring device is developed to monitor and control the energy usage of appliances in real-time by using microcontroller and Wi-Fi modules to transfer the data collected to the mobile. Similar work was also carried out by [17-19] using a Raspberry Pi as a microcontroller and cloud-based system to monitor the energy consumption through android and iOS applications. Besides the mobile application, the monitoring data also can be display through the webpage using an open-source IoT cloud platform. Researcher [20-22] uses the Thingspeak IoT cloud platform to fetched and analyse electricity usage. The user can monitor their energy consumption and their bill usage by using a unique Id from the web page.

In conclusion, based on the review, the monitoring device should monitor electricity usage to save money. Literature reviews have indicated several methods or intended to monitor the energy consumption using microcontroller and Wi-Fi module at low cost. Most literature designed devices that need the device to be installed to the appliances or at the meter. This paper proposed a small-scale IoT device for monitoring electrical energy consumption in an office building. It was designed in a low-cost and user-friendly device. The proposed design can be conveniently attached to the appliances to support efficient energy management.

2. METHODOLOGY

Our proposed methodology aims to develop a small-scale and low-cost solution for an energy web-based monitoring system that capable to detect the ON or OFF state of any appliances, send the data to the server, monitor and record the energy consumption in the web database. The system is the application of the IoT concept known as the Energy Monitoring System (EMOSY). Figure 1 shows the system overview of EMOSY consists of an antenna, electrostatic sensor, microcontroller NodeMCUV3, a database, and a website monitoring page.

The electrostatic sensor is not used to measure the power consumption of any electrical appliance, but to detect whether there is static electricity on the electrical appliance. The detected static electricity will be used to indicate whether the device is turned on or off. Compared with the closed state, if the appliance is turned on, the static electricity reading will be higher. The electrostatic reading is converted into digital form by a microcontroller with built-in ADC function, and sent to the database through the WiFi module ESP8266 integrated with the Arduino NodeMCU. Every time data is sent to the database, the date and time the data was captured is also saved in the database. Therefore, the total time that the appliance is turned on can be calculated. Calculate energy consumption by knowing the wattage information of electrical appliances. The data saved in the database will be displayed on the interactive website page.

The electrostatic sensor is a device to detect the electrostatic field from the appliances. For this sensor development, the concept of voltage detector is applied. A conductor carrying a current produces a small magnetic field around it, while the type of magnetic field depends on the type of current flowing through the conductor. The principle of this electrostatic circuit is to detect this changing magnetic field and indicate the presence of the voltage. In order to detect the voltage, three cascade NPN transistor 2N2222 is used. The collector-to-emitter current in the transistor is determined depending on the amount of base current. The current gain for the transistor used in this project approximately 200 which is the ratio of collector-emitter current to the base. The electronic sensor circuit consists of 3 transistors (2N2222), 3 resistors (1 MΩ, 100 kΩ and 220 Ω), and an antenna. An antenna is connected to the base of the first NPN Transistor. Once the antenna is close to the electrostatic field, a small current (electric induction) will be induced in the antenna, and then amplified by the first transistor. The amplified signal will be transmitted to the second transistor, and the second transistor will amplify it again. The amplified signal is then passed to the third transistor for another amplification. From the amplified signal, the output signal is sent to an analog input pin of the microcontroller NodeMCU. This signal will be converted by 10 bits of Analog to Digital Converter (ADC) build in NodeMCU

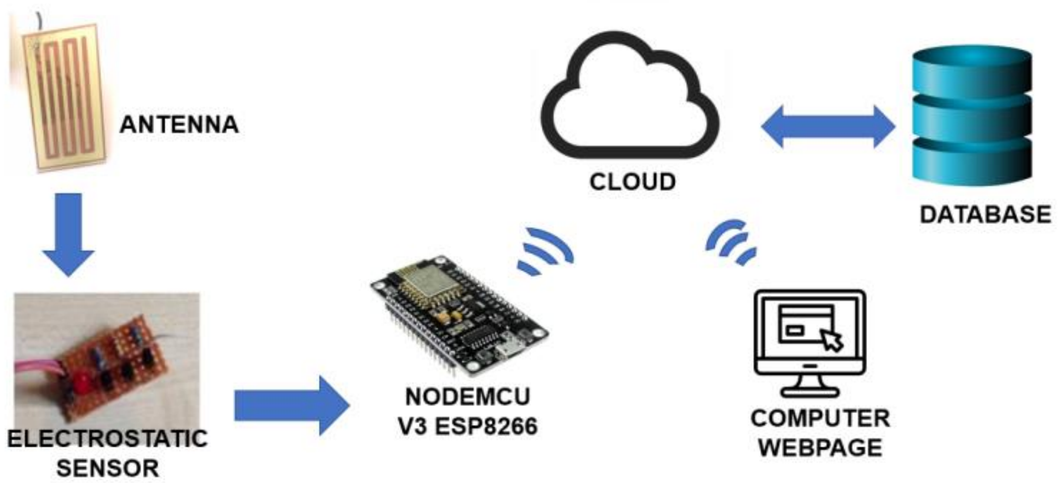

Figure 1. System overview of Energy Monitoring System

ESP 8266 is a Wi-Fi module used to transmit data/signal from NodeMCU to the database in a web server. The ESP8266 Wi-Fi module is a low-cost Wi-Fi module that works on 802.11b/g/n protocol and build-in in NodeMCU. In this project, NodeMCU is programmed to read data from the sensor and sends it to the database via a Wi-Fi module every 5 minutes. The Wi-Fi module needs to be initialized with local Wi-Fi SSID and password prior to communicating with the database server.

These data send to the server from node MCU through Wi-Fi module ESP8266 in decimal value from 0 to 1024 representing the strength of electrostatic field detected on appliances. This value indicates the status of the ON or OFF state of the appliances. These values vary from one appliance to another. It also varies depending on the distance between the antenna and the appliance's power supply unit. Therefore, a calibration procedure is necessary for every installation of new appliances. The calibration process is used to determine the decimal value of the data which determined the ON state of the appliance. The calibration is done on the website by setting a high threshold and low threshold value. The high threshold value is the minimum value that indicates the appliance is in an ON state. Meanwhile, Low Threshold is the maximum value that indicates the appliance in an OFF state.

Based on the data saved in the database, the duration(time) of the ON state is calculated. Each data represents duration (5 minutes) and further converted in form of hours for energy calculation. The conversion is done on the website page using HTML and PHP coding. For the electricity bills, the estimated billing is calculated based on tariff rates provided by Malaysia utility company, Tenaga Nasional Berhad as shown in Table 1. The calculation of energy consumption is based on the following formula:

$$Energy = P \times t \quad (1)$$

Where;
P = Appliances power rating (kW)
t = Appliance usage hour (h)

Table 1 Tariff of Domestic Category in Malaysia

Tariff Category	Unit	Current Rate (RM)
1-200 kWh/ month	Sen/kWh	21.80
201-300 kWh/ month	Sen/kWh	33.40
301-600 kWh/ month	Sen/kWh	51.60
601-900 kWh/ month	Sen/kWh	54.60
901 kWh onwards/ month	Sen/kWh	57.10

3. RESULTS AND DISCUSSON

3.1 The Prototype

Figure 2 shows the prototype of the EMOSY. The size of the EMOSY is designed as compact as 9 cm x 5 cm. The hardware part was designed to be portable and practical which can be placed at any position on the appliances. There is no modification of internal or external connection of appliances which can void any warranty of appliances. The placement of this EMOSY is different for each appliance. The determination of placement is based on the signal strength detected by the antenna. This process is needed to be done prior to the installation of the device on any appliances. The printed circuit board (PCB) of energy monitoring system (EMOSY) was fabricated using the Proteus 8.5 software. The 3D visualization image is shown in Figure 3 and was made in a single layer only.

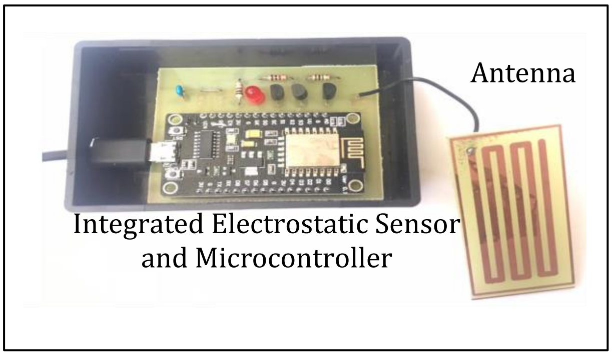

Figure 2. Prototype of EMOSY

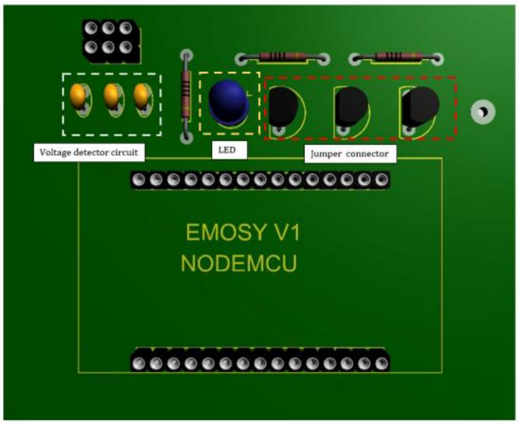

Figure 3. 3D Visualization

3.2 The EMOSY Webpage

Figure 4 shows the main dashboard of the webpage that shows the total energy and billing for all noids. The experimental results showed that the developed energy monitoring system has been successfully recorded the sensor reading for ON state and OFF state of any appliances. The result also shows the system able to calculate in the real-time estimated power consumption of any appliances based on the total duration (time) of the ON state. The actual total cost also has been successfully calculated for each appliance. In addition, the cumulative power consumption and cost for all appliances used in the project also able to be displayed separately.

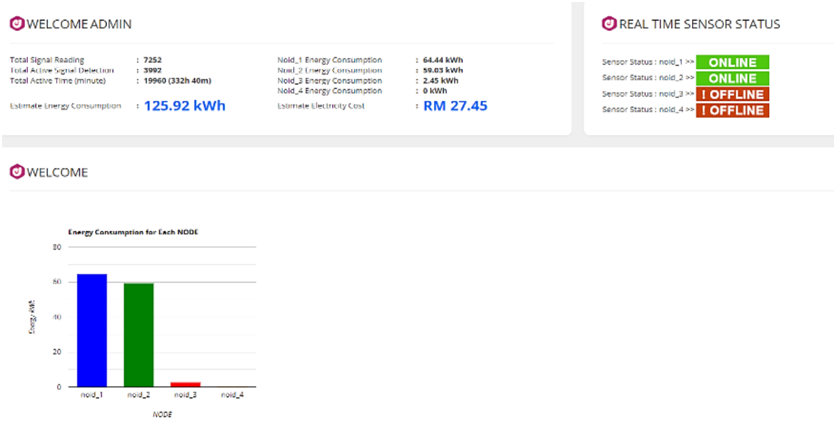

Figure 4. Homepage of energy monitoring system (EMOSY)

3.3 Simulation Results

The website page of this project is developed in two different parts. The first part is used to display a real-time graphical representation of daily, weekly, or monthly data for each node. Node is the label name used to identify each set of sensors and microcontroller. In this project, 4 sets of nodes have been developed for 4 different appliances. However, for this experiment, only two nodes (noid_1 and noid_2) are used to monitor two different appliances which are a computer and 1Hp air conditioner. The second stage involves a real-time display of total energy consumption for each node and estimated electricity costs for each node. The web page was designed using Adobe Dreamweaver with HTML and PHP coding. MySQL language is used to communicate and manipulate data in the database server. For testing purposes, Xampp was installed and used to create localhost on the local computer. A log-in page has also been created to provide users with a secure environment and provide secure access to web data.

Figure 5 and Figure 6 show the voltage detection data of the computer and 1Hp air-conditioner respectively. The sensor sends the analog value and the microprocessor converts the signal into digital form (10 bits ADC). The calculation of voltage detection value is shown in equation (2).

$$\text{Voltage detection value} = ((\text{digital read})/1024) \times 5V \quad (2)$$

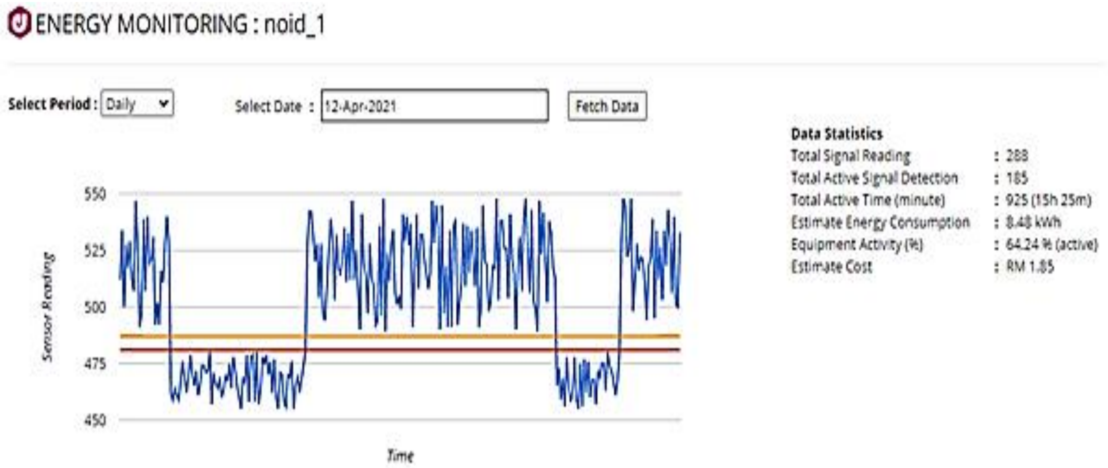

Figure 5. Threshold values setting for computer

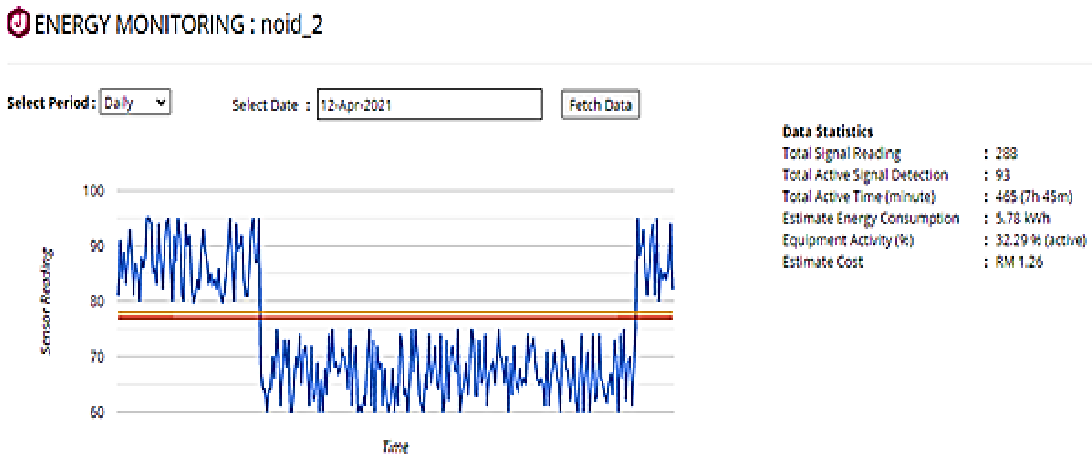

Figure 6. Threshold values setting for air-conditioner

Table 2 Threshold value and estimated energy consumption for noid_1 and noid_2

Noid	Status	Threshold Value	Estimated Energy Consumption (kWh)
Noid_1	ON	>487	64.44
	OFF	<481	
Noid_2	ON	>78	59.03
	OFF	<77	

After installation of any node on appliances, a calibration procedure is necessary to be done to determine the correct value of high threshold and low threshold. These values are different for each appliance depending on the signal strength detected by the sensor. During calibration process for noid_1 (computer), the data sent to the database are above 487 while the computer is turn ON. If the computer is turn OFF, the values are below 481. Therefore, the high threshold value for noid_1 is set to 487 and the low threshold value is 481. The setting can be done on setting page of the website. The same procedure is done for noid_2 (air conditioner). The high threshold and low threshold for noid_2 is 78 and 77 respectively. All data was tabulated in Table 2. From the data logging period, the energy usage of the computer and air-conditioner are calculated thus the total billing is calculated as shown in Figure 7 and Figure 8. For this experiment, the data is logged from 10 April 2021 to 19 April 2021.

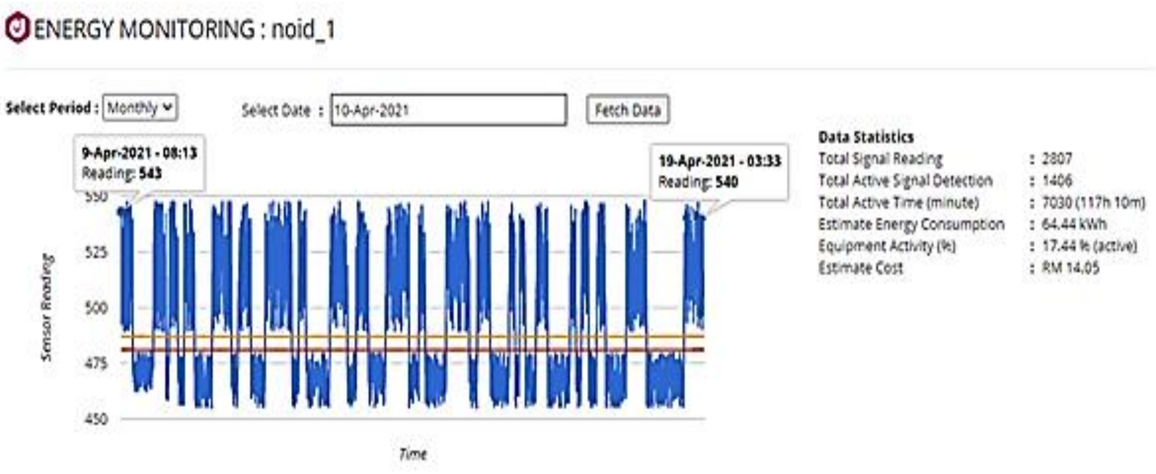

Figure 7. Energy consumption for noid_1

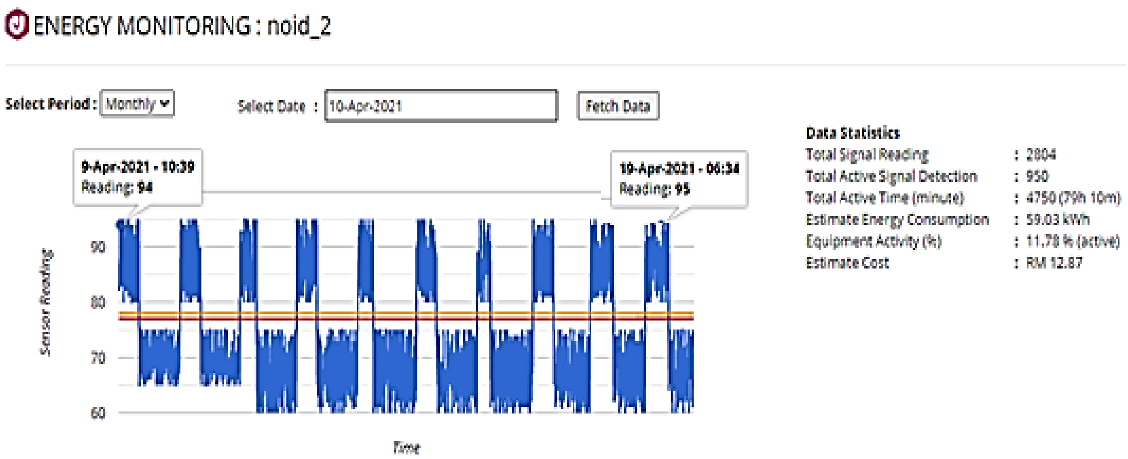

Figure 8. Energy consumption for noid_2

4. CONCLUSION

A small-scale monitoring system with IoT called EMOSY has been developed for energy monitoring purposes. It was designed to be portable and easy to place on any device without any modification on the appliances. These attributes give a great advantage for EMOSY since installation on any appliances would not void any warranty of the appliances. The EMOSY used an electrostatic sensor to sense the appliance's electricity, and the reading is sent to the database to be saved in real-time. Therefore, the information displayed on the website is in real-time. User can always check and monitor the electricity usage in real-time which give the real-time performance of energy monitoring. The sensor used in EMOSY to detect electrostatic is very simple by using the transistor amplification concept. The prototype of the EMOSY is designed with compact size with an integrated microcontroller and WIFI module (nodeMCU). Finally, the EMOSY can provide the user an effortless system to monitor the energy consumption of the appliances at a low-cost value. Total cost for 1 set of EMOSY is estimated around USD 15 which is much cheaper compared to commercial device cost around USD 1000. With size less than a credit card and the cost less than RM65.00, a small-scale and low- cost energy monitoring system has been successfully developed and tested.

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