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ORIGINAL RESEARCH

A SMART GSM-BASED HOME ELECTRICAL APPLIANCES REMOTE CONTROL SYSTEM

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Abstract

Energy control systems have, over the years, experienced significant transformation due to technological innovations. Its importance has led to the development of a few models to realize home automation and resolve energy wastage. Wise use of electricity helps a nation become more energy-efficient, reduces the environmental impact, saves money on the electricity bills, and keeps the nation's electricity supply more reliable. This paper presents a prototype design to reduce electricity wastage in Ghanaian homes and offices. A Global System for Mobiles (GSM) module is used for receiving short message service (SMS) from the user's mobile phone that automatically enables the controller to take any further action such as to switch ON or OFF the home electrical appliances like light, air-conditioner, fan, etc. The system is activated when the user sends the SMS to the microcontroller. Upon receiving the SMS command, the microcontroller unit automatically controls the home electrical appliances by switching ON or OFF the device accordingly. A system prototype was developed and tested successfully. The system provides an effective mechanism to aid the efficient utilization of power in a developing country such as Ghana.

KEYWORDS:

Automation, Electrical Appliances, Energy Consumption, Energy-Efficient, Switch

1 | INTRODUCTION

TheThe use of electricity as one of the main sources of energy is critical and vital in modern lives since the advancement of digital information has led to a rapid change in human lifestyle. Technological advances have led to the development of control mechanisms for electrical devices to provide efficient energy management for households and workplaces. Electricity consumption in Ghana is estimated to be increasing by 10% per annum due to the demand from the growing population. There is a need to, in every way possible, conserve energy. In Ghana, undoubtedly, it is clear from the constant "blackouts" that the current national grid lacks security because of the unpredictable variation in power generation and distribution. The recent energy crisis in Ghana and the entire sub-region justifies the need for the present power system situation to be controlled since electrical energy is a limited resource that is not readily available.

Due to lifestyle issues, several people leaving their residence fail to turn off specific electrical devices that are not supposed to be in use, leading to energy wastage. Even though it is not always feasible to be physically around the home environment but whatever the case, much should be done to moderate energy wastage. In Ghana, these wastages are very high such that it is undesirable for economic development. Consequently, current technologies must widely resolve these energy wastages. Negligence on consumers' path to energy saving and safety practices can result in very high electric bills, power wastage, and reduced lifespan of electrical appliances. If we accidentally leave any home appliances, such as bulbs, microwave oven, tv, fan, etc., switched on, one can access these remotely via the mobile phone and switch them off through SMS. The Energy Commission of Ghana June 2014 launched the campaign "switch off the freezer" to educate the public to reduce energy consumption amid a substantial drop in energy generation. The campaign encouraged various households to switch their refrigerators and freezers off between 6 pm-12 am to save about 200-300MW of active power. This study has proven that switching off electrical appliances yields economic benefits. Thus, consumers save money, and the nation moves towards the goal of sustainable energy use. Home appliances could lead to high energy consumption if left on when not in service for a long time. Electrical home appliances that are left on when not in use or on standby mode in the homes account for 13 percent of household electricity consumption lost, a new survey revealed by the Gramax Energy Group (2014). This means that about 33 percent of the power generated in Ghana is lost through system losses and household negligence, the survey revealed. Switching off electrical appliances every day could be a good and economical way to save energy and pay fewer bills.

This paper presents the design and implementation of a smart GSM-based home energy remote control system that uses an embedded base station and a mobile software application on a smartphone to control the electrical appliances from any location wirelessly.

2 | PREVIOUS RESEARCHES

Several works have presented designs that employ a global system for mobile communication (GSM) technology[1–5]. In Parameswaran et al.[6], a smart home energy management system using GSM was proposed. This model primarily employed a power module, GSM modem, liquid crystal display (LCD), temperature, and passive infrared (PIR) sensor connected to a microcontroller unit. The power module has relays that switch the system's main power supply to an auxiliary (solar) power unit and vice versa based on signals received from the microcontroller. The temperature sensor detects and isolates electrical equipment from short circuits, and the PIR sensor likewise detects the user's presence to ensure the operation of light loads. The GSM modem enables communication of the system's information to the user via short message service (SMS). Even though this system has a low implementation cost and is cost and energy-saving, routine maintenance of the auxiliary (solar) power unit is required for effective operation. Any disruption in its process could result in a system failure.

Mubdir et al.[7] designed an energy-saving smart home automation system using an adaptive algorithm based on Hidden Markov Model (HMM). This smart home energy management system is essentially composed of a sensing unit (SU), a smart home gateway (HSG), and an end appliance unit (EAU). The sensing unit is made of both a PIR sensor that detects the user's indoor activities and a magnetic contact switch (door sensor) that likewise monitors the status of the main entrance door. Data collected from these sensors are transferred to the HSG and provided to the adaptive algorithm. The HSG primarily comprises a GSM modem and wireless fidelity (Wi-Fi) module interfaced with a microcontroller. It controls the EAUs through a Wi-Fi network based on data received from the sensing unit. The EAUs utilize electromechanical relays that either disconnect or trigger the operation of connected electrical appliances. A GSM modem is employed to enable remote communication and control of the home. Although this system, through its adaptive algorithm, saves some amount (18%) of energy and can be incorporated with security features, each appliance requires an EAU, which can be capital intensive for households with a lot of appliances. Moreover, using a Wi-Fi module in its operation makes the system less energy-saving.

Sy and Irfan[8], Chauhan et al.[9], Amoran et al.[10], Gaikwad and Kalshetty[11] present a home automation system using Bluetooth technology. Concerning Chauhan et al.[9], the model presented a Bluetooth-based home automation system using an android phone. This system utilized a microcontroller unit, Bluetooth module, and relay board essentially for its hardware

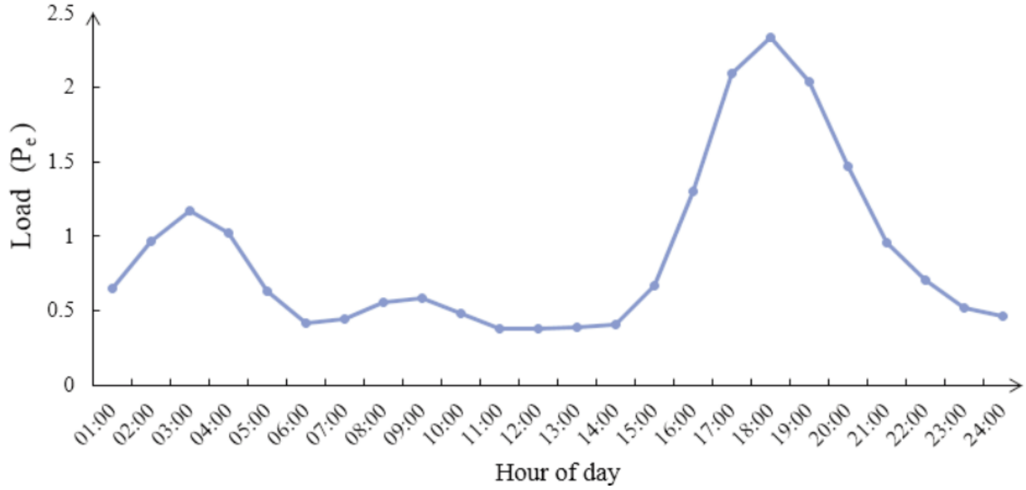


FIGURE 1 A daily load profile of a household.

implementation and an android application for its software design. The android application provides a user interface that authenticates the user's identity, searches, and pairs discoverable Bluetooth devices. Upon receiving signals from the user, the system enables control of electrical appliances using relays. Subsequently, a notification is provided to alert the user. This model is less expensive, user-friendly, and energy-efficient; nonetheless, Bluetooth provides limited remote operation and control.

Several studies have presented a variety of home energy management and control systems that uses wireless fidelity networks[12–16]. In reference to the model developed in[15], the proposed system is principally made of relays and a Wi-Fi module interfaced with a microcontroller. A user issue commands to the system over a Wi-Fi module through a smartphone application. Based on the signals received, the microcontroller triggers a relay to activate the required action as per its programmed algorithm. Though this model ensures faster data transfer and minimizes energy wastage, it is limited to a defined area or range of operation due to the use of Wi-Fi and restricted to only android-based smartphones.

Several models proposed in[17–20] employ voice or speech control in home automation systems to achieve energy management. Shan and Reddy[20] showcased a voice-based control system that employed a Geeetech voice recognition module. A user's commands are recorded with this module via a microphone. These recorded analog commands are converted to digital signals and transmitted to a microcontroller via Bluetooth. The microcontroller receives and processes the digital signals, which subsequently triggers relays to implement the desired control function. Alternatively, a Bluetooth module was provided to establish distant communication and control of appliances. However, this system offers energy efficiency and Bluetooth limits remote control operations.

Zigbee-based home automation systems have been developed in[21–25]. Regarding[21], a low-cost automation system having a separate transmitter and receiver module was proposed. Commands from a user are issued to a microcontroller via a keypad. These signals are processed and transferred from the transmitter module to a receiver module through the transmitter's Zigbee module. The transmitted signals are received over the receiver's Zigbee module, processed by a microcontroller, and, per its program, trigger the required relays to execute the needed action. Unlike wired-based home automation systems, Zigbee provides a low wireless cost and remote control of home appliances over short-range and periods, saving energy. Nevertheless, its low data speed, regular maintenance, and security vulnerability make it unreliable.

3 | MATERIAL AND METHOD

There are three variables used in this study, i.e. energy/Power Consumption of Home Appliances, electrical bill for an appliance, and load profile. The energy consumption of any home with an electrical appliance is generally based on the Eq. 1.

FIGURE 2 System architecture of a smart GSM-based home electrical appliances remote control system.

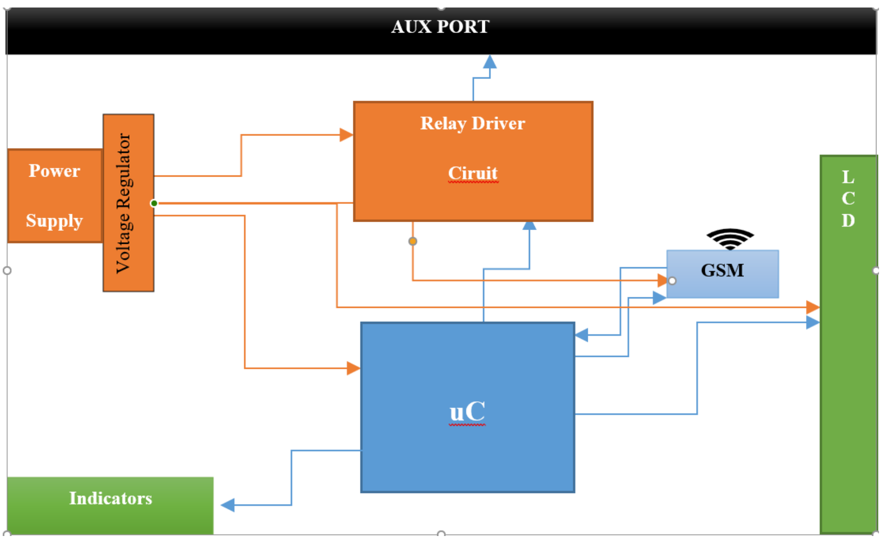


FIGURE 3 System block of a smart GSM-based home electrical appliances remote control system.

$$E = P \times \frac{1}{1000} \tag{1}$$

where E = energy consumed in (kWh or J), P = the wattage or rated active power of the appliance in (W), and t = operational time of the appliance expressed in (h). This equation, therefore, implies that the rated active power and the operating time of the appliances both influence the value of the energy consumed. The electricity bill for an appliance is calculated as follow.

$$Electricity\_bill = Energy\_consumption \times Electricity\_tariff \tag{2}$$

Electricity tariffs are rules or rates set by utility regulators for electricity supply to different consumers. For households in Ghana, the electricity tariff for households is framed at GHS 0.354 per kWh. Hence a higher consumption results in a higher bill. The load profile of a typical household with electrical appliances is given as Figure 1 [26, 27].

The given curve shows a peak hour where electrical appliances are primarily used and an off-peak hour, indicating the period when most devices are off. The area under this curve is the daily energy consumed.

TABLE 1 Prototype hardware components for the smart GSM-based home electrical appliances remote control system.

Component	Image	Description
Microcontroller	Figure 4 -a	A microcontroller from the PIC family. It was used as the smart unit for this project. All data processing and communications are done in the smart unit.
LCD	Figure 4 -b	An HD44780 LCD is used to display and report the status of the system
Relay	Figure 4 -c	A relay switch is used to connect the ULN2803 driver to the relay.
Relay driver	Figure 4 -d	A ULN2803 IC chip is used as a relay driver for switching ON/OFF a higher-level signal on the opposite side.
Power Supply Unit PSU	Figure 4 -e	PSU contains a transformer for ac source, a bridge rectifier to convert to a dc source, and the voltage regulator to get a 5V DC source. The PSU is used an integrated voltage regulator.
GSM Module	Figure 4 -f	A GSM communication module sends AT commands from the system prototype to the mobile software application and vice versa.
Status Indicators	Figure 4 -g	LEDs are used as status indicators and for troubleshooting.

3.1 | System Architecture

As shown in Figure 2 , the system architecture consists of an embedded base station and a mobile software application running on the user's smartphone. The base station has an auxiliary port through which all the electrical appliances to be remotely controlled are connected. The remote user uses the mobile software application on the smartphone to send text messages in the form of a data package that includes all commands and instructions to be taken. The system then switches ON or OFF the connected electrical appliances and updates the status with indicators and display. To check the status of any connected electrical appliances or load, the remote user sends a dedicated text message to the GSM communication module to request a status update of the said electrical appliance. Afterward, a feedback message is sent back to the user's mobile application.

3.2 | System Block Diagram

The block diagram of the system is shown in Figure 3 . The system consists of five (5) blocks or units: Power Supply Unit (PSU), Display Unit (DU), Microcontroller Unit (MU), Communication Unit (CU), and Relay Switch Unit (RSU). The power supply is regulated and distributed to the microcontroller, GSM, LCD, and relay driver units. The microcontroller and communication unit, which serves as the smart unit of the system, is equipped with a UART circuit that interfaces seamlessly with any AT command supporting the GSM modem. The user at a remote location sends SMS from the mobile phone to control the home electrical appliances. Upon receiving the mobile data package, the microcontroller decodes the received message and takes the necessary action. The smart unit pulls the SMS received via the smartphone, decodes it, identifies the MSN number, and switches on the relays attached to its port to control the electrical appliances. After a successful operation, the smart unit sends an acknowledgment to the user's mobile phone through SMS. Any SMS from an unauthorized MSN number is silently ignored.

At power-on, the system runs a power-on self-test (POST) check by activating and deactivating the GSM module and after that displays the system's status with the indicators (LED and LCD). The system calls the GSM modem to set the communication unit in active mode. After activation, the modem checks for hardware support or otherwise. If the hardware is not supported, missing, or any other hardware problem should occur, the system reports error and communication, and the application is terminated. In case of a positive hardware response, the serial port is opened for communication, and GSM hardware allows for transmission and reception of SMS.

3.3 | System Hardware Prototype Design

A hardware prototype was designed and tested. Table 1 contains some of the hardware components used and their functional descriptions. Figure 4 shows the images of each components that composed the smart GSM-based home electrical appliances remote control system.

There are five (5) main units: PSU, DU, MU, CU, and RSU. Figure 5 contains a schematic for the individual units, and Figure 6 shows details of the system circuit diagram for the prototype and units interfacing to the central microcontroller.

Implementation of the prototype was done on a perf board. Two perf boards were used to form two blocks: Block one and Block two. Block one consists of the PIC16F877A microcontroller chip, the GSM modem, the power supply unit, 16MHz crystal oscillator, and LCD connection port. Block two is made up of the relay drivers and four relays. These are connected to the loads

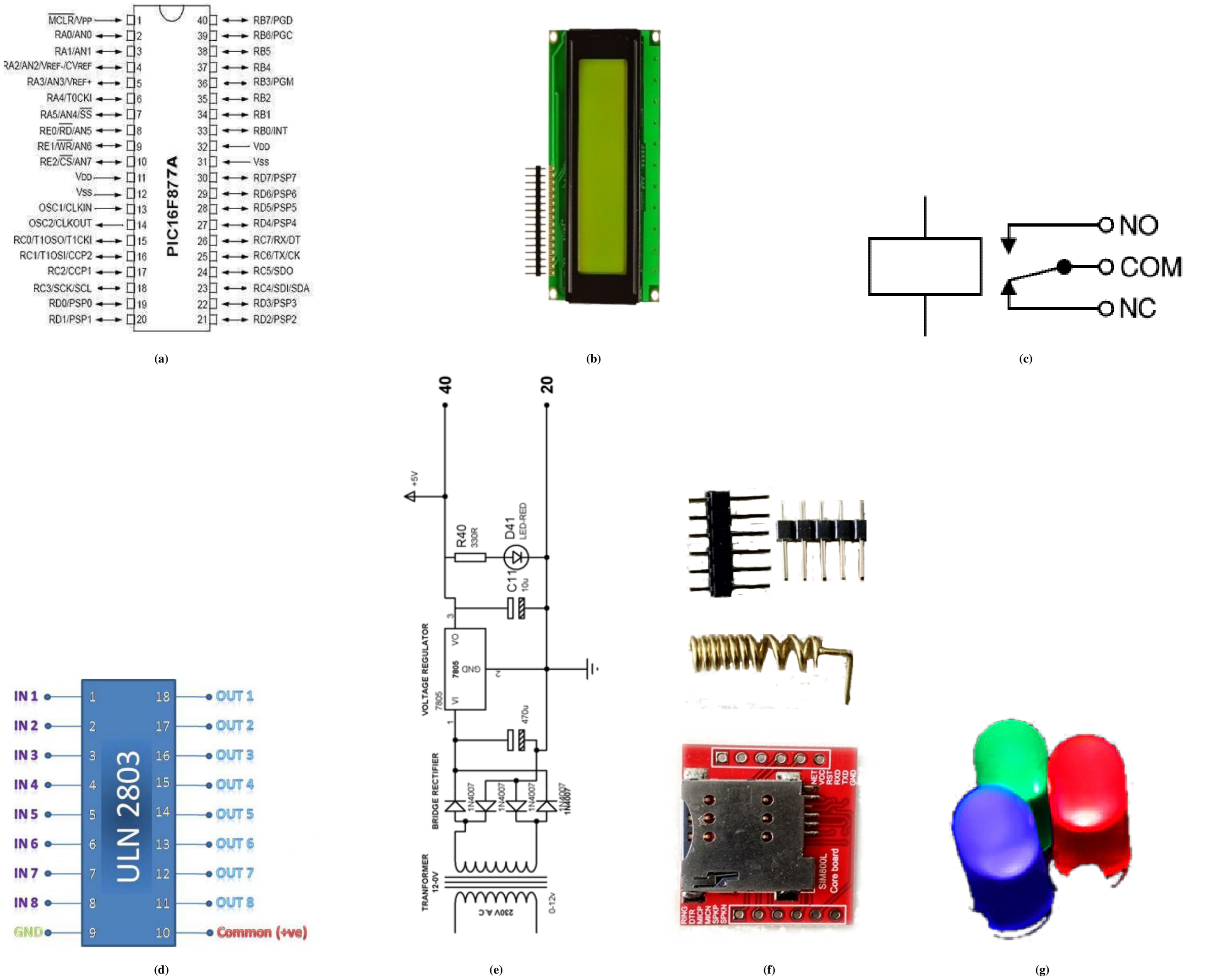


FIGURE 4 Images of each hardware components required for the smart GSM-based home electrical appliances remote control system.

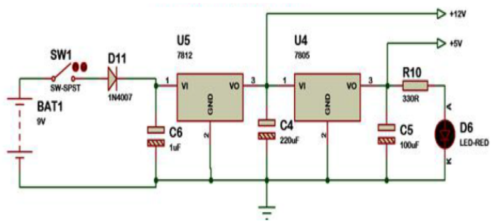
to be controlled. For test and demonstration purposes, LEDs were used as loads. Figure 7 depicts the system prototype used for testing and evaluation.

4 | RESULTS AND DISCUSSION

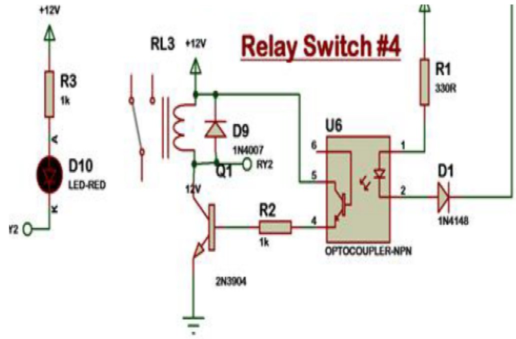
The individual hardware components and well as the complete system was tested. A test was performed to check first the GSM hardware module. The initial communication was established by opening the serial port of the GSM module. Serial communication begins immediately if the port opening was successful and terminates if otherwise. Figures 8 and Figure 9 show a successful system initialization and post results on the LCD.

The system prototype was connected to an electrical switch, a television, a light bulb, and an electric fan for test and evaluation purposes. Figures 10 and Figures 11 show the result of the test.

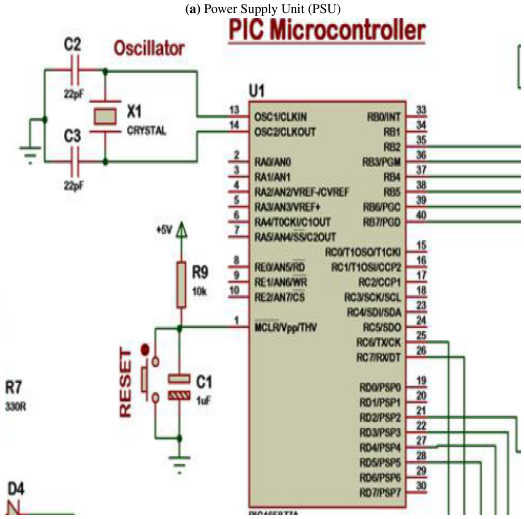
Various requests and action commands were sent to the smart unit for testing and evaluation. Tables 3 and Tables 4 contain example commands and actions taken upon reception.



(a) Power Supply Unit (PSU)

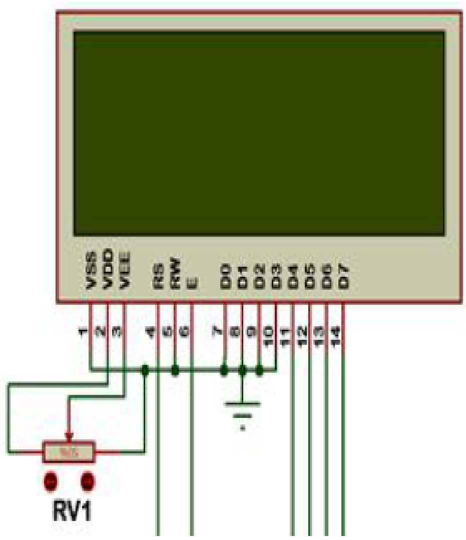


(b) Relay Switch Unit (RSU)



(c) Microcontroller Unit (MU)

(d) Communication Unit (CU)



(e) Display Unit (DU)

FIGURE 5 Schematic of the individual units.

When the user sends, for example, the command "rq", a feedback message is returned to the user, indicating the status of the individual electrical appliances attached to the aux port. Figure 12 shows screenshots of the mobile software application during the test phase.

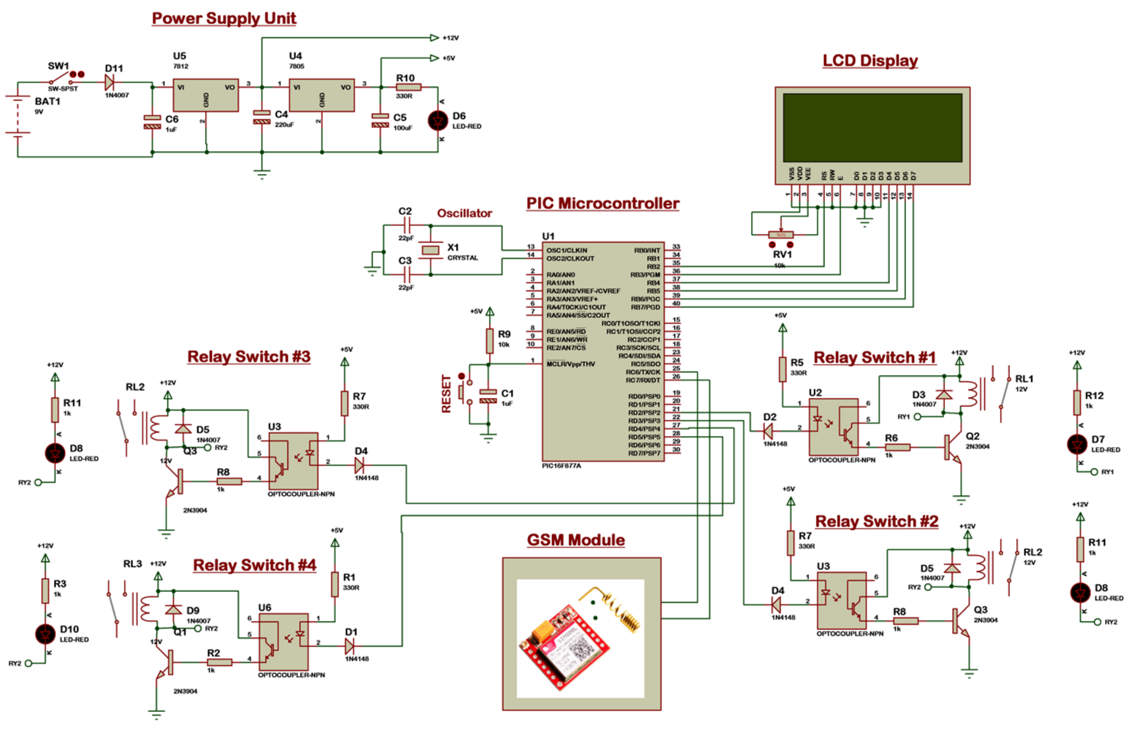


FIGURE 6 System circuit diagram.

TABLE 2 Hardware component list.

Commponent	Commponent
Microcontroller (PIC16F877A)	Resistors (1k, 10k, 330R)
GSM Module	Transistor (BC547)
4x20 LCD	Jumper Wires
5V Relay	IC - Seat (28- Pins)
Opto-coupler 4N35	Variable Resistor (10K)
Transistor BC547	Switch
Regulated Supply Module (12V, 2A)	LED (red)
Push Button (Momentary)	Male/Female Header Pin
Perf Board (PCB)	Junction Box (Package)
Electrolytic Capacitors (470uF, 100uF, 10uF)	I6MHz Quartz Crystal
Ceramic Capacitors (100nF, 22pF)	

5 | CONCLUSION

This paper has presented a low-cost and remotely controlled solution for automation and regulation of energy consumption of electrical appliances in homes. The approach discussed was found to be smart, efficient, and cost-saving. The prototype design performed as expected and was satisfactory to user needs and requirements. More interesting are the extensive capabilities and the cost-saving of the system. From the convenience of a simple software application running on a smartphone, a user can control and monitor virtually any electrical appliances in the household. Future works would look at the aux pins addressing and, for that matter, attached electrical appliances addressing. Tamper awareness would be implemented, and external access from unknown devices would be blocked. Port multiplexing would be implemented to provide room for more electrical appliances.

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This research did not receive any specific grant from fundint agencies in the public, commercial, or not-for-profit sector.

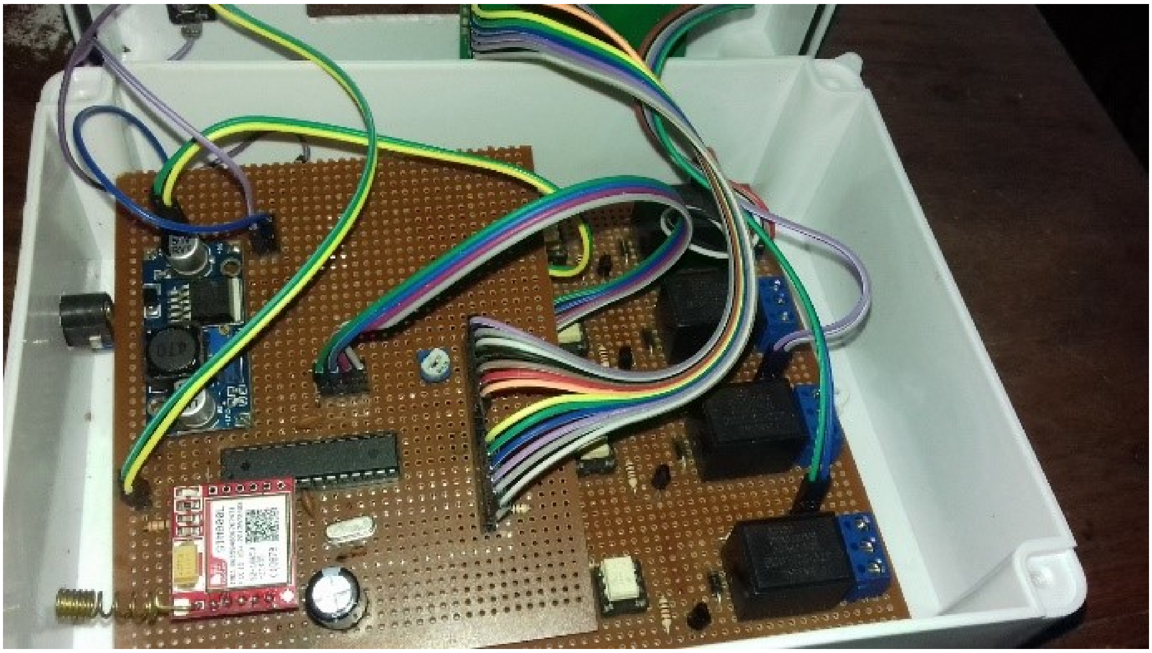


FIGURE 7 System prototype.

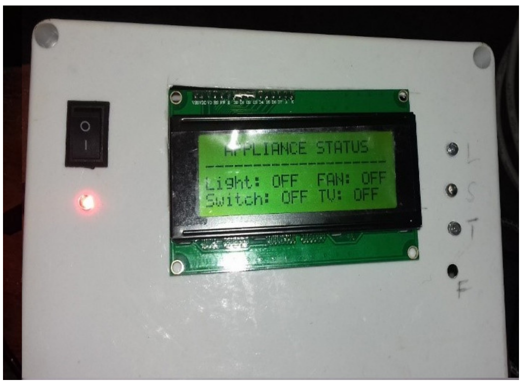


FIGURE 8 System prototype status after post.

FIGURE 9 Prototype status after GSM initialization.

TABLE 3 Commands and feedback messages ON.

Appliance	Message sent by the user to switch ON	Feedback message received by the sender
Light	L1rq	Light ON
Switch	S1rq	Switch ON
TV	T1rq	TV ON
Fan	F1rq	Fan ON
	L1S1T1F1rq	Light ON, Switch ON, TV ON, Fan ON

DECLARATION OF COMPETING INTEREST

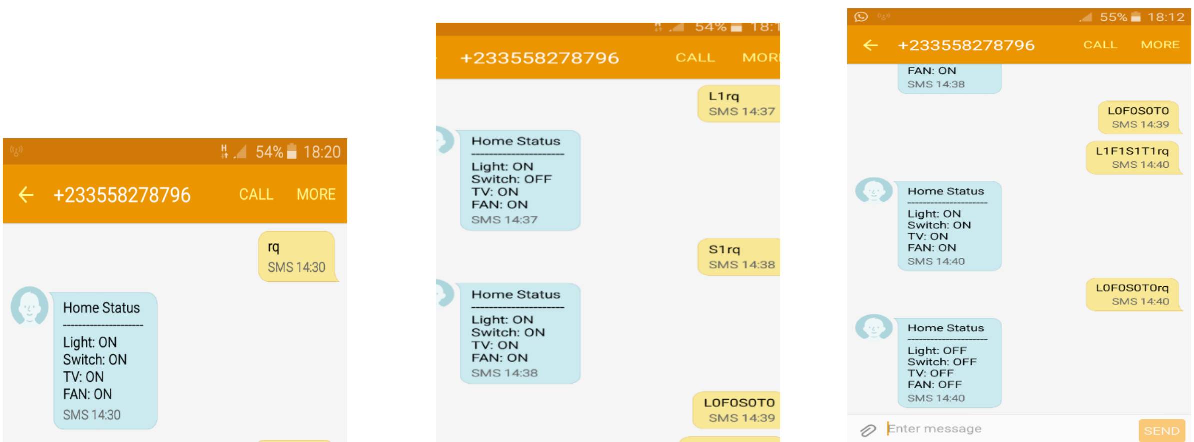
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

FIGURE 10 Communication test.

FIGURE 11 Electrical appliance test.

TABLE 4 Commands and feedback message OFF.

Appliance	Message sent by the user to switch OFF	Feedback message received by the sender
Light	L0rq	Light OFF
Switch	S0rq	Switch OFF
TV	T0rq	TV OFF
Fan	F0rq	Fan OFF
	L0S0T0F0rq	Light OFF, Switch OFF, TV OFF, Fan OFF



(a) (b) (c)

FIGURE 12 Mobile software screen shoots.

CREDIT

Elvis Tamakloe: Writing - Review and Editing, Formal Analysis and Investigation. **Benjamin Kommey:** Conceptualization, Methodology, Writing - Original Draft, Supervision, Resources.

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