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Microcontroller-based Power Outlet for Energy Monitoring and Control with a Mobile Interface

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ABSTRACT
The surge in the global demand for energy has mandated numerous research to be carried out and still being carried out to find more efficient means of energy generation, management, and control of energy-consuming devices. This paper presents the design and construction of a microcontroller-based power outlet for energy monitoring and control with a mobile interface. This system is used in managing and controlling the consumption of energy in residential and non-residential houses. The characteristics components include a local embedded system, and a mobile application from which the user can set energy budget, and time when the system is required to switch off control to an outlet. The value of the energy budget is used by the system to ensure that supply is turned off immediately the budget is exhausted. Energy consumption data are also logged for the user in case of future references and analysis. The system was tested and results gotten were recorded. The system, if efficiently optimized could be used as a power scheduling system to manage major appliances for automatic and intelligent control.

***Keywords* -** Energy budget, Mobile application, Power outlet, Real-time, Remote control.

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I. INTRODUCTION

Energy has been one of the most discussed and researched topics since the last few decades. It has been the driving force for the world's technological advancements. The demand for energy as a result of the growing world population and a continuous rise in the numbers of energy-consuming devices has prompted researchers and engineers to continually seek ways to generate more energy and more importantly to conserve energy consumption and reduce the rate at which it is lost.

Management of energy is important in addressing the high energy demand as well as the way energy is used. The adoption and implementation of several smart energy management techniques have further improved energy conservation and regulation. Collectively, greenhouse gas emissions must be decreased in order to reduce significantly the risks posed by climate change. Some of the most dangerous consequences include intensifying droughts, storms, heat waves, the flooding of coastal economies brought on by rising sea levels, acidifying oceans, increasing wildfires and extreme weather events across the world. Reducing fossils dependence, tackling global warming, strengthening energy security and, thus, improving our health are today's main concerns [1].

Governments have set ambitious goals regarding the increase of renewable energy production, energy savings and greenhouse gas emission reduction in 2030 EU Energy Strategy [1] and the intended nationally- determined contributions to the Paris agreement [2].

There is no doubt that energy production systems need to be changed since today they rely heavily on oil, natural gas, and coal for generation. Nevertheless, rather than focusing only on new sources for energy supply, reducing and optimizing the demand should also be explored, as it would bring similar benefits. It is estimated that in 2017, a total of 24.57 billion KWh of energy was consumed in Nigeria [3]. Also, 6,803MW of power was generated and 15% of this was lost [3]. With a better and more efficient system especially in the homes and offices, this level of wasted power can be cut to the barest minimum.

This paper presents a way energy can be managed by employing a system comprising of an embedded system and a mobile application to assist users to automate the energy management in their homes. The user is able to use the mobile application to set energy budget and or time for switching on or off supply such that the embedded system is able to turn off supply when the energy cost computed exceeds the budget that was set.

II. LITERATURE REVIEW

The work in [4] designed a set of wireless intelligent socket control system based on the MSP430 single-chip microcomputer, which can achieve the wireless control home mobile intelligent socket. The system can work in the normal mode and timing mode. In order to ensure the safety of electricity, the entire systems are with overload, overvoltage and overcurrent protection. When the systems are running, the wall socket can be changed by phone APP or SMS instructions. The smart socket of all the voltage, current, power, and running time can be displayed by the LCD screen. The testing results show that the system has high reliability and security characteristics and has broad application prospects. But their system lacks the ability to monitor energy consumption in real-time and also the ability to report power failures.

The work in [5] proposed a design for an intelligent home control system based on Wi-Fi. Using a Wi-Fi socket to set up LAN to realize intelligent home system, Wi-Fi smart socket is mainly composed of three parts, including a hardware platform, server, and mobile phone App client. They discovered that they can use Wi-Fi to realize the intelligent control of the mobile terminal to the home equipment and the real-time monitoring of the temperature, the high-temperature alarms off, the timing off and other functions. Their system provides real-time monitoring of temperature and also the ability to control the system. But it lacks the ability to measure energy consumption in real-time and also, does not notify the user of a power failure.

The work in [6] proposed a feasible and lightweight HEMS, with a smart socket that is capable of appliance recognition. The smart socket based on appliance recognition could calculate the appliance’s power consumption and shut off the electrical power of appliances in standby mode. It could identify appliances' operational-mode status and quickly extracted the appliance eigenvalues via a finite state machine. Considering the low computing power of the smart socket, the method of appliance recognition adopted in this system is based on variable weight Euclidean distance. Experimental results show that the similarity among the same type of appliance was more than 80%, and almost all of appliances could be recognized in 18 seconds[7]. Therefore, the flexibility and feasibility of the proposed system are thus demonstrated. But it lacks the ability to notify the user of a power failure.

III. SYSTEM DESIGN

The Energy Management System measures the energy being consumed by a load, it also controls this load and manages the energy being consumed based on the user's preset values. These values could be either or all of the user's energy cost budget, the time a user desires the load to be cut off from the supply, a direct ON or OFF command from the user to either turn on or turn off the supply to the load. The LED display enables the user to monitor locally, the energy being consumed by a load.

The main goal is to design a system that would measure, monitor and control energy used by a load on a real-time basis, to ensure that energy is not indiscriminately used. This ensures that energy consumption remains at the desired level or set-point as described or initiated by the user’s budget, also giving the user the ability to set the time he or she desires a load to be connected or disconnected from the supply.

The local system will be able to communicate with a mobile phone where the dedicated mobile application resides. The mobile application provides function like setting energy budgets, setting the time for the load to be either connected or disconnected from the source, the ability for the user to turn off or turn on a power socket instantly by way of pressing the buttons on the mobile application, and also display the previous and current results or status of the energy consumed. This system design objective guides the work carried out in the design of the system. Fig. 1 below illustrates briefly the system design.

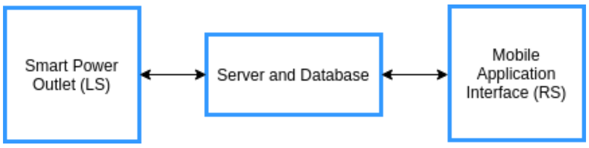

Figure 1: System basic block diagram

3.1 Hardware design

The Energy Management system is made up of four interoperable blocks with two hardware blocks, each consisting of several modules to achieve a specific purpose.

The hardware blocks include:

(i) The Energy Management Local System
(ii) The Communication System

The other two blocks are:

(i) The Mobile Application Interface
(ii) The Home/Office Appliance Interface

The block diagram of the smart power outlet with a mobile application interface is shown in Fig. 2. Fig. 3 shows the block diagram of the mobile application and home/appliance interface. The energy management system acts as a single input, multiple output switch, each output connects to a common input, where the sum of the total power leaving the smart power outlet equals the total input power. A wireless signal independently controls each output, which can either operate as an open or closed path. An internal microcontroller device controls each of the loads independently so that one load does not affect the status of another one.

The energy management system in the form of a power outlet is able to switch supply to an appliance either by accepting a fixed energy budget from the user, a time for switching the supply either on or off, an "ON" or "OFF" command from the user or the user can choose to take all the approaches. All these can be done remotely via the mobile application.

When the local system receives the command from the user; if the command is for the local system to either turn on or turn off supply to an appliance connected to one of the outlets, the local system responds to this using a channel relay module to switch supply to the outlet thereby disconnecting or reconnecting the appliance to the supply.

3.2 Software Design

This section contains the design of the program flow of the energy management system in the form of a microcontroller-based power outlet, dubbed as the Smart Power Outlet (SPO), and its mobile application interface.

Different software models were employed in the software design of this project. The programs for the microcontroller, the software for the server and communication/control from the mobile application (SPOv1.0) module were designed to ensure real-time monitoring and control.

For each design, the general appropriate software design procedures were employed. The procedures include (i) Problem identification and definition (ii) System analysis (iii) Program design (iv) Program coding (v) Testing (unit, integration and full system test) (vi) Documentation and implementation

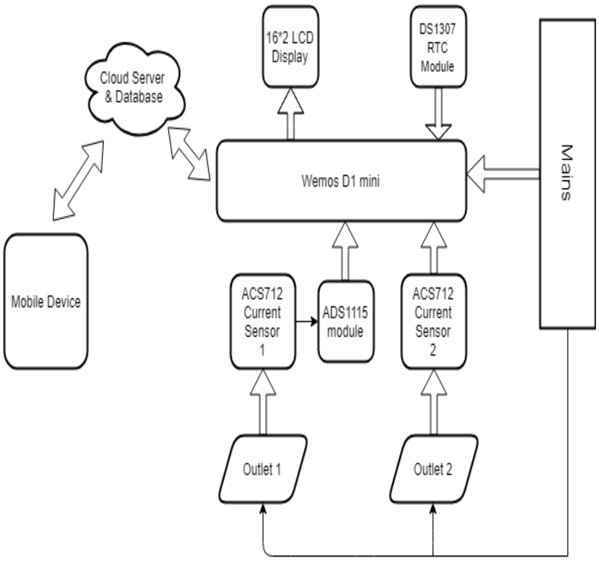

Figure 2: System with mobile application

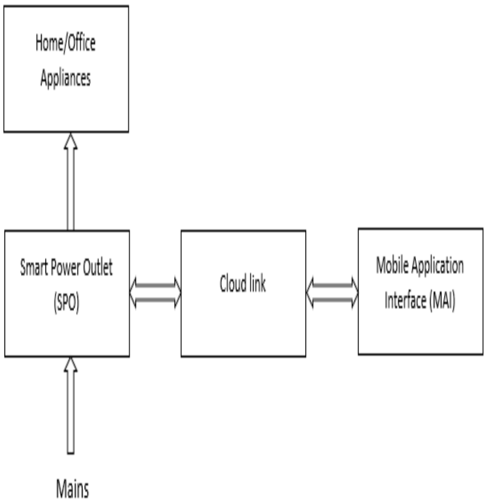

Figure 3: System with mobile application

The mobile application was built with Java using Android Studio as the Integrated Development Environment (IDE) [8]. It provides a remote interface to make or change settings in the local SPO system. The speed of the mobile application built should be as fast as possible with little latency especially with the fact that the application or software is built for IoT purposes.

The Android application built with Java using the Android Studio IDE is a very good choice for IoT applications because it is very fast and easy to access. Building with these technologies listed gives you a better and more efficient mobile application that can function without much time lags and can enable the user to access his/her devices remotely over the internet with just a click. The server-side aspect of the software was built with Javascript which provides a lot of rich libraries and frameworks to developers in order to build high performance web servers [9].

In the mobile application, given a rate in Naira per kilowatt-hour (N/KWH), say X and budget in Naira, say Y and the total duration of the budget in any unit of time is given by

$$E = \frac{Y}{X} \text{ (KWH)} \qquad (1)$$

$$\text{Power} = \frac{E}{time} \text{ (Hrs)} \qquad (2)$$

From (2) we can see that the current taken by an AC load is directly proportional to the power. The power factor of a domestic load is practically constant and assuming fluctuations in voltage to be minimal then the current is directly dependent on the power was taken by the load. Consequently, by controlling the current in a household the power consumed can be kept within a budget value.

3.3 Program Design

The mobile application and the webserver are the major components that drive the remote monitoring and controlling of the energy management system. A more detailed explanation of the entire workflow of the software including the description of the program itself is made using the help of program flowcharts. Here each module is separately discussed and explained with the help of a flowchart. The following block diagrams show the result of the program design stage of SPO for implementing some of the software requirements

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3.4 User Authentication

Before a user can use the mobile application to monitor and control his home/office appliances, the user must be authenticated first. The user does this by entering his or her username and password. Fig. 4 represents the flowchart of the program flow.

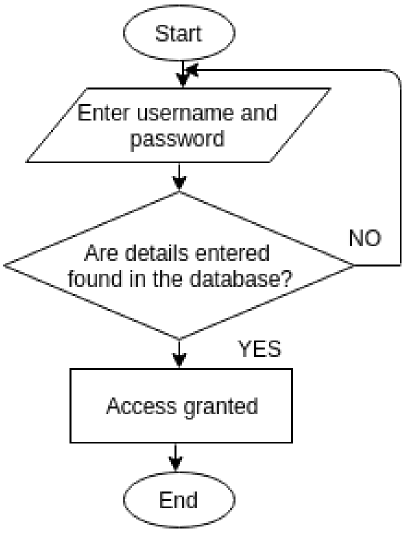

Figure 4: Flowchart of user authentication system

3.5 Outlet Control (Mobile Application Phase)

The user should be able to control appliances in the home/office remotely with the help of the mobile application and this program flow is represented in Fig. 5 below

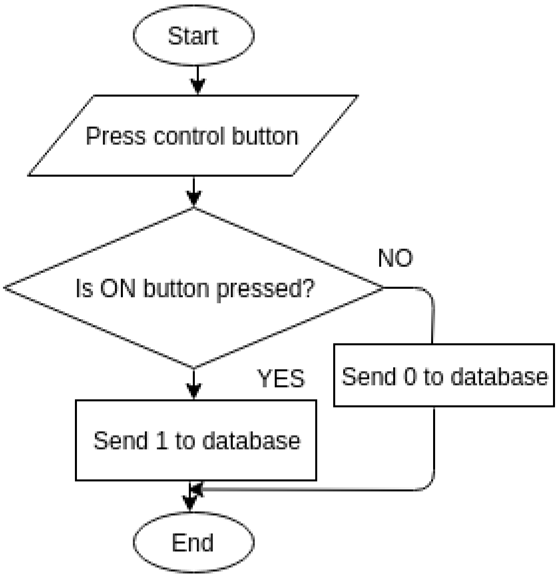

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Figure 5: Flowchart of outlet control–MAI phase

3.6 Outlet Control (Microcontroller Phase)

The controlling which involves the switching is done by the microcontroller, and the program flow is represented in Fig. 6 below.

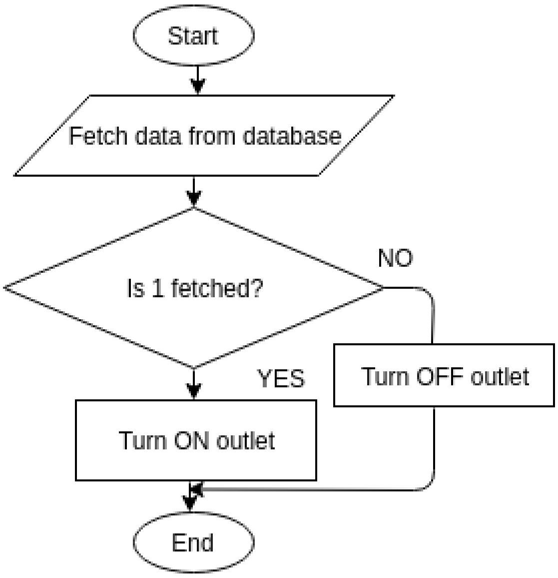


Figure 6: Outlet control – Microcontroller Phase

3.7 Energy Monitoring

One key feature of the Smart Power Outlet is energy measurement and monitoring. It enables the user to view and monitor the energy usage of his or her appliances in real-time. So, Fig. 7 represents the program flow of the energy monitoring system.

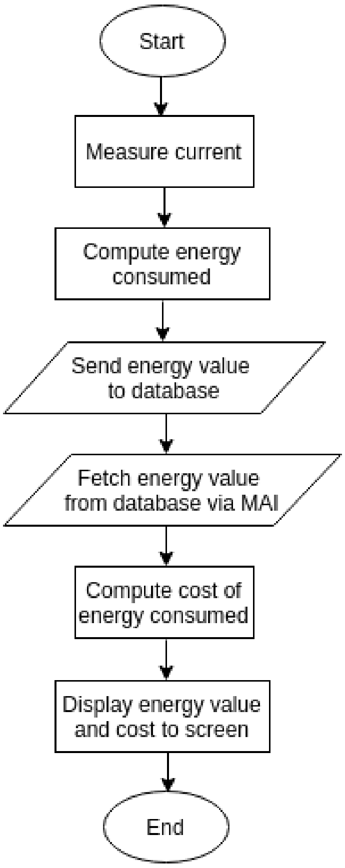


Figure 7: Flowchart of smart power outlet energy monitoring system

3.8 Energy Threshold

Sometimes, users might desire to be able to set energy threshold values in order for the system to switch off control once that value is reached or exceeded. This feature is very important and would be implemented in this project design. Hence, Fig. 8 above is the representation of its program flow.

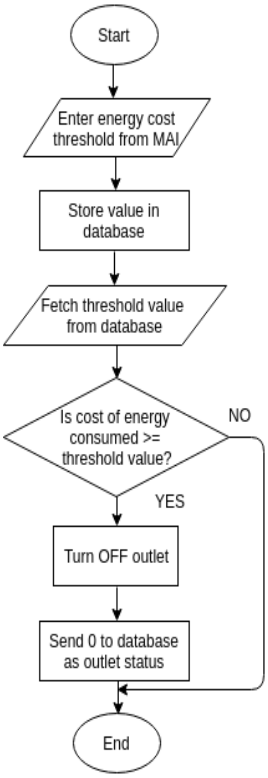


Figure 8: Flowchart of energy threshold control system

3.9 Time Control System

As part of energy consumption management, the SPO would give the user the ability to set time when the system is to turn OFF or ON the outlets. This program flow is represented in Fig. 9 below.

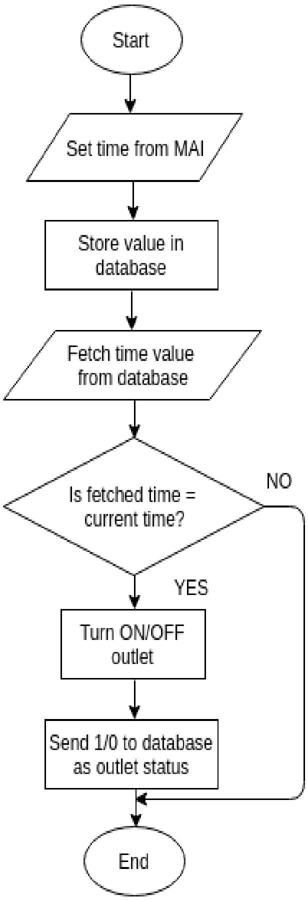


Figure 9: Flowchart of the time control system

3.10 System Testing

After the design, the system was tested unit by unit, module by module, subsystem by subsystem alongside the mobile application to determine that all the sub-units and subsystems were in a good working condition. The design was first simulated to determine the behavior of each subsystem before implementation.

The postman software was used to test the various API (Application Programming Interface) endpoints used in building the backend/server of the smart power outlet. Postman enables you to test your endpoints by allowing you to make HTTP (HyperText Transfer Protocol) requests.

IV. RESULTS AND DISCUSSIONS

Table 1 shows the energy value measured by the local system during a two hours test time. Table 2 shows the command sent from the mobile application and the observations, and then Table 3 shows the energy threshold value as set by the user along with the observations.

Table 1: Energy consumed on outlets 1 and 2

Outlet	**Average Rated (Watts)**	**Consumption in 2 hours (WH)**
Outlet 1	57	114
Outlet 2	223	446

Table 2: Results obtained via mobile application

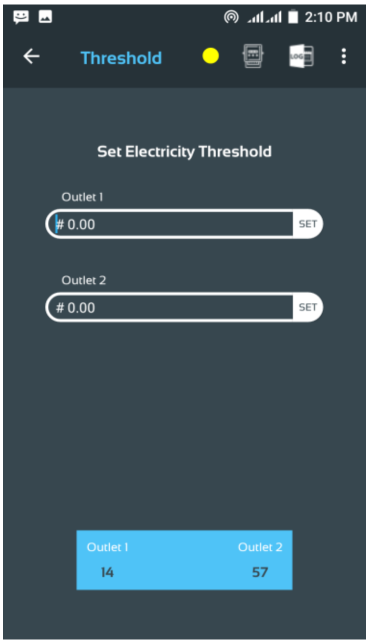
Outlet	**Command**	**Observation**
Outlet 1	ON	Outlet 1 was turned on
Outlet 2	OFF	Outlet 2 was turned off

Table 3: Results obtained via mobile application of energy threshold settings for outlets 1 and 2

Outlet	**Energy Threshold Value**	**Observation**
Outlet 1	14	When the energy consumed became equal to the threshold value, outlet 1 was turned off
Outlet 2	57	When the energy consumed became equal to the threshold value, outlet 1 was turned off

The mobile application was used extensively during the testing process, as it was used to switch on and off the outlets by way of pressing the respective buttons, it was used to set threshold values and also to set the time the user desires the supply to the various outlets to be switched off or on. The work was initially aimed at saving just indiscriminate energy consumed, but aside from the energy being saved, the user was also given the ability to schedule when he or she wants the outlets to be turned on or off. This is done via the mobile application. This use case is very important especially when a user wants any appliance connected to any of the outlets to be switched on or off automatically during a particular time of the day.

The system's budget and time schedule settings, and the local smart power outlet system are shown in Figs. 10,11 and 12.



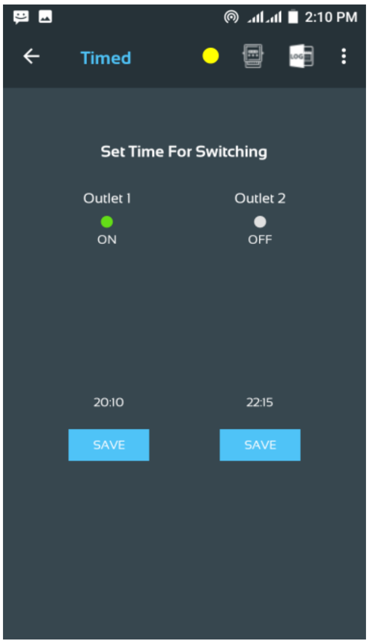
Set Electricity Threshold

Outlet 1
0.00

Outlet 2
0.00

Outlet 1 14
Outlet 2 57

Figure 10: Energy threshold setting screenshot



Set Time For Switching

Outlet 1
ON
20:10

Outlet 2
OFF
22:15

Figure 11: Time schedule setting screenshot

Figure 12: The local smart power outlet

V. CONCLUSION

The automatic control system realizes the automatic control for intelligent electrical outlets by WIFI communication technology and internet technology. The system is not only advantageous in cutting the amount of energy consumed indiscriminately, but it also helps users schedule time of the day they may want their appliances to be turned on or off. Also, the portability of the system has made it quite easy to be deployed anywhere.

This work focuses on the development of a Smart Power Outlet for energy management. The energy meter is designed to measure the different electrical energy parameters such as current and compute the energy consumed. The presence of microcontroller chips and integrated circuits makes this energy meter smarter and somewhat autonomous, thereby making it possible for users to seamlessly control and monitor their energy usage.

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