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An IoT-based Smart Plug Energy Monitoring System

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***Abstract*—Over the years, considerable efforts have been made to maintain electricity. However, there is still a significant need to explore new technologies and solutions conserve and enhance electricity supply. This project discusses research studies and applications conducted in the field of energy control, including a comparison of these applications undertaken in order to highlight constraints that need to be further addressed. This can be considered as the first step in developing a system that helps building owners to control their electricity consumption using Internet of Things (IoT) technologies. The main phases of the proposed system are data collection, data analysis and mobile application development. The project utilizes Wi-Fi smart plugs to collect active power consumption data, of which analysis is conducted on the cloud. The mobile application allows the building owner to manage buildings, and to obtain active and accumulated consumption data of plugged-in devices. This paper involves the architecture design of the proposed system, and the experimentation, testing, and implementation. The application was tested and the active and accumulative consumption per device and per building were reported. To confirm the accuracy of the active power consumption measurements from the smart plugs, a comparison is performed between these values and the active power consumptions measured by the company and shown on the labels. The results showed that using IoT-based smart plugs gives accurate readings.**

Keywords—Internet of things; IoT; smart plugs; electricity; energy consumption

I. INTRODUCTION

Electricity plays an important role in different aspects of our lives ranging from homes, industries, education, business, health, and transport [1]. The production of electricity may utilize a range of different resources, including non-renewable natural resources such as fossil fuels, in addition to renewable energy resources (RES) such as solar and wind. The burning of fossil fuels to produce electricity can cause various types of environmental damage, such as depletion of resources, increased pollution and waste generation [2][3]. Consequently, electricity consumption is becoming a major public concern and many countries and scientific communities are dedicating their effort to the search for solutions to control and manage the use of electricity [4].

In Saudi Arabia, efforts to conserve electricity have been intensified. According to the 2030 vision, the plan is to reduce energy consumption in different sectors by 20%, which will contribute significantly, saving about one million barrels of oil per day [5], [6]. Accordingly, the Saudi Energy Efficiency Center (SEEC) was established with the aim of conserving natural resources and enhancing energy efficiency. In addition, SEEC developed the Saudi Energy Efficiency Program (SEEP) which implemented a number of campaigns, including 35 initiatives to increase energy efficiency and improve society's awareness. SEEP also established the National Energy Services Company (Tarshid) to achieve two main objectives which are: the rehabilitation of government buildings to reduce consumption and support for the private sector with investment in the energy efficiency services sectors [7]-[9]. Therefore, to contribute to these initiatives, innovative ideas are needed which support and enhance recent technologies in order to monitor the electricity consumption of buildings.

The existing solutions can be classified according to meters' types into traditional meters and smart meters. For the traditional meter, manual consumption readings need to be conducted by humans for each building. Smart meters, on the other hand, can store the data themselves and send it automatically to the electricity company [10]. However these meters are only capable of recording the electricity consumption of the building as a whole; they are not capable of providing more detailed information, for example the consumption of each individual appliance. Richer information of this type could potentially support building rehabilitation projects by identifying those appliances consuming most power, providing a case for replacing them with more energy-saving ones. More detailed consumption information could also enhance the consumption awareness of building owners, supporting them in understanding electricity usage patterns.

To address the above-mentioned problems, a new technology is needed, capable of collecting and measuring building electricity consumption to inform understanding of usage behaviors. The IoT, in conjunction with smart plugs, can collect electricity consumption information in respect of plugged-in devices, supporting enhanced user awareness and helping to identify those devices that consume the most electricity [11]. This project will therefore develop a mobile application using the IoT and smart plugs to enable the building owners to access their electricity consumption data. The application will also allow building owners to understand the electricity consumption of appliances, which may assist in cost reductions.

The contributions from this study are the following:

- A review and comparison of different applications that have been developed for electricity monitoring systems highlighting any limitations and areas for improvement.
- Development of an IoT-based smart plug energy monitoring system utilizing smart plug devices and the cloud service for data analysis. The data collected and stored on the cloud can be further deployed within an artificial intelligence model, to detect consumption patterns and identify anomalies.

- An experimental, real-world case study to test the functionality of the proposed system and report the results.

The remainder of this paper is organized as follows: Section II presents the background information necessary for the understanding of the project; in Section III, related studies of similar applications are reviewed and compared with the presented application; Sections IV and V provide a description of the proposed solution, together with the hardware and software specifications; Section VI describes and discusses the experiment based on a real-world case study and reports the results; finally, Section VII provides the conclusion and recommendations for future work.

II. BACKGROUND

A. Electricity Consumption

A range of different concepts, measurements and equations is necessary to the understanding of electricity consumption, as well as an appreciation of the distinction between power (Watts/kW) and energy (Watthour/kwh). Firstly, electricity can be defined as the main source of energy that provides a flow of electrical power. It is measured in Watts (W), which is the unit of electrical power. The power is calculated by multiplying the current (Ampere A) and the voltage (V) as shown in Eq. (1) [12][13]:

$$Power\ P\ (Watts)\ =\ Current\ (A)\ *\ Voltage\ (V) \quad (1)$$

Power is the electricity currently being used, which is also referred to as active power consumption [13]. Energy can be defined as the total amount of electricity consumed over a period of time (i.e. accumulative power consumption) and is computed according to Eq. (2) [13][14]:

$$\text{Energy (Wh)}\ =\ \text{Power (W)}\ *\ \text{hours (h)} \quad (2)$$

$$\text{Energy (kWh)}\ =\ \text{Energy (Wh)}/\,1000 \quad (3)$$

For example, if you use a device that gives active power equal to 500 Watt (0.5 kW) for five hours, then the energy or the total amount of electricity that has been consumed is 2,500 Wh or 2.5kWh. To sum up, in order to compute the electricity consumption of any device, the active power consumption (W) and the number of daily working hours of the device (h) must be known. Then the daily and monthly electricity consumption can be calculated as follows [14]:

$$D\text{aily Electricity consumption of the device}\ = \text{Power (watt)}\ *\ \text{Daily working hours} \quad (4)$$

$$\text{Monthly Electricity consumption of the device}\ = \text{Daily Electricity consumption}\ *\ 30 \quad (5)$$

B. Smart Plugs

The smart plug is defined as ‘a separate electronic piece of hardware that serves as a proxy between the energy source and energy-consuming device’. So, it is an electronic device that allows the user to obtain real-time data of electricity consumption of the electric appliance or device, which is plugged in using a web panel or mobile application. The plugs also convert the appliances into smart devices to control them remotely [15], [16].

The hardware components of the smart plug, can be described as consisting of four sub-systems units which are: power meter; power switch; network node; and processing. The power meter is responsible for collecting the active energy consumption of the appliances connected to the smart plugs. Different information can be measured including active power consumption W, voltage V and current A. The power switch can be used to control the devices connected to the plugs by turning them to on or off, using the application. The network node allows a connection to be made with different external devices such as gateways using wireless technology, for example Wi-Fi, or Bluetooth low energy. The primary core components of the plug are the processing unit, which arranges the interaction between the power meter and the network unit [17].

Regarding commercial smart plugs products, a number of different companies provide plugs with a range of features. The consumer wishing to select the most appropriate product for their needs will need to understand their requirements. Table I presents brief information regarding the features of some examples of the commercial smart plugs that are available.

According to Table I, electricity consumption data may be transmitting utilizing different wireless technologies such as Wi-Fi, BLE, Zigbee. It is evident that the majority of the products use Wi-Fi, while Mokosmart products provide different wireless configurations. Regarding the transmission range, the coverage range will equate to that of the Wi-Fi router to which the plug is connected. If, as in the case of Mokosmart, BLE is used, the range will be 100 meters to connect with the mobile application or gateway. Regarding the maximum power of the connected devices, all plugs can be connected with devices that have a maximum power of 1800 W, while Mokosmart can be connected with 2400 W. For the power consumption of the plug itself, it can be seen that Eve and Mokosmart provide the lowest power with 0.001 and 0.075 respectively. Regarding pricing, D-Link and Mokosmart are the cheapest products.

Regarding the features, it can be seen that smart plug products provide one or both of two main functions: remote controlling and monitoring electricity consumption. The remote controlling allows the switching on and off of electronic devices using the mobile phone application or a hands-free voice control. The electricity consumption monitoring function allows power consumption of any plugged-in device to be monitored, using a mobile application or a web panel. Consumers need to exercise caution when selecting a product, as may items provide remote controlling only, for example D-Link. In addition, a critical feature to be considered by consumers who interested in developing the application is the provision of a software development kit (SDK) and the compatibility of the smart plug with IoT cloud services.

TABLE I. SMART PLUG PRODUCTS

Company	Transmission Technology	Transmission range	Maximum power (W)	Power consumption of the plug (W)	Price (SR)	Features
Mokosmart[28]	Bluetooth ,Wi-Fi, Zigbee	Above 100 meters for the BLE. Internet-connected in the Wi-fi	2400	0.075	75	• Monitoring energy consumption. • Remote controlling. • Support API for APP and cloud server development. • Measures active and accumulative power consumption. • Support SDK.
Eve [29]	Wi-Fi	Internet-connected.	1800	0.001	263	• Monitoring energy consumption. • Remote controlling. • Schedule devices.
TP-Link [30]	Wi-Fi	Internet-connected.	1800	3.50	131 – 188.	• Monitoring energy consumption. • Remote controlling. • Amazon Echo Voice Control. • Schedule devices.
WeMo(Belkin) [31]	Wi-Fi	Internet-connected	1800	1.5	188 – 375	• Monitoring energy consumption. • Remote controlling. • Hands-free voice control. • Schedule devices
Insteon [32]	Insteon	Everywhere	1800	< 0.4	487	• Monitoring energy consumption. • Remote controlling. • Schedule devices.
D-Link[33]	Wi-Fi	Internet-connected.	1800	< 3	59	• Remote controlling. • Hands-free voice control. • Schedule devices.

The SDK allows the user to interact with the plugs in the implementation phase. In case the user wishes to utilize IoT cloud services, the plugs should be compatible with cloud platforms using well-known IoT protocols such as MQTT (Message Queuing Telemetry Transport). In accordance with the conclusions from this discussion and in light of the available features, the smart plug to be used in this project is the Mokosmart. This provides different wireless configuration; can be connected with high power devices up to 2400 W; has the lowest power consumption; and is compatible with the IoT Cloud platform that supports MQTT. These plugs represent the sensors to be used in the project.

III. RELATED WORKS

A number of research studies and applications conducted and developed in the field of energy monitoring systems are presented in this section. The significant work is reviewed, which contributed to the development of the energy monitoring systems including both multi-sensor and single-point sensor approaches. Moreover, the section considers the different applications developed for energy monitoring and presents a comparison between them, to reveal the limitations and any issues that require improvement.

A. Research Studies

In this section, existing research studies in the field of appliance load monitoring are presented. These studies can be categorized into smart meter approaches or smart plugs approaches. This categorization is based on the location of the sensors used to collect electricity consumption data. For the smart meter approaches, the meter is placed at the entrance of the building and can measure the overall electricity consumption. The smart plugs, on the other hand, are located into each socket to measure the electricity consumption for each device [18]. These studies can be also categorized into multi-sensor or single-point sensor projects, according to the number of sensors used to collect the electricity consumption data. In the multi-sensor approaches, the sensors should be installed at the power outlets or at each device, while, in case of single-point approaches, there is only one sensor to monitor the building [19]. All of these approaches aim to monitor the electricity consumption of appliances used in a building.

1) Single-point sensor approaches: The smart meter can collect the overall electricity consumption of any building; however, it does not provide any appliance-specific (that is, device-level) consumption information. Therefore, in order to recognize the appliances according to their electricity consumption, there is a single sensor attached to the smart meter to collect different characteristics of electrical load. Machine learning techniques are then applied to recognize different appliances. Each of these approaches involves its own issues; for example, in the case of the smart meter, a technical expert is required to undertake the setup of the smart meter in accordance with requirements; the results may be inaccurate; and previous knowledge of appliance power signatures is required in order to implement the machine learning techniques as these require a training phase [18], [19].

2) Multi-sensor approaches: Artur et al. proposed a study of an IoT-based solution to identify household appliances, monitor their consumption and detect anomalies in these devices. The identification of these appliances is possible where they possess a unique Electric Load Signature (ELS). The ELS can be defined as an electrical characteristics unique to each appliance which includes: voltage, current, active, reactive and powers. The proposed solution is a Home Energy Management (HEM) system capable of exposing and identifying appliances, and measuring their electricity consumption. The smart plugs are used to read the electrical parameters of each appliance, and the data is sent to HEM using the internet (Wi-Fi) or ZigBee. The ELS thus created is then stored in a database. The data is subsequently analyzed using a machine-learning algorithm to detect the appliance. The results demonstrate that 10,799 records were collected and that the system perform the required training and analysis to classify these records and identify the appliances. The records created included 3,600 records for the refrigerator, 3,599 records for the washing machine and 3,600 records for the TV [2].

In 2019, Ashwin and Krishnamoorthy proposed an IoT-based smart plug load energy management system for an office environment. The main objectives of the study were to improve energy management, and to controlling devices. The project used smart plugs to measure the total consumption of each appliances in the office. The appliances used to test the system included a printer and a coffee vending machine. The developed system is a web application to monitor the smart plugs, collect data and send notifications to the users where a pre-determined limit is exceeded. The system also implemented a scheduling method in which the devices could be turned off at a specific time. Moreover, the system could identify consumer behavior. An analysis performed to compare the total energy consumed before and after implementing the system demonstrated a reduction in electricity consumption [20].

Ahmed et al. propose a method that aims to monitor electric power using smart plugs. It targets analyzing and understanding of the energy consumed by appliances. A mobile application has been developed on a Windows phone to control appliances in a room by an on-and-off switch and the establishment of operating schedules. The application also provides features to design the layout of the user’s house in addition to the behavior of connected devices. On the other hand, an interactive web application has been designed to show the energy consumed by different houses on the map, to help the Power Distribution Companies to analyze and study consumption behavior. The results of this study contributed to increased awareness of energy conservation in UAE and to reductions in consumption [1].

In 2020, Shohin Aheleroffa et al. proposed an IoT-enabled framework that aims to transform any appliance into a smart appliance and to allow the collection of data using sensors and actuators. As a case study, researchers integrated an IoT board within the central control board of a traditional refrigerator to transform it into a smart refrigerator. This board can collect data which includes: temperature and cooling level, and which also reads the states of different actuators such as the heater, the compressor, or the air fan. The data collected is periodically sent to the IoT platform using Wi-Fi technology to store data in a database called Ubidots. This study in [21] also lists suggestions for different IoT platforms which could be utlilized in similar systems such as: AWS IoT, IBMWatson IoT, and Azure IoT. The IoT platform can support the analysis and visualization of the received and can display the results on the dashboard. The user can also control their refrigerator using a mobile phone connected to the device by Bluetooth technology. It should be noted that this proposed framework can be applied in respect of all home appliances[21].

According to the studies outlined above, it is clear that different approaches exist which may be categorized into single-point-based approaches or multi-sensor-based approaches. The single-point sensors can provide data about overall consumption and anticipated consumption per device based on machine-learning algorithms. However, they do require technical expertise to achieve the correct setup in attaching the sensor to the smart meter as well as a priori knowledge of appliance power signatures. On the other hand, multi-sensor-based approaches can provide device-level electricity consumption information, but requires a separate smart plug for each individual device.

B. *Applications*

In this section, a number of applications in the field of electricity monitoring are presented, and their features outlined. A comparison is also provided between these applications and the proposed application, so that the best features of similar applications may be incorporated and to identify limitations and areas for improvement.

1) SmartLife application: SmartLife is a smart device management application which is used to control smart devices such as smart plugs, smart cameras, or smart vacuum cleaners. It is compatible with multiple smart plugs such TECKIN Smart Plug, Tan Tan Smart Plug and YTE Smart Plug and with multiple smart devices [22]. SmartLife Application measures electrical consumption of the smart devices only where they include an energy monitoring feature. Bluetooth low energy technology connects the application to the smart plugs. The application provides building owners with features such as the ability to add and control multiple devices, and to receive notifications when scheduled events occur. Additionally, it provides a monthly report including statistics of electrical consumption, a timer or scheduling tool for automatic control of devices, and cloud storage using an Amazon server. Furthermore, it provides a family control facility to allow differential control permissions to different family members — for example limiting the ability to control settings to a single family member while allowing all to control the devices. [23]

2) Insteon hub application: The Insteon system consists of a web and smartphone application which converts the home into a smart home. This facilitates the control of home appliances. Insteon requires a hub to exert control over compatible devices. The hub is plugged into the wall and connected to router via Ethernet [24]. There is no limit to the number of devices that may be added on Insteon hub which Insteon connects to the router using the home's existing power wires. This helps Insteon signals to transfer commands in the house unaffected by walls or other Wi-Fi blocking materials. To prevent signal overload [25], the radio frequency used by Insteon for communication is distinct from the one used by Wi-Fi. The Insteon app enables the building owners to manage smart plugs by adding devices, and by adding rooms that can group devices according to their position, and defining zones that can group rooms within the same building. In addition, it permits the user to establish schedules for controlling devices, receives notification relating to its sensor, and can flag up warnings relating to water leaks, motion, and door/window breaches if the necessary sensors are in place. [26].

3) Zuli application: The mission of Zuli application is to track and manage the building's appliances. This is a smartphone application compatible with a Zuli smart plug. Communication with the smart plug through Bluetooth is necessary for use of the features of the application [27]. The Zuli application contains numerous features, for instance supporting interaction between devices able based on the owner's location, through the utilization of iBeacon technology using Bluetooth low energy. The application can monitor energy usage and obtain the number of Watts, Volts, and Amps that proceed through the plug. It can additionally obtain the anticipated monthly costs, can assign a schedule for every day on the week and assign a timer to automatically turn on and off the devices [28].

4) Sense application: Sense is a web and smartphone application for monitoring electricity consumption. It requires hardware called the Sense monitor to be installed in the electrical panel of the building. Two sensors, clamp around the main power leads to ascertain the amount of electricity being used [29]. Sense uses a machine learning algorithm to automatically classify the active devices based on historical data of similar devices collected from other users. The device name may then be confirmed or modified by the consumer [30].To run the Sense application, the application should be connected to the Sense monitor via Wi-Fi technology [29]. The Sense monitor collects energy usage data and sends it through Wi-Fi to the cloud. Consumers may thento track thir electricity consumption using either their smartphone or computer. Sense helps consumers to reduce electricity utilization by encouraging them to set targets and track progress. It also allows them to monitor their electrical consumption in real time. Additionally, it provides daily, weekly, and monthly reports which include energy consumption measurements, average usage, and statistics related to specific devices [31]. In addition, the Sense application can detect the value of the monthly bill. Furthermore, Compatible with Wemo and Kasa smart plugs, it is therefore capable of utilizing the multi-sensor approaches represented by the smart plugs to identify devices faster, to compute consumption per device more accurately and to allow consumers to control their devices directly [32].

5) EnergyCloud application: EnergyCloud is a mobile application that uses machine learning technology to analyze usage patterns. It aims to reduce electricity consumption and costs through the ready availability of energy data [33]. The requirements of this application include: the EnergyCloud Sensor which is installed within the electricity meter to transmit meter readings to a gateway called CloudConnector. This gateway sends all the electrical consumption data to the cloud [34]. The EnergyCloud Sensor is compatible with analog disk meters and digital meter [35]. The mobile application provides many services which include real-time consumption measurement and make a monthly consumption comparisons. The application also provides tools to encourage reductions in consumption, such as notifications where usage has been successful decreased, or where a predefined consumption limit has been exceeded [36]

Table II shows the availability of a range of different types of applications, for example: single-point sensor applications such as EnergyCloud and multi-sensor based applications such as SmartLife, Insteon, and Zuli. One application, Sense, is capable of operating using both approaches. The EnergyCloud application requires installation of a sensor within the electrical meter to collect the overall energy consumption data. It uses a machine-learning algorithm to identify devices and provides anticipated readings of device-level consumption. However, as discussed in the literature review section, above, there are problems attendant upon the single-point approach, such as the production of inaccurate results, more complex sensor installation requirements necessitating the services of an electrician,, and the need for previous knowledge of the consumption profiles of the devices [18], [19]. In the case of multi-sensor based applications, it can be seen that smart plugs play an essential role, and are utilized for different objectives:

they allow remote controlling of the devices without energy monitoring or may provide energy monitoring in addition to the remote controlling features. Insteon is an example of an application solely providing remote control functionality for devices, though it is important in terms of the objective of this paper to maintain the focus on applications which deliver energy monitoring functionality, such as Zuli. It may also be seen in Table II that none of the applications currently available supports the Arabic language—a gap in the energy monitoring market that urgently needs to be filled. In addition, the majority of available applications do not support the 'manage building' feature which provides the capability for managing multiple buildings. Smartlife is the only application to benefit from this feature. In terms of a notifications facility to support users in reducing energy consumption, this is available in only one application, EnergyCloud. Applications providing effective monitoring consumption typically support smart plug management, appliance management, provision of historical as well as active power data, and cloud storage utilization. Consequently, the user is recommended to review products carefully before selecting, to ensure they incorporate these essential capabilities.

TABLE II. COMPARISONS BETWEEN APPLICATIONS

Features	SmartLife	Insteon	Zuli	Sense	EnergyCloud	SPEM
Manage Smart Plug	☐	☐	☐	☐	X	☐
Manage building	☐	X	X	X	X	☐
Manage Appliance	☐	☐	☐	☐	X	☐
Monthly cost of devices	☐	X	☐	☐	☐	☐
Expected cost of the building consumption	x	X	X	☐	☐	☐
Monthly Report	☐	X	☐	☐	☐	☐
Historical Power	☐	X	☐	☐	☐	☐
Provide consumption alert	X	X	X	X	☐	☐
Arabic Language	X	X	X	X	X	☐
Turn off/on devices	☐	☐	☐	☐	X	X
Control Voltage	☐	☐	X	☐	X	X
Voice control	☐	☐	X	X	☐	X
Provide Cloud Storage	☐	X	X	☐	☐	☐
Multi sensor/ Single sensor	Multi sensor	Multi sensor	Multi sensor	Multi sensor/ Single sensor	Single sensor	Multi sensor

We will develop an IoT- based smart plugs system which is informed by the domain analysis presented in this section and which assists owners to monitor the electricity consumption of their buildings. The system will allow building owners to register their details within the application, to use the application features, will support Arabic language and provide multiple features including smart plug management, appliance management, active and historical consumption data per appliance, monthly reports covering consumption and anticipated costs. Additionally, a 'manage building' capability will be included as well as alerts to support reductions in consumption.. Further development may be undertaken in future to develop features relating to the on/off control of the smart plugs and the use of voice control.

IV. PROPOSED SOLUTION

A. *System Architecture*

This study proposes a solution consisting of an IoT smart electricity monitoring system which assists building owners to monitor electricity consumption. The main components of the solution are: smart plugs, server, and mobile application. The application will operate as presented in Fig. 1. Smart plugs will be installed and configured in the buildings which, once connected to the building will, using Bluetooth Low Energy (BLE), transmit information to a gateway, including: smart plug ID; active power consumption (watt); real-time current (A); and voltage (V). The gateways will collect the information and send them to the server. Once active power consumption data collection becomes operational, a processing and analysis task must then be undertaken to calculate the accumulative electricity consumption of the appliances connected to the plugs. The mobile application enables building owners to manage smart plugs and appliances, to monitor the active and accumulative consumption of the appliances, and to identity those appliances consuming the most electricity. The proposed solution will thus contribute to enhancing user awareness, encouraging the replacement of older devices, and better energy conservation, thus reducing electricity bills and achieving the sustainability objectives.

The architectural design of the proposed system has four layers as shown in Fig. 2: the perception layer, the network layer, the data storage layer, and the application layer. The perception layer is the first layer of the IoT architecture, in this which the smart plugs are used to detect and collect information including smart plug ID, active power consumption (watt), real-time current (A), and voltage (V). The second, or network layer connects the smartplugs and the network equipment (that is, the gateway), to transfer information to the servers. The data storage layer is represented by the IoT platform that can receive information from the sensors and store it in a cloud-based database. The application layer allows user interaction with the system, using the mobile application, and is responsible for the provision of application-specific services to the user.

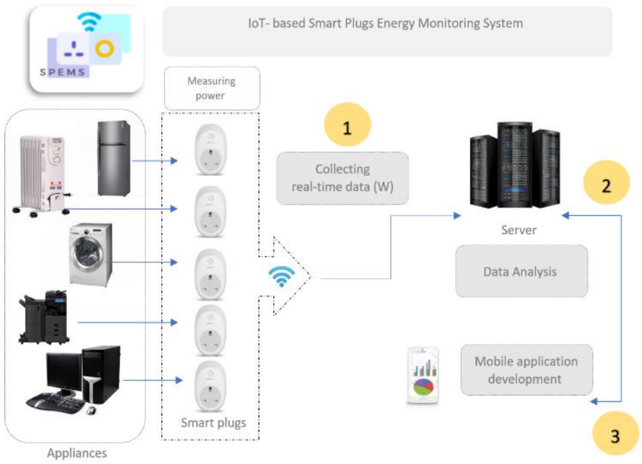


Fig. 1. The proposed solution.

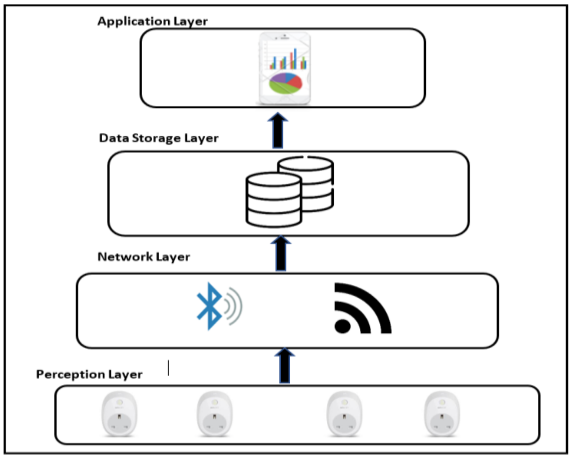


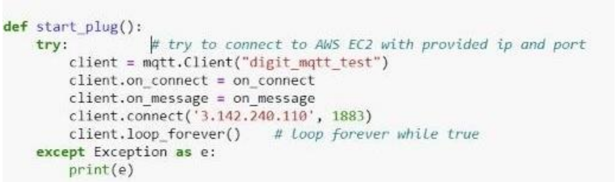
Fig. 2. The IoT architecture of the proposed solution.

V. SYSTEM IMPLEMENTATION

The main goal of the proposed system is the collection of active power consumption data for any device and the computation of the energy consumption. The Wi-Fi smart plug is utilized as a hardware component. In accordance with the findings of the comparative enquiry, presented in Table I, the smart plugs selected for this project are Mokosmart. These plugs provide a range of potential wireless configurations, which are Wi-Fi, BLE and Zigbee. BLE smart plugs must be connected first with gateway and then with the Wi-Fi modem, while the Wi-Fi plugs are connected directly to the modem. This project used the Wi-Fi plugs, as the most cost-effective choice, we used the Wi-Fi plugs.The Mokosmart Wi-Fi plugs can be connected with high power devices up to 2400 W, have low power consumption, and are compatible with the IoT Cloud platform that support the Message Queuing Telemetry Transport (MQTT) protocol. These plugs represent the sensors that will be used in the proposed project. Samsung phones were for this project, since the application is designed to be compatible with Android platform.

In terms of the software, a range of different tools are used to develop the proposed system which includes three main processes: data collection, data analysis and mobile application development. For data collection, the Amazon Elastic Compute Cloud (Amazon EC2) is used, which is a cloud service provided by Amazon which provides cloud computation [37]. It is compatible with the MQTT protocol, so it is used as server to receive records from smart plugs. The MQTT protocol, a publish/subscribe protocol for messaging transport with minimal network bandwidth, is a standard messaging protocol that serves IoT devices. The smart plugs used in the project support the MQTT protocol, once they are connected to the internet. They will publish power data to MQTT Broker and the MQTT Client will subscribe to the topic to get the power data [38].

Subsequently, a python script was developed from scratch, as shown in Fig. 3, to read data from smart plugs using the MQTT protocol and to store it in the database. The python code is written using Jupyter Notebook [39] which provides an online python environment. A python code was also written to analyze received data and to compute daily, monthly consumption of each device, and also the daily, monthly consumption of each building, in addition to the anticipated cost of electricity consumption per month. For the database, the Firebase was utilized, a platform provided by Google with many services for developed mobile and web applications [40]. It is used to store user information and data received from the smart plug. The mobile application was developed using Android Studio 2020.3.1 [41].



```
def start_plug():
    try:            # try to connect to AWS EC2 with provided ip and port
        client = mqtt.Client("digit_mqtt_test")
        client.on_connect = on_connect
        client.on_message = on_message
        client.connect('3.142.240.110', 1883)
        client.loop_forever()    # loop forever while true
    except Exception as e:
        print(e)
```

Fig. 3. Code segment of connect to MQTT protocol.

The steps followed to connect the system components are set out below:

1) *Configuring* the smart plugs to connect them to the EC2 cloud service;

2) *Implementing* the python code to read data from the smart plugs using the MQTT protocol as presented in Fig. 3;

3) *Connecting* EC2 to the database to store the data;

4) *Connecting* the mobile application to the database.

VI. THE EXPERIMENT

The IoT-based smart electricity monitoring system is developed as a mobile application that use the Internet of Things (IoT) and Smart Plugs to enable building owners to access their electricity consumption data and to understand the electricity consumption of individual devices connected to the plugs which can contribute to reducing electricity bills. This experiment was conducted in residential buildings. The experiment consists of three phases:

- Installation phase: The actual installation of the smart plugs in the building and connecting them to devices.
- The execution phase: The demonstration of the use of the proposed application to monitor real-time data and compute daily and monthly electricity consumption.
- Testing phase: To conduct performance and stress testing.

A. *Installation and Deployment Phase*

In terms of the hardware used, a number of home appliances were tested in this experiment including refrigerator, hair dryer, television and washing machine). These devices are attached to Wi-Fi smart plugs according to the specification presented in Table III.

TABLE III. SPECIFICATIONS OF HOME APPLIANCES

Device	Consumption range measured by company (W) that exist on the label	Model no	Company
Refrigerator	400 - 550	ASKN – SBS - 521-RFG	ASKEMO
Hair dryer	1000 - 1200	EW - 920	Easy Way
Television	120 - 155	65UJ670V - TD	LG
Washing machine	2000 - 3000	WF21T6500GV	Samsung

B. *Execution Phase*

In the execution phase, various home appliances are monitored. The system will start to receive the sensor readings from home appliances and to perform different functions including the following:

1) Active power consumption per device: The proposed system lists all the connected home appliances with their active power consumption measured using Watt (W). As shown in Table IV and Fig. 4, different readings are taken for each device. This gives building owners an indication which are the devices that have high consumption. It can be seen that the hair dryer and washing machine have higher active consumption that the refrigerator and the television.

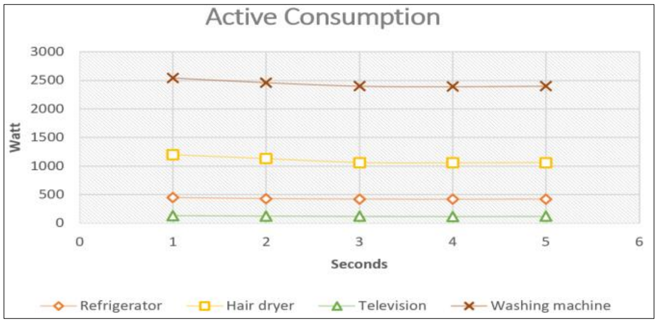


Fig. 4. Active power consumption for different appliances.

It is important to make sure that all electrical appliances are efficient in consuming energy. Consumers can know the efficiency of any appliance by referring to the attached energy efficiency label. Accordingly, the proposed system should transmit an efficiency alert to building owner if a device exceeds the standard consumption or has a normal consumption. The standard consumptions are typically defined by the electricity company to increase consumer awareness. To confirm the accuracy of the active power consumption measurements from the smart plugs, a comparison is performed between these values and the active power consumptions measured by the company and shown on the labels. The results are shown in Table V and Fig. 5.

TABLE IV. ACTIVE POWER CONSUMPTION PER DEVICE (W)

Device	Reading 1	Reading 2	Reading 3	Reading 4	Reading 5
Refrigerator	450	430	420	417	420
Hair dryer	1200	1130	1060	1055	1060
Television	130	125	120	118	120
Washing machine	2540	2460	2400	2391	2400

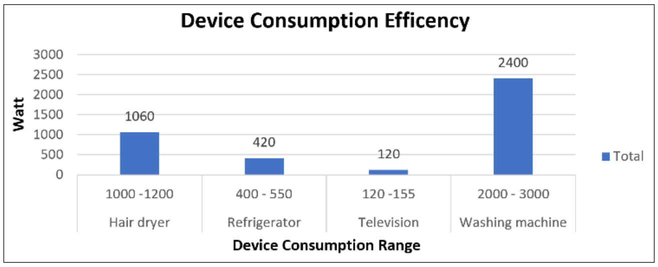


Fig. 5. The device consumption efficiency.

TABLE V. COMPARISON BETWEEN THE MEASURED AND ACTUAL ACTIVE CONSUMPTION

Device	Consumption measured by smart plug (W) (average of the actual active consumption)	Consumption range measured by company (W) (that exist on the label)
Refrigerator	420	400–550
Hair dryer	1060	1000-1200
Television	120	120–155
Washing machine	2400	2000-3000

2) Accumulative power consumption per device: As mentioned previously, in order to compute much the electricity consumption of any device, there is a need to know the active power consumption (W) and the number of daily working hours of the device (h). Then the daily and monthly electricity consumption can be calculated, as shown in Table VI and Fig. 6. The active power of the refrigerator is 420 Watt for 24 hours, so the energy or the total amount of electricity consumed is 10800Wh or 10.8kWh. The monthly consumption can calculated according to the number of days the device is used. Additionally, the building owner shall be able to display a monthly report of device consumption of a building and the expected monthly cost of the electricity consumption, based on the electricity company tariff.

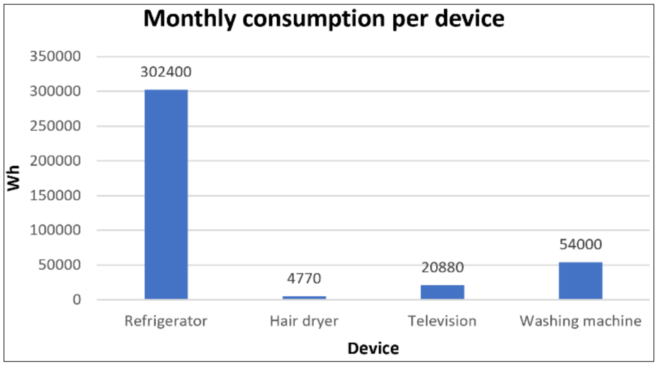


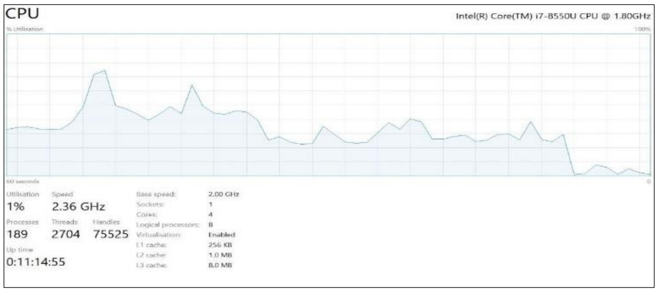
Fig. 6. The monthly consumption per device.

TABLE VI. DAILY ELECTRICITY CONSUMPTION PER DEVICE

Device	active power consumption (W)	# of hours the device is used (h/day)	Daily consumption (Wh)	monthly consumption (Wh)
Refrigerator	420	24	10080	302400
Hair dryer	1060	0.15	159	4770
Television	120	5.8	696	20880
Washing machine	2400	0.75	1800	54000

C. Testing Phase

1) Performance testing: Performance testing is a type of software testing that is used to analyze a system's capabilities and performance under a certain workload. To test our application's performance, we used activity monitor software which tracks operation. As shown in Fig. 7, the test results over a 30-minute period demonstrate that the CPU usage of the program was 1% of the total available CPU as a minimum value, though the CPU usage may potentially reach 32 % as a maximum value in specific situations.

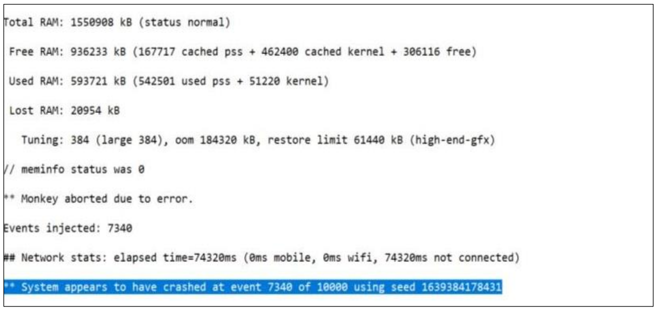


Utilisation 1%
Speed 2.36 GHz
Processes 189
Threads 2704
Handles 75525
Up time 0:11:14:55
Base speed: 2.00 GHz
Sockets: 1
Cores: 4
Logical processors: 8
Virtualisation: Enabled
L1 cache: 256 KB
L2 cache: 1.0 MB
L3 cache: 8.0 MB

Fig. 7. Minmum and maximum CPU performance.

With regard to memory usage, during a 30-minute testing period, it was observed that the proposed application allocates around 395MB of the total available memory.

2) Stress testing: Stress tests are used to test a system's capacity beyond its top limit, which can cause performance degradation. To perform the stress testing we used monkey which is a command-line utility that provides the system with a pseudo-random stream of user events. The command, (adb shell monkey-pcom.example.log_in 10000 > testfinal.txt) was utilized to run stress testing in the proposed system. The number of user events was 1000. The system is capable of handling 7340 random user actions, such as clicks, touches, and addition of a device, as shown in Fig. 8. The test completed 7340 occurences, demonstrating that the system has no unhandled exceptions and will work successfully under the stress of unexpected activities.



```
Total RAM: 1550908 kB (status normal)

 Free RAM: 936233 kB (167717 cached pss + 462400 cached kernel + 306116 free)

 Used RAM: 593721 kB (542501 used pss + 51220 kernel)

 Lost RAM: 20954 kB

   Tuning: 384 (large 384), oom 184320 kB, restore limit 61440 kB (high-end-gfx)

// meminfo status was 0

** Monkey aborted due to error.

Events injected: 7340

## Network stats: elapsed time=74320ms (0ms mobile, 0ms wifi, 74320ms not connected)

** System appears to have crashed at event 7340 of 10000 using seed 1639384178431
```

Fig. 8. Stress testing.

VII. CONCLUSION

IoT has a huge benefit to consumers in terms of energy efficiency. The proposed system which is an IoT-based Smart Plugs electricity monitoring system allows consumers to measure, analyze and check energy active and accumulative consumption per devices and per building. This can help consumers to make rapid adaptations and corrective actions to control their energy consumption and costs. The system also can be useful for individuals to increase awareness, to know their electricity consumption and to replace high energy consuming devices. Furthermore, the system can support rehabilitation projects, identifying devices that need to be replaced.

For future work, the collected data can be used in an AI model to detect anomalies and use machine learning techniques to predict patterns of future consumption to recognize the devices connecting automatically to smart plugs. The system also can provide suggested corrective actions that will lead to improvements in energy efficiency.

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