IoT-Based portable modules for energy consumption monitoring in smart home system

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Abstract. Energy consumption has become one of the major problems in Indonesia. The use of recent technology is highly beneficial since various automation could be done even in simple devices. In this research, portable smart home modules based on the internet of things (IoT) technology to monitor the power consumption in household electrical devices were built. The module consisted of current sensors, voltage sensors, and IoT Wi-Fi Development Board. It communicated with the server, built using the Raspberry Pi, using the MQTT protocol. The server was equipped with web pages that allowed users to monitor the devices' electrical power usage. Therefore, all of the connected modules could be monitored to provide information regarding an electric household device's defect. The results had shown that the prototypes of the modules had been successfully built. It was shown that very slight differences were found between the system measurements compared to the manual one using the 60 seconds interval measurements. The power consumed by the module was very low, where the current sensor uses 0.125 Watt while the voltage sensor uses 0.001 Watt. The portable devices were developed in the shape of small boxes; therefore, it could be easy to move and install.

1. Introduction

Internet refers to the entire communication network that uses electronic media. Since it emerged for the first time, the internet continues to be explored and developed further by experts. It was known that several companies labeled technology with different terms. General Electric (GE) had used the term "Industrial Internet" for the industrial purpose of the Internet of Things while Cisco called it the Internet of Everything, while others named it the Internet 4.0 [1]. Furthermore, the internet functions in finding information and accessible through special-purpose built devices and using any devices connected to the internet, including any electronic objects connected to local and global networks through embedded sensors [2]. It brings advantages to the connected devices to be run and active every day.

Internet of things (IoT), a global network infrastructure, connects physical and virtual objects through data communication over the network, capturing data using sensors. The technology refers to and utilizes an electronic device that will later communicate through an internet network [3]. Its implementation, such as smart home, is beneficial since various automation could be done, which reduces the intervention of humans that reduce the risks of human error. Smart home with devices set for operating the house "smartly" will control the electric power usage through efficient usage of the household devices.

Indonesia is one of the countries with a high level of energy, in this case, electrical power. Indonesia's energy consumption is continuously increasing, with the industry taking the most use with
34.8%. Meanwhile, the household was in second place with 30.7% of the electrical power. However, it is shown that Indonesia is one of the countries with a high level of energy-wasting [4]. It means that the high consumption is not balanced with the wise use of the energy, in this case, the electrical energy. Therefore, energy efficiency becomes the main focus of our study.

The practical and efficient use of energy has become one of the significant issues widely discussed globally. Data from the ASEAN Center for Energy (ACE) showed that households’ electrical energy use was second of the most energy usage, behind industrial use. Furthermore, the waste of electrical energy is high if there is no control over electrical power or energy [5]. Smart home technology is one of the solutions to tackle such problems. The technology can help people in management and controlling the process within the house. Research on smart home implementations has been done, and most are in the form of home automation [6]–[9]. It focused not only on the products themselves but also on supporting technologies such as network connectivity [10]–[12]. It means that proper management of the devices and sensors will provide the optimal advantages of the smart home technology itself, in the sense of power or energy consumption.

Home automation using various devices such as a PLC embedded control system or single-board computer, like Raspberry Pi [13], could be utilized to provide control to home devices through the internet [14], [15]. An application could be built to translate the commands given by users, such as SMS, into the microcontroller protocol to be sent to an Arduino device [16]. The researchers found that the distance does not affect the system response time.

Aryanto [17] has provided an implementation of Raspberry Pi in an IoT-based system that could dynamically manage and control modules with specific tasks, in this case, monitor the consumption of household electrical power. The built system can be installed in any household electrical devices. However, the prototype still required some space, and therefore it was less ergonomic to be installed or not readily movable and vulnerable for the exposures of the exterior materials such as water or dust. Portability is the essential requirement of easy to use and to move yet maintain the effective use of technology. Like mini-computers and sensors, some products have been massively produced with various available upgrades for its functionality while supporting this feature. Such devices could provide more than just the essential operation of a computer and, therefore, can build a system that can support high mobility. Raspberry Pi is a mini-sized computer the size of a credit card developed in the UK by the Raspberry Pi Foundation [18]. Its ability to do sophisticated tasks and its advantages in size enables it to be used in various research projects that raised the IoT as their main topics [19]. The mini-computer can also be combined with other microcontroller devices or sensors to further explore its ability to solve such problems using IoT technology.

This work was focused on developing a set of portable devices equipped with the appropriate IoT-based application, where device modules can be easily connected to a residential network with the simple yet secure authentication mode. A small server was built using the Raspberry Pi to manage the house's registered electronic devices with its management modules.

2. Method
This work was done based on the approach that was adapted from the prototyping methodology. It was started with the initial requirement analysis, where all of the needs of the system to be operating were appropriately listed, described, observed, and collected. After all of the requirements were fulfilled, the cycle of processes then began. In the approach, the researchers divided the cycle phases into two, the hardware and software processes.

The software was developed using the basic prototyping methodology. More specific analysis for the software requirements was done to ensure that the developed software fit its needs. The planned portable devices' characteristics became one of the critical considerations in our preparation to deliver secure installable devices or modules as the nature of the portability itself. The thorough descriptions led the process to the design phase. The design of the related software was done to guide the development phase later. The hardware development consists of the functional hardware prototyping and the making of the portable container. The functional hardware building was done
following the standard methodology. The two groups of processes were evaluated within the hardware integration before later integrated with the built software. The whole process of system development can be seen in Figure 1.

Figure 1. The stages of methodology that had been conducted in this work.

Two significant parts of the software were being developed. The first one was for automatic communication among devices, and the other part was the one that is used for the monitoring processes since the main task of IoT technology is to tackle the complicated task with the advantages of automation. The ability of the devices to communicate with each other becomes one of the essential features. In this work, all communication among the devices was designed using the MQTT Protocol [20]. Modules installed in the household electronic devices were designed to actively deliver the devices’ electric power consumption data to the server. The server was designed to receive the designated data received from the sender modules and then stored the data in the database. Later, the data were processed to conclude that the related device was still working correctly or not based on the server's calculation. The information about the electronic device's functionality was accessible through the web-based interface in the server itself.
In this study, three main modules were designed and prototyped: server module, client module, and remote module. The server for the monitoring process of the household electronic devices was run using a Raspberry Pi device. It is a mini-sized computer the size of a credit card developed by the Raspberry Pi Foundation and has become one of the latest innovative brands of electronic products [13]. It communicated with the modules that collected data from the electric devices through the embedded sensors. The reader modules were packed in a container to provide the modules' portability, making it easier to be moved and installed. Furthermore, the remote modules consisted of the infrared peripheral with a simple controller to map specific frequencies to the connected electronic device. The modules were designed to be easily set up regarding the frequency list of the connected electronic devices.

The performance of the built prototype was tested by running the modules in a certain length of time, measured several vital features, i.e., temperature and humidity of a room, the power consumption of the devices, and the measurement's accuracy itself. The measurements were intended to further develop the module itself in maintaining the proper action for the efficient use of electrical power. The measurements were done within a month of use of the modules. The consistencies of the performance of the modules were monitored, and any issues that occurred were documented. The accuracy was measured by comparing the system's measurement results to the manual process done and confirmed by two experts. The electronic devices used in this work were refrigerator, television, air conditioner, and electric fan.

3. Results and Discussions

The system was designed based on the method described in the previous section. There were two main phases of the development, namely software and hardware development. The system's design had several parameters used as an indicator in determining units or electronic devices' functionality, in standard or has malfunction conditions measured by electrical power consumption. Those three indicators were: (1) the flowing current to electronic devices, (2) the temperature within the environment where the electronic devices were operating, (3) the humidity level of the environment of the portable packages. The design was done into two main parts: the design of hardware modules and the design of the software modules, and each was implemented accordingly based on the main phases of the proposed method.

The hardware parts mainly consisted of a controller, mechanical devices, and a data processor. A reader module was designed to read a specific feature of the environment, i.e., humidity and temperature, also the electric current consumed by the electrical device. Each of the readers was equipped with a Wi-Fi board Node MCUESP12-E, mechanical drives, relays, a sensor, and a power supply. Meanwhile, the server was developed by utilizing the Raspberry Pi single-board computer to receive the reader's data through the MQTT protocol. The design of the hardware and its communication using the selected protocol can be seen in Figure 2 below.
The readers were divided into three types of modules, i.e., temperature modules, humidity modules, and power consumption monitoring modules. The tests were performed to provide the modules' accuracy and consistency measurements, connect to the network and communicate with the server. The modules were set in a residential environment, as shown in Figure 3. The tests were done on all of the modules based on the type of modules.

A web-based user interface was developed to simplify the setting or monitoring processes of the connected modules. The webpages were built under the currently available technologies such as PHP, javascript, ajax, and HTTPS protocol to ensure the system's compatibility and implementation in the future. Meanwhile, the communication through the IoT technology was defined under the MQTT protocol. The testing showed that all the data sent by the sensors in all reader modules could be
delivered and displayed within the web pages. Figure 4 below shows that the system’s dashboard was displayed, consisting of two electric power, and one temperature modules were connected.

![Dashboard page of the server, showing connected modules.](image)

**Figure 4.** Dashboard page of the server, showing connected modules.

Furthermore, the web interfaces were pages where users can access the particular function of the system. It can monitor the measurement results done by modules such as the electricity consumption measurements of each module attached to electric devices, the temperature and humidity measurements inside a room, and the number of devices where the infrared sender was attached. The settings of each module could be regulated through the setting page. These settings, including the threshold of average values at a particular time to indicate the electric device is still working correctly or not.

The modules were contained in small boxes, as shown in Figure 5, where it was easy to be installed or moved. It provided the advantages of portable devices’ characteristics. There were four types of modules developed, namely the electrical consumption monitor module, remote module, temperature and humidity monitor module, and the server—all of the modules communicated through the wireless connection utilizing a WiFi-hotspot device, as described previously.

![Developed portable devices.](image)

**Figure 5.** Developed portable devices. (A) server; (B) humidity/temperature monitor; (C) remote module; (D) electrical power consumption monitor
The test result showed that the reader modules, consisting of a sensor, processor board, and wireless communication peripheral, could deliver the server's measurement data. The measurements were done in a 60 seconds interval scheme—the data validated by the experts using the manual measurements of the tested module. There was a slightly average of 3% differences between the system measurements compared to the manual one.

This research was aimed at building portable smart home modules using the internet of things technology to monitor household electrical devices' power consumption. The module consisted of an ACN26 current sensor, a voltage sensor, an MCU Node Module ESP12-E, and an electronic board. The tests were done on household devices, i.e., AC, TV, refrigerator, and ironing. The sensors successfully captured the intended measurements. Two experts confirmed the manual measurements, and therefore, it concluded that the module was following the actual voltages' measurements. The power consumed by the module was very low, where the current sensor itself only uses 0.125 Watt, while the voltage sensor only uses 0.001 Watt. The advantage of this type of hardware is when a portable device can be used immediately without being assembled beforehand.

The security of data transfer, however, was not explored further. The transmission was done using the existing, proven protocols, which can be assumed that data could be preserved safely. Furthermore, the box containers of the built prototypes could be better designed. The development of 3D printing technology could provide a compact design with good functional and aesthetic usability.

4. Conclusion
This work has provided a prototype of portable modules of IoT-based smart homes that can monitor household electrical devices. It provided the automation in turn off the device when it consumed the electrical power inconsistently, indicating the device's abnormality function. A set of portable modules based on the IoT technology was devised to provide data or information regarding the electric power consumption of household electrical devices such as refrigerators, televisions, air conditioners, and electric fans. The reader modules, consisting of sensors, measured the key features correctly and delivered them to the server via the MQTT protocol. The server was also capable of delivering information regarding energy consumption usage using the developed web pages accordingly. The portable devices were developed in the shape of small boxes; therefore, it could be easy to move and installed. The reader modules used current and voltage sensors with an Arduino Nano as the controller. Meanwhile, the server used the Raspberry Pi devices to receive, process, and store data that can be observed through the built web pages. Although there were some differences in the actual measurements, the developed modules' voltages were still under the existing voltages since the difference was minimal.

There are high possibilities in developing this prototype further into a more functional module or system for daily use. The prototype's portability has proven the ease of using the modules to be moved or switched to other electrical devices. Several improvements can be made to gain the developed system's primary goal to reduce electrical power use. However, this study still does not focus on the modules' capability to be used in a very long time. Therefore, further study regarding the system's functionality and modules over a long period could be done. The concept of energy-efficient usage in a smart home can be improved by utilizing more advanced technology, such as low power network connectivity [21].

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