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Smart power switch using internet of things

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ABSTRACT

The increase in electricity consumption coupled with the lack of a convenient way to assist the consumers to lower their electricity consumption is a growing concern. Smart internet of things (IoT)-based devices has been developed in this regard. However, no specific standards were followed, and this is a problem for the consumer as they have to own different smart device from different brands which results in higher cost. To solve these issues, a smart power switch using IoT is proposed. The system consists of microcontroller (ESP32), relay and current sensor (ACS712). The ACS712 measures the current of the appliance. The ESP32 then send these readings to server. Whenever the ESP32 receives switching commands from the cloud platform, ESP32 will activate the relay and hence switching the appliance. The cloud platform is linux based virtual private server (VPS) running on Django Python and structured query language (SQL) ite database. The mobile application built using flutter to allow both iOS and android users to use the app to control and monitor the normal appliances. The server, circuit and mobile application have showed a real-time data exchange, fast response, numerical, graphical consumption presentation and capable of setting energy or power limit for the appliance to not exceed.

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1. INTRODUCTION

The advancement in internet of things (IoT) has sparked the invention of smart devices in a wide range of applications which includes garbage monitoring system [1] and water flow monitoring system [2]. A smart automation system for home based on IoT was recently proposed in [3]. Another such application is energy monitoring system for domestic user. With the growing need to consume electricity more efficiently and the rising awareness among the people to do so, a smart energy monitoring system is a necessity. Yet, there are technical barriers which needs to be overcome in order to speed up the adoption rate of such technology among the people. Firstly, some of the existing energy monitoring system requires multiple smart devices having different user interface (UI)s to control each single device. In other word, the user needs to control each device from a different mobile or web application depending on what the manufacturer has decided to choose. This could translate to higher cost of replacing the existing house appliances with smart appliances as each device comes from different manufacturer which uses different approach to build every single device. In addition, some of the existing systems lacks the energy monitoring feature. In this paper, an economical solution for monitoring and controlling electrical appliances will be presented in response to the gaps found in existing systems in the literature.

Household electricity consumption is expected to grow in tandem with the increase in the number of appliances in each house and the population growth [4], [5]. According to a questionnaire that was distributed among the university students in Malaysia, results obtained from the survey showed that the characteristics of the appliances is the reason behind the increase in the electricity consumption [6]. Furthermore, Covid-19 pandemic has caused an increase in electricity consumption in the residential sector, in the same time the electricity consumption was significantly decreasing in industrial sector [7]. This is due to the implementation of the full lockdown in the world as most businesses and manufacturers were not working during that time and most people stayed at home and worked from home which results in more energy usage in the residential sector.

More to add, according to the data collected in 2019 on the energy consumption of the Europe Union, 26% of the energy produced was consumed by the household. 64% of the consumption was for the space heating, almost 15% went for water heating, 14% was consumed by lightning and other house appliances and the rest was consumed by cooking, cooling spaces and others [8]. According to a questionnaire that was distributed among the university students in Malaysia, results obtained from the survey showed that the characteristics of the appliances is the reason behind the increase in the electricity consumption [6]. An energy management algorithm based on fuzzy logic has been proposed to minimise electricity consumption in a smart home [9].

While it is important for the penetration rate of renewable energy such as solar energy to be increased, optimising the electricity consumption is also a necessity to preserve energy sustainability [10]. A recent study highlighted the importance of orientation of solar panel installation to maximise solar energy harvesting [11]. Various methods were proposed to reduce the energy consumption [12]-[13]. In terms of smart power outlet based on IoT, some progress has been documented in [14]-[18]. IoT-based devices consist of the hardware (i.e. the microcontrollers, sensors and actuators) and software component. Microcontrollers common in the market includes ESP32, Arduino Uno and Raspberry Pi. In this project, ESP32 is selected due to its cost effectiveness and additional functionalities [19]. In terms of communication protocols, WiFi is chosen over others such as Bluetooth, MiWi, Zigbee, LoRa and LTE mainly due to its capability to transmit data over a long distance with high speed as well as its cost effectiveness [20]. The system to be proposed in this paper combines the strengths and overcomes the weaknesses such as complicated design and unfriendly user interface as documented in [14]-[18].

2. METHOD

Figure 1 illustrates the overall methodology of this project. The circuit is designed by integrating a 30A current sensor (ACS712), 5V DC power supply module (Hi-link), ESP32 microcontroller module, 5V relay (single pole double through), 3.3V voltage regulator and several other miscellaneous components as shown in Figure 2. ACS712 is a current sensor used to sense the current applied using an integrated Hall effect based linear sensor integrated circuit (IC) and can be used in automotive industry and commercial applications. Note that all the component used in this project are restriction of hazardous substances directive (RoHS) compliant. RoHS is an initiative that aims to protect the human health and the environment by decreasing the number of the electronic and electrical components which uses hazardous substances [21]. A 5W, 46mA floor lamp will be used as the load.

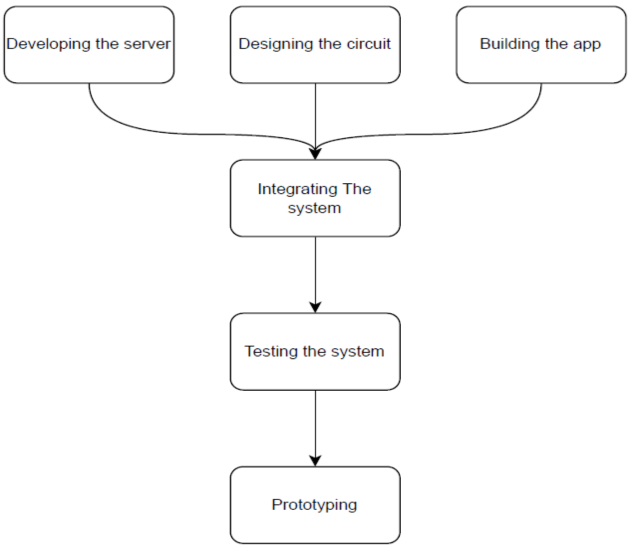


Figure 1. Development process of the proposed system

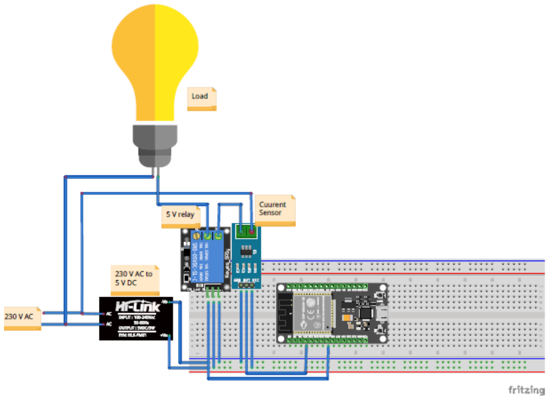


Figure 2. Circuit design

One of the most essential part in any IoT based projects is cloud platform. There is a variety of cloud platforms that are available to choose from such as Google Firebase, Azure, AWS, ThingSpeak, UbiDots, and Heroku. In this project, the decision was to use a linux based virtual private server (VPS) with a server running on Django Python and structured query language (SQL)ite database due to its scalability, consistency, reliability and security. Figure 3 illustrates how the ESP32 interacts with the server.

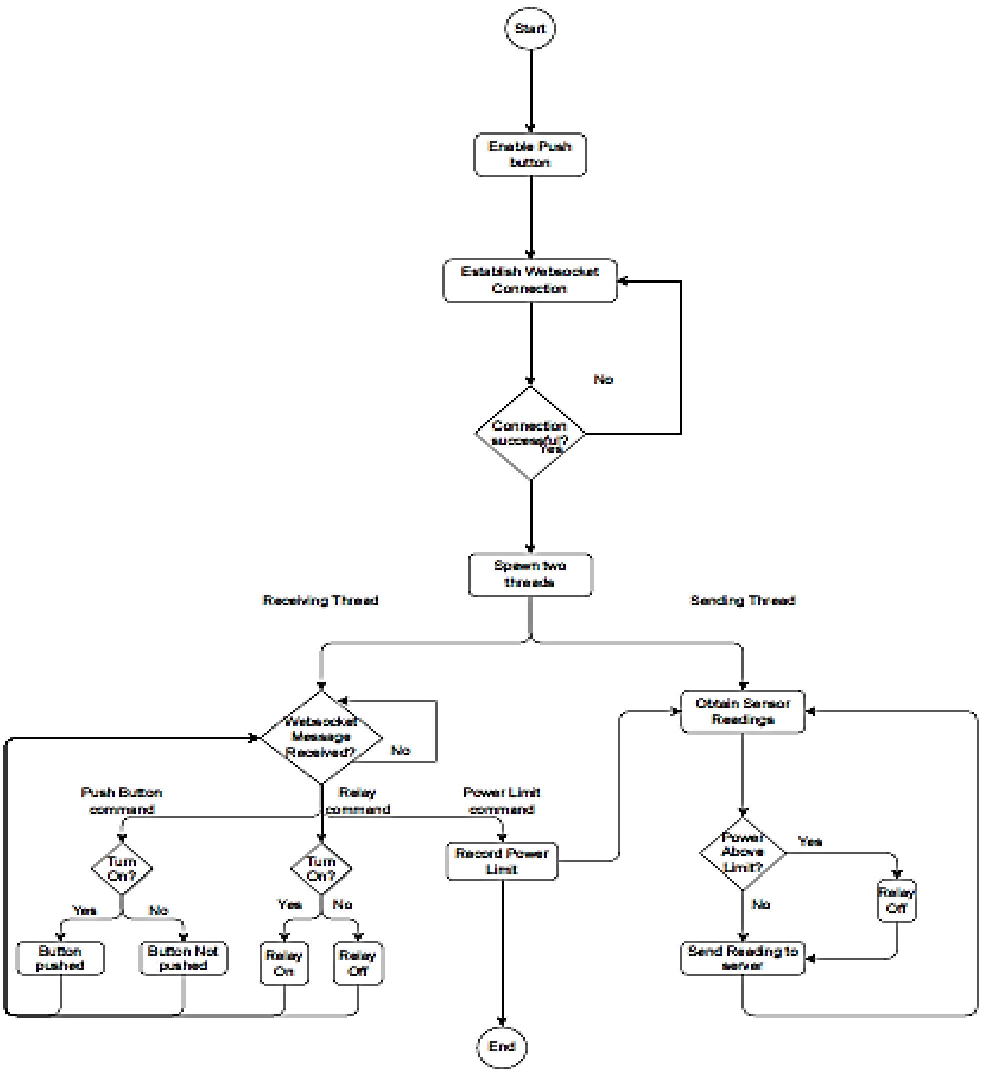


Figure 3. Server and ESP32

Once the power supply is connected to the printed circuit board (PCB), the push button is enabled which means the system is ready to be used in offline mode. The next step is the ESP32 (client) and the server attempt to establish Websocket connection. This step is repeated until there is a successful connection. Then, two threads will be spawned, one for receiving and one for sending. In the sending thread, the ESP32 is responsible for collecting the current values using the current sensor and before sending it to the server in a JSON format, a check on whether the power have exceeded the limit set previously by the user if so the appliance is turned off through the relay, if not the appliance will remain on.

Moving to the receiving thread, once the ESP32 has received a message then this message needs to be identified. There are three types of messages which are push button commands, relay commands or power limit commands. In case of push button command, if it's turned on then the status is updated to the button is pushed and if not, the status is button is not pushed. As for the relay command sent from the server to the ESP32 if it was turned on, the relay will turn on and hence the appliance is turned on and the status is updated to the relay is on and if it's not, the status is changed to the relay is off. The last type of message is power limit set by the user once the ESP32 has received, it will check whether the energy or power have exceeded the limit or not.

As mentioned before, the server is the link between the mobile application and the ESP32. Figure 4 explains the process of how the server interacts with the mobile application. The proposed system uses Websocket instead of hypertext transfer protocol (HTTP). Websocket is bidirectional while HTTP is unidirectional. Both of them uses a client and server communication. However, in HTTP, the client needs to send a request in order for the server to respond hence, it's called unidirectional. As for the Websocket, as long as the connection is alive between the server and the client, both of them will send and update the data without requiring a request to be sent. In other words, Websocket is used whenever a real-time data is required.

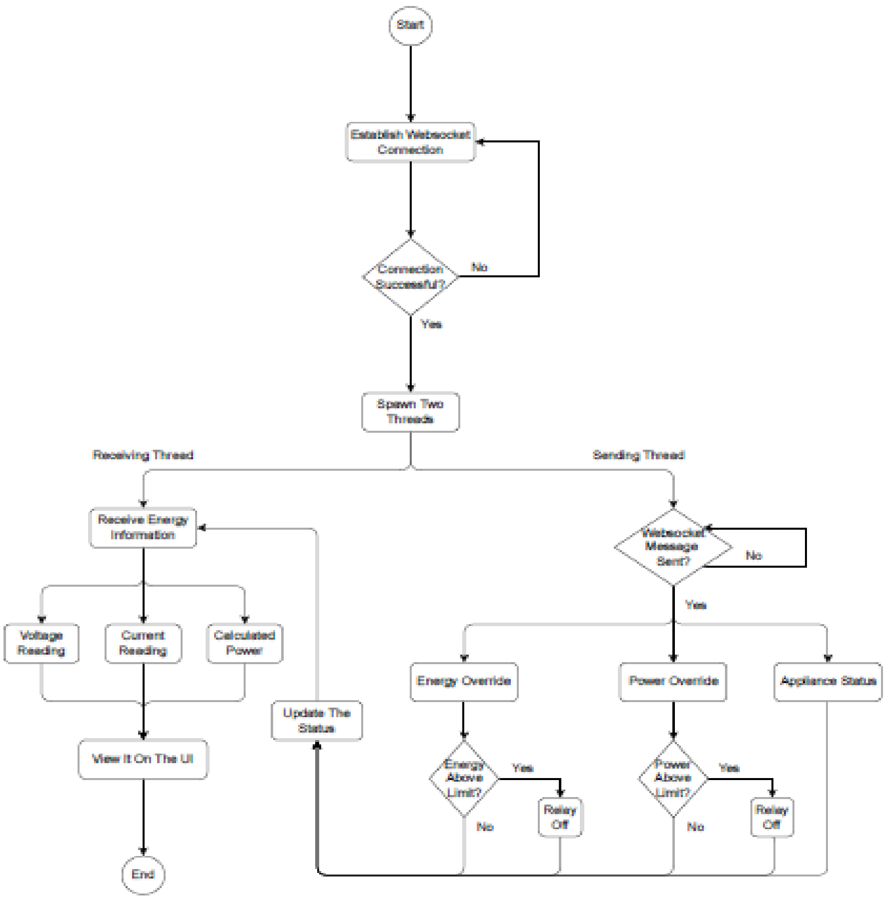


Figure 4. Server and mobile application

As it can be seen from Figure 4, once the Websocket connection is established between the server and the mobile application, there will be two threads sending thread and receiving thread just like the server and the ESP32 in Figure 3.10. There are three types of messages that are sent from the application to the server which are energy override, power override and appliance status. Both energy and power overrides need to pass the test of whether the limit that was set by the user has exceeded the limit. If it did the relay is then turned off if not the status is updated in the server. On the receiving side, the application receives the energy information. The energy information are voltage reading, current reading and the calculated power.

The last important part of the proposed system is the mobile application. The mobile application's role in the proposed system is to allow the user to control the appliance and monitor the power, energy and current consumption. When it comes to building a mobile application, there are many options such as Kotlin, Swift, Objective-C, Python, and React Native [22]. The proposed system used Flutter to build the mobile application. Flutter is an open source UI framework, it's powered by Dart language and it was created by Google [23]. Unlike other frameworks used to build mobile applications, Flutter allows the developer to create a single application that is capable to function on different screen sizes, devices and operating systems. Flutter is capable of working on Android, iOS, Linux, MacOS, Microsoft Windows, Web Platforms and Fuchsia [24]. In addition, the time consumed for building a mobile application is relatively less than some of the other frameworks, the maintenance is more difficult in native applications than flutter based application, native applications requires different updates for different iOS. In a scenario where a mobile application is needed to be available for iOS and Android users, in some cases two developers need to be employed for each platform. The main rule of the mobile application in the proposed system is to allow the user to monitor the energy consumption and control the appliances with a few extra features. There are some considerations taken during the implementation of the mobile application such as simplicity; the app is easy to use and all the app components are accessible and understandable [25], [26]. In addition, multiple tests were performed to avoid any existing bugs and ensuring it's able to run smoothly on iOS and Android. The app ran on android studio emulator Pixel 4 XL, an actual Huawei P30 pro, an iPhone 13 emulator and chrome web app.

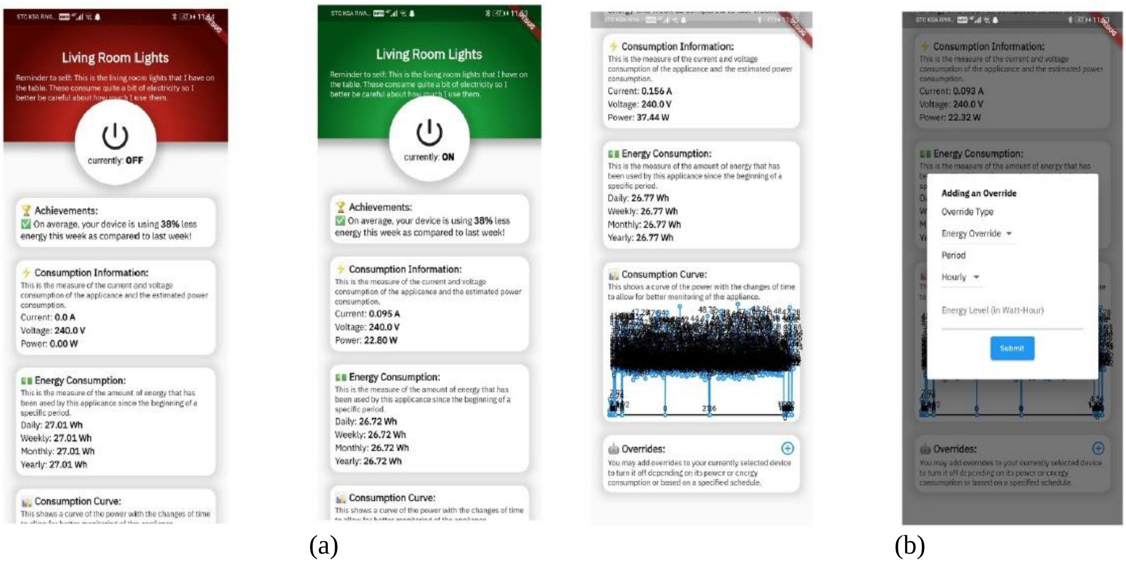
3. RESULTS AND DISCUSSION

Figure 5 shows the screenshot of the mobile application. The mobile application UI consists of only one page. The first part as shown in Figure 5(a) and Figure 5(b), consist of the name, brief description of the appliance, on/off button, achievements, consumption information and energy consumption. The button is used to turn on/off the appliance by simply pressing on the button, showing the status of appliance whether it's on or off and the color changes on the top screen from red to green and vise versa based on the appliance status. The Achievement section is to inform the user whether he has used more or less energy for the specific appliance than last week, and is viewed in the form of a percentage. The Consumption Informations section is filled with a real-time measurement of three main parameters which are the current obtained from the current sensor, the voltage that was chosen based on the standard supply of the country and power which is calculated in the server. All this information is presented in numerical presentation. As for the power calculated, it's presented in a graphical presentation to provide the user with a better experience in monitoring the power and the specific time for the electricity consumption. The Energy Consumption section allows the user to monitor the energy consumption daily, weekly, monthly and yearly. The user is able to see the power consumption curve (Power vs Time). In addition, the user can choose to override the energy or power level according to the desired period as shown in Figure 5(c). Figure 6 shows the integrated system.

Table 1 summarises the comparison between the proposed system (PS) and several other existing systems proposed in the literature. As can be seen from Table 1, all of the existing projects apps are only available on one platform either iOS or Android. When it comes to size of the prototype most of the existing projects offers a small prototype and looks like the standard power outlet. As for the cloud platform the proposed system and a some of the existing projects are capable of scaling. However, references did not mention whether they are using the free version or the monthly subscription of Google Firebase. Most of the existing projects offer offline operation which is very important for this project in case the connection was lost. Finally, the proposed system is the only system that is capable of providing a real time data. This is due to the use of Websockets instead of HTTP. Despite the fact that the proposed system was tested only on controlling and monitoring the electricity consumption of a floor lamp. Theoretically, it's be able to control any type of loads with ratings below 7A.

Table 1. Comparison with other existing systems

Ref	Multiple platform	Small size	Cloud platform scalability	Offline operation	Real-time
[14]	X	✓	✓	✓	X
[15]	X	-	✓	✓	X
[16]	X	✓	X	X	X
[17]	X	X	X	X	X
[18]	X	✓	X	✓	X
PS	✓	✓	✓	✓	✓



(c)

Figure 5. Screenshots of the mobile application (a) brief description of the app with on/off button, (b) energy consumption information, and (c) override feature

Figure 6. Integration of the whole system

4. CONCLUSION

The proposed system showed its capability to provide the user with a rigid and green prototype. In addition, the system provides a user-friendly and easy to use mobile application. Furthermore, the system is compatible with different types of load as long as it follows the same ratings. Lastly, the system is scalable and can be extended to add more prototypes. Moving forward, different prototypes can be built for several equipment ratings as the current prototype is only capable of controlling and monitoring appliances that rated below 10 A as the relay only can withstand 10 A and the current sensor is capable of withstanding 30 A. Secondly, is to add the machine learning concept to the smart power outlets so that it can predict the user behaviour and act on it without any human interactions.

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Abdulaziz Khalid Eid Abougamea has recently graduated from Multimedia University as an Electrical Engineer with first class honors. He and his team have participated and managed to obtain a silver medal in the 33rd International Invention, Innovation and Technology Exhibition (ITEX'22) in Malaysia via his invention titled smart household energy monitoring system. He can be contacted at email: abougameaabdulaziz@gmail.com.

Siow Chun Lim received his Ph. D. (Electrical Engineering) from Universiti Putra Malaysia. He is currently a Senior Lecturer and Programme Coordinator at Faculty of Engineering, Multimedia University. He was the former Chair of Centre for Electric Energy and Automation (CEEA). Siow is in the Energy Working Group of ASEAN Federation of Engineering Organisations and IEC TC 81 (Lightning Protection) committee working specifically in the development of lightning risk assessment standards. Presently, he is also chairing the Electrical Engineering Technical Division of the Institution of Engineers Malaysia. His research interest includes renewable energy, electrical earthing, lightning protection and engineering education. He can be contacted at email: clsiow@mmu.edu.my.