DEVELOPMENT OF GSM BASED HOME AUTOMATION SYSTEM USING ARDUINO UNO MICROCONTROLLER

Supported by tetfund TERTIARY EDUCATION TRUST FUND

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Received: April 6, 2021 **Accepted:** July 11, 2021

Abstract: With the rapid expansion in population growth, advancement in the building and an associated increase in the energy consumption of energy-demanding appliances in residential building, there is a crucial need for energy conservation measures. Lack of remote access and control of household appliances has been identified as one of the main factors of energy wastage in Nigeria. This study presents the development of a global system for mobile communication (GSM) based home automation system (HAS). GSM SIM900 module was used as short message service gateway to switch ON or OFF the home appliances such as Fans, Fridge, Bulbs, Air-conditioner, Television set, DVD, DSTV, Speakers, etc via Arduino Uno microcontroller. Contrary to the wireless communication-based home automation that is prone to connectivity issues, limited coverage areas and security threat, the GSM based HAS is ubiquitous, accessible and also allows the homeowner to gain full remote control of household appliances and prevents imposter access via a password-protected system. The designed prototype was tested and further evaluated via questionnaire and the result show satisfactory performance in terms of network accessibility, usability, communication, functionality, interactivity, control and SMS notification schemes. Hence, this GSM-based home automation is recommended for household implementation which can serve as dual benefits in minimizing energy wastage and optimizing the energy consumption of electrical appliances in residential building

Keywords: Development, Arduino Uno, home automation, GSM, energy management

Introduction

Currently, global energy deficit has been a critical issue in the energy sector. Hence, the energy demand is on increasing as a result of population growth, urbanization, the quest for modern buildings, energy-demanding applications, and advancement in the building. As a result, energy use in residential buildings has witnessed rapid and incessant growth in recent decades. This is further inveterate by International Energy Agency that energy consumption in residential appliances constitutes almost 40% of annual energy consumption in developed countries and account for over 50% in Africa (www.iea.org). Researchers have also established that energy consumption in residential building depends on income level, occupant lifestyle, building, and household features, appliances, and thermal comfort desire. It also varies across the regions with 40% in the USA, 26.1% in the EU of which 14.1% is consumed by lighting and electrical appliances, 28% in the UK, 15% in Spain, 81% in Nigeria, 40-50% in Malawi and 23% in South Africa (Berardi, 2015; Eurostat, 2018; Kalua, 2020; Pérez-Lombard *et al*., 2008; Rn *et al*., 2020; Williams *et al*., 2020).

In 2016, two-third of 450Mtoe energy is consumed by residential buildings (Rousselot, 2018). It is further reported in the work of Okubanjo and coworkers that the larger fraction of this energy is wasted and could not be accounted for (Oyetola *et al*., 2019). Despite the injection of alternative (renewable) sources of energy into the energy mix to sustain and boost energy supply, the energy sectors are still facing a formidable energy crisis. Hence, the increasing concern of energy wastage and abnormal billing system in energy-demanding applications in residential buildings has stimulated the interest of researchers and scientists to integrate sensors, actuators, and network connectivity into the building via smartphone for efficient energy management and control. This scheme is termed as smart or intelligent home automation system (HAS) with core benefits of optimal control of home appliances, energy use reduction, energy-saving and safety (Fabi *et al*., 2017). The adoption of smartphone and recent trends in communication technology and the embedded system has transformed and improved energy use in the building. The communication technology has been adopted in a home automation system for different applications such as Bluetooth based home automation system (Sriskanthan *et al*., 2002), Wi-Fi-based HAS (Elshafee & Hamed, 2012), the Internet-of-Things (IoT) based HAS (Balamurali *et al*., 2017; Bhavna, 2018; Rajebhosale *et al*., 2017; Saurabh *et al*., 2017; Yang *et al*., 2018), Arduino based HAS (Gota *et al*., 2020; Ma & NiSan, 2020; Nathan *et al*., 2015). Artificial intelligent bases HAS (Coombs, 2020), cloud and android platform based HAS (Korkmaz *et al*., 2015), smart-agent based model HAS (Mehdi & Roshchin, 2015), ZigBee wireless communication based HAS (Güneş & Akdaş, 2016), GSM-based HAS (Khamees *et al*., 2018) Arduino and IoT based HAS (Aruna & Lakshmi, 2020; Kumar, 2020) and Brainwave based HAS (Zaki *et al*., 2018). For the sake of brevity, all the reviewed works of literature, along with their major findings are summarized in Table 1.

This study presented, Arduino Uno and SIM 900 GSM module based home automation system. The system is model to control electrical appliances through latest and evolving communication technologies such as Global System for Mobile Communication (GSM) that supports SMS communication between system hardware components. The choice of a wireless GSM network over other networks is the core benefits of a broad range of wireless connectivity, higher spectral efficiency and higher packet access. Besides, it facilitates roaming and protects the privacy of communication through encryption. The main objectives of this study are to develop a home automation system that can (1) optimize the energy consumption of electronic and electrical appliances in the households, (2) to enhance easy monitoring and controlling of electronic devices via smartphone for the vulnerable and low-income earners, (3) to minimize energy cost and save energy use through the integration of a GSM module and Arduino Uno microcontroller.

Table 1: A summary of recent literature on the home automation system

Author/year	Ref.	Technology used	Findings
Ashraf *et al.* (2020)	(Neha *et al.*, 2020)	Arduino, Android application	▪ Implementation of android based application to facilitate home appliances control for the elder and disable people.
Abu Sulayman *et al.* (2018)	(Abu Sulayman *et al.*, 2018)	Arduino, smartphone, PC home server	▪ Development of Matlab GUI to enhance effective monitoring and controlling of appliances from the user end.
Jiri (2015)	(Spale, 2015)	Web-server, AVR-based board	▪ Development of an adaptive web client for controlling gas boiler. ▪ Temperature optimization via internet
Nisar and Ibrahim (2018)	(Nisar & Ibrahim, 2018)	ZigBee, Android smartphone, Arduino, Bluetooth	▪ The developed system is capable to assist the physically challenged people to gain full access of their home appliances via ZigBee and Bluetooth and android based smartphone.
Singh *et al*. (2018)	(Saraswathi *et al.*, 2018)	IoT, MQTT protocol, Arduino	▪ Easy interaction of home appliances control ▪ Appliances control is based on sensor tariff conditions
Singh and Ansari (2019)	(Singh & Ansari, 2019)	Wi-Fi, ESP8266, Arduino, Sensors, IoT	▪ Allow multiple users to remotely control home appliances. ▪ The proposed system is an energy management conservative. ▪ The application is suitable for home, security and safety use
Chioran and Valean (2015)	(Chioran & Valean, 2020)	Arduino, Visual C-App, Sensors	▪ Proposed an alternative home automation system to wireless communication which averts the risk of electromagnetic radiation
Gurek *et al*. (2015)	(Korkmaz *et al*., 2015)	Cloud, Android, Google Cloud platform and Google Cloud message	▪ Message between components is based on google services. ▪ The system is flexible for future integration.
Manoj *et al*. (2018)	(Manoj & Subba, 2018)	Arduino, Bluetooth, Android application	▪ Embedded with user security to prevent unauthorized user ▪ The system communication is Bluetooth based.
Prusty (2017)	(Prusty, 2017)	Bluetooth, Arduino, Android	▪ Bluetooth automated system ▪ Friendly and easy to use. ▪ In built facility that supports home automation for people with disability.
Zaki *et al*. (2018)	(Zaki *et al*., 2018)	Raspberry Pi, BCI, Neural pattern recognition, EEG-based computer system	▪ Integration of neural pattern recognition to facilitate home appliances control for people with Amyotrophic lateral deficiencies.
Lalit *et al*.	(Lalit *et al.*, 2018)	Arduino Uno, IoT, ESP8266-01Wi-Fi module	▪ The developed system is server independent to allow easy connectivity access. ▪ The system is password-protected to prevent an imposter from gaining remote access to the home appliances.
Sharif *et al*. (2018)	(Sharif *et al*., 2018)	Arduino, sensors, IoT, Smartphone	▪ Miscellaneous tasks in the living units are centralized for easy remote control via smartphone.
Karyawati *et al*. (2017)	(Dewi *et al*., 2018)	Android application, web-server, smartphone (Gawai), sensors, Modem	▪ Proposed IoT based energy management for home automation. ▪ It minimizes the use of PLN with a reduction of about 18.6% efficiency
Khairwal (2018)	(Kaur *et al.*, 2016)	Smartphone, Android application, Wi-Fi module	▪ Developed a low-cost monitoring system for building fire automation
Gray *et al.* (2020)	(Gray *et al.*, 2020)	IoT, Modem (HGW), Cloud service, Sensors, Actuators	▪ Developed a system-level model to evaluate the significant impact of energy consumption for consumer HAS on household devices. ▪ The result of his study shows that HAS consumed more than one-third of the total energy used in the middling home without significant influence on ICT energy

Vujovic and Maksimovic (2015)	(Vujović & Maksimović, 2015)	Raspberry Pi, sensors, IoT	imprint. ▪ Implemented a raspberry Pi sensor web-based HAS system to enhance flexibility and functionality.

Materials and Method

In this paper, various hardware components are integrated into designing and implementing a customized GSM based home automation system. These components are well-detailed as follows:

Smartphone

A smart phone is a handled mobile device embedded with an integrated circuit to enhance cellular network connectivity. It is a compact based device integrated with cellular and mobile computing capabilities. It is similar to a mini-computer that runs on a mobile operating system (OS) with inbuilt hardware capabilities that enable the device to perform special tasks. It is further integrated with various sensors that can be leveraged with mobile software such as a magnetometer, proximity sensors, and gyroscope and also supports 2G, 3G, 4G, 4GLTLE data network, Bluetooth, Wi-Fi and satellite navigation wireless communication. The core functions of the smartphone are for voice calls and text messaging and it is further extended with latest technologies to cover internet services, multimedia functionalities, video chatting, and location tracking device-GPS, biometric for identification, digital assistant, and software application. The smartphone is depicted in Fig. 1a.

Arduino Uno

Arduino Uno (Quer, 2014) is the most acceptable board among Arduino series board-based. It is considered as an open-source-based hardware computing platform for developers and programmers. The Arduino Uno board uses the ATmega 328 microcontroller and has unique features of ATmega 8U2 chip over other boards of Arduino for USB to-serial converter. This microcontroller features an inbuilt 14 digital I/O (6 pins can be utilized as PWM output) and 6 analogue inputs, 16 MHz crystal oscillator, USB port connection, connector Jack, ICSP header, and reset button. The latest version of the Arduino Uno (Rv3) has been improved and upgraded with new features to accommodate future purposes. The ATmega328 microcontroller is coded in the Arduino integrated development (IDE) using C or C++ programming language. The Arduino Uno has enabling-communication features that can be interfaced with a computer, other Arduino and microcontrollers. It supports Wi-Fi (ESP8266), Bluetooth, GPS, and GSM via UART TTL (5V) serial communication, and 12C (TWI) and SPI communication for sensors. The Arduino Uno is depicted in Fig. 1b.

GSM module SIM900

SIM900 is an embedded hardware GSM/GPRS module in a Surface Mount Technology (SMT) platform integrated with single-chip AMR926EJ-S core processor (Nasution *et al.*, 2017). It has an inbuilt subscriber identity module (SIM) cardholder that establishes communication with the GSM/GPRS technology. It supports Quad-band frequencies of 850/900/1800/1900 MHz and also features RS322-based serial port for connection, RF antenna for sending/receiving a signal to the SIM, 12 GIPOs, 2 PWMs, ADC, DC jack, SMA connector, Voltage regulator, U,FI connector and Power led. SIM900 enhances SMS, MMS, GPRS, Audio, Voice, Fax, and Data communication via UART using AT command (Jivani, 2014; Panth & Jivani, 2011).

It uses UART protocol to communicate with Arduino and other microcontrollers in most embedded applications and also embedded with TCP/IP protocol stack. The SIM900 GSM module can be integrated with Internet-of-Things (IoT) and embedded system. The GSM module SIM900 is illustrated in Fig. 1c.

Buck converter

Buck converters are emerging in low voltage, low power applications (Kovacevic & Stojanovic, 2016). It is a power-based converter for scaling down DC supply voltage to a lower output level via a switching control using a pulse width modulation technique (Potnuru & Anilkumar, 2017; Viswanatha & Reddy, 2017). The buck converter is also known as a step-down converter, switching converter. It belongs to the class of switched-mode power supply (SMP) with greater power efficiency. It uses inductor and capacitor as a filter component for smoothing the output voltage. The bulk converter has two modes of operation namely, the continuous conduction mode (CCM) and discontinuous conduction mode (DCM). In the continuous conduction mode, the inductor current remains positive throughout the switching period and the inductor current remains zero for some time in the discontinuous mode. The core advantages of the bulk converter are for matching load with the power supply, circuit isolation and voltage regulation. In most cases, it is integrated into electronics circuit or low power DC/DC conversion applications to compensate for different voltage requirement of all components that function at various voltage domain. The DC-DC buck converter is shown in Fig. 1d.

Four-channel relay module

A relay is an electromechanical switch that mainly functions as an isolator between controlled and control circuit. It operates electrically and uses the principle of electromagnetic induction to control electronic circuits and devices. The relay consists of four parts namely, (1) electromagnet (2) Armature (3) spring and (4) set of electrical contacts. Thus, a 4 channel relay is a module integrated with four relays for switching control of various home appliances and other devices with large current capacity. It features four SPDT relay output with 4, 15-20mA Driver current, equipped with high current relay with maximum switching voltage and current of 250VAC/30VDC and 10A respectively, optoisolated inputs and LED relay output status. It can be integrated with a microcontroller such as Arduino, Raspberry Pi, 8051, AVR, PIC, DSP, ARM and TTL logic for direct control of electrical appliances. The 4-channel relay is depicted in Fig. 1e.

Adapter

The adapter is a device that converts electricity from a mains to a low voltage direct current (DC) suitable to power electronics or embedded devices or components. It is usually used to adapt the electricity to a voltage needed by most electronics components. It is rated based on the power requirement of the components. An AC-to-DC is a switched-mode power supply that is embedded with a transformer, a rectifier, and an electronic filter to function as a voltage converter. The adapter is shown in Fig. 1f.

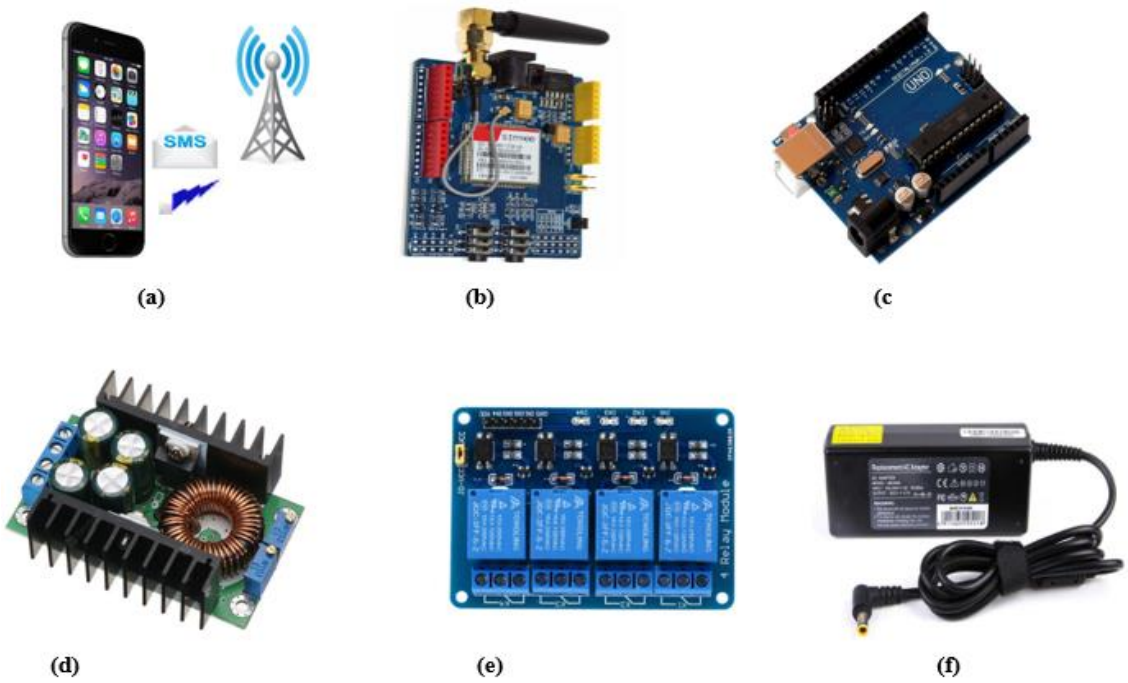

Fig. 1: The hardware components for the home automation system; (a) Smartphone (b) sim900 GSM Module (c) Arduino Uno (d) Bulk converter (e) 4 Channel Relay (f) DC supply

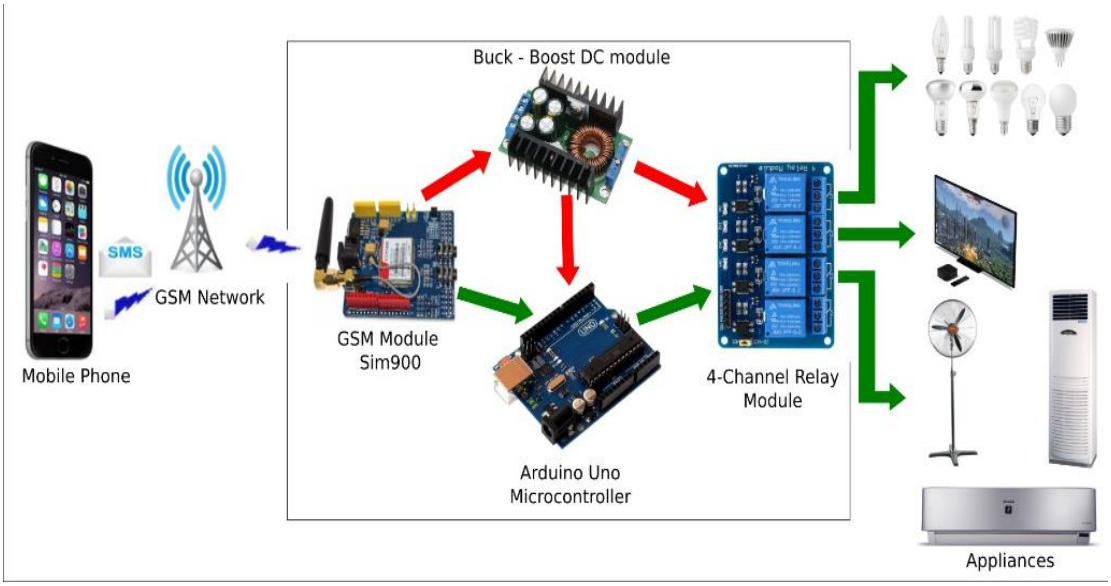

Fig. 2: System architecture

System architecture

The system architecture is the conceptual framework of the proposed GSM based home automation system. The system design is based on four-tier structural features namely: Tier-I, Tier-II, Tier-III and Tier-IV. Tier-I consists of a mobile station, a smartphone that serves as a controller for sending and receiving commands and messages via cellular network connectivity of 2G. In Nigeria, the network service providers are Glo, MTN, 9mobile, and Airtel. It also used to establish command and control text messages to the connected devices. Tier-II is the data processing unit which includes an Arduino Uno microcontroller. It acts as the brain of the processing units. The Tier-2 is responsible for coordinating, controlling, and managing the communication inflow of the connected hardware components. Various wireless communications are accessible for Tier-III such as 2G, 3G, 4G and 4G LTE.

Tier-III is a communication module that consists of a GSM/GPRS unit. This unit is accountable for communication between the microcontroller and the smartphone. It is SMS-based hardware for receiving and sending SMS data and commands. Tier-IV is the relay switching module that utilizes a 4-channel relay to activate and deactivate the household appliances and devices. Tier-IV is connected to the home appliances such as Fans, Fridge, Bulbs, Air-conditioner, Television set, DVD, DSTV, Speakers, etc through an electrical main as illustrated in the system architecture shown in Fig. 2.

System implementation

The main hardware components are assembled on the Vero-board and further tested for continuity and functionality of connected devices and later integrated into a prototype design. The Vcc and GND of the GSM module sim900 and 4-channel relay are joined to Vcc and GND pins of the Arduino Uno. Also, the connection of the GSM module sim900 with the Arduino Uno microcontroller is achieved via TX serial pin (transit) and RX serial pin interface. The transit signal pin (TX) and the receive signal pin of a serial portion of the sim900 module are connected to the physical pin7 and pin8, respectively. Arduino Uno digital pins 4-7 are connected with IN pins1-4 of the 4-channel relay module. Further, the GND pins of the relay module and buck converter are mapped with the GND of the Arduino Uno microcontroller. So, the Vcc pins of the 4-channel relay are linked with the 5V pin of the Arduino Uno. 8A constant voltage module step-down the dc voltage of 19.5 V power adapter to 5V constant voltage to drive the Arduino Uno and further converted to the required voltage by buck converter to drive other peripheral devices based on the voltage specification. Furthermore, the Arduino Uno then transmitted the text messages through the UART communication interface using a set of AT commands to the 4-channel relay via sim900 GSM module and a smartphone (mobile station). The overall schematic diagram of the GSM based home automation system is shown in Fig. 3.

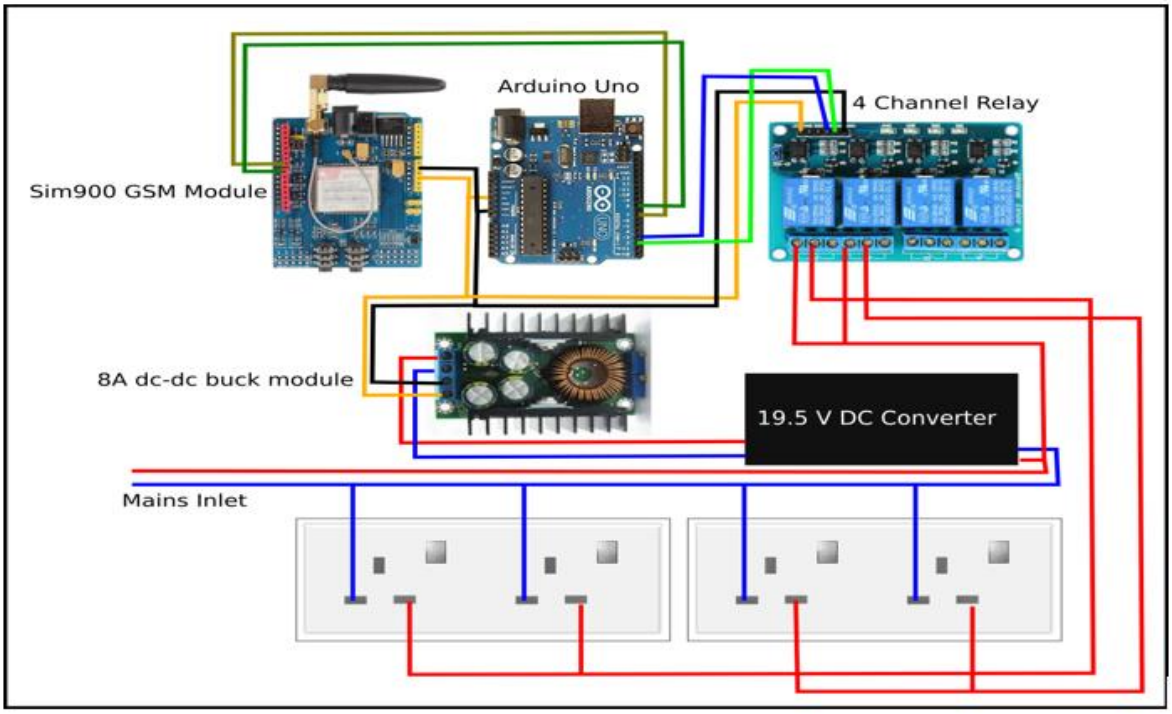

Fig. 3: Schematic diagram of GSM Based HAS

Results and Discussion

The GSM home automation system consists of an Arduino Uno as a controller, SIM900 as an SMS gateway, 4-channel relay as an output and a smartphone as an input. The system functions based on the set of instructions or messages sent through a smartphone via SMS gateway to the Arduino Uno microcontroller. Hence, the Arduino Uno further interprets, extracts, processes and controls the relay switching unit based on the user-defined instruction inform of a string of data to either switch ON or OFF the household appliances and devices. Then, the user receives a notification as feedback mechanisms from the Arduino Uno via the smartphone on the status of the appliances. The design prototype was experimental with ten different input data string to confirm its potency as well as the Arduino Uno SMS feedback schemes was also examined as illustrated in Table 1.

Table 1: SMS feedback schemes from Arduino

S/N	String data input	Socket output	SMS notification from Arduino Uno
1	" sc1on"	Socket 1 *on*	"Socket 1 on Master"
2	" sc2on"	Socket 2 *on*	"Socket 2 on Master"
3	" sc3on"	Socket 3 *on*	"Socket 3 on Master"
4	" sc4on"	Socket 4 *on*	"Socket 4 on Master"
5	" scotton"	All Socket *on*	"All Socket on Master"
6	" sc1off"	Socket 1 *off*	"Socket 1off Master"
7	" sc2off"	Socket 2 *off*	"Socket 2 off Master"
8	" sc3off"	Socket 3 *off*	"Socket 3 off Master"
9	" sc4off"	Socket 4 *off*	"Socket 4 off Master"
10	"scotton"	All Socket *off*	"All Socket off Master"

In the design prototype was further tested with the available service provider networks in three areas to evaluate network performance as illustrated in Figs. 4, 5 and 6. Also, the system prototype functionality was examined by 10 users via a questionnaire based on 5-point Likert scale rating on 1to 5 scale with 5 denoted "Excellent" and 1indicated "poor" as illustrated in Table 2. About 80% of the users rated "Excellent" and 20% users rated with "Good". The users' rating distribution, as well as the questionnaire's assessment statement is shown in Table 3.

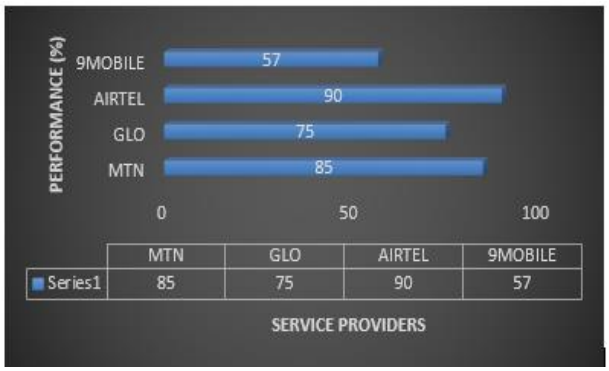

Fig. 4: Performance analysis of network service providers in Ibogun Campus

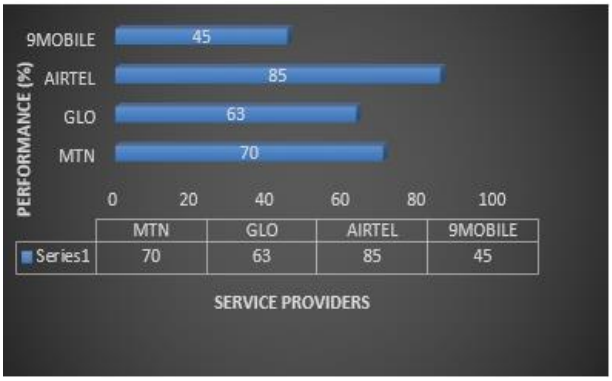

Fig. 5: Performance analysis of network service providers in Ibogun Olagun

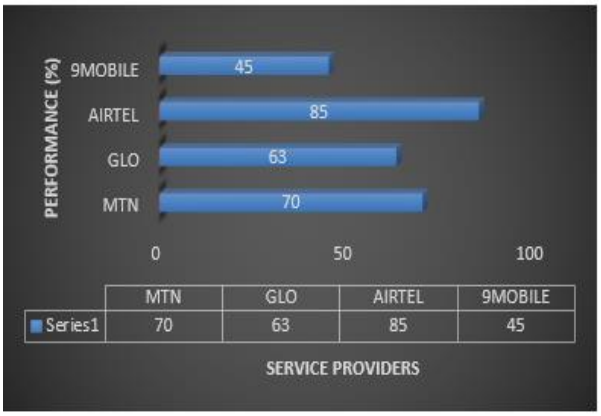

Fig. 6: Performance analysis of network service providers in Ibogun Fashina

Table 2: Data measurement index

Scale	Range	Interpretation
1	4.6-5.0	Excellent
2	3.7-4.5	Good
3	2.8-3.6	Average
4	1.9-2.7	Fair

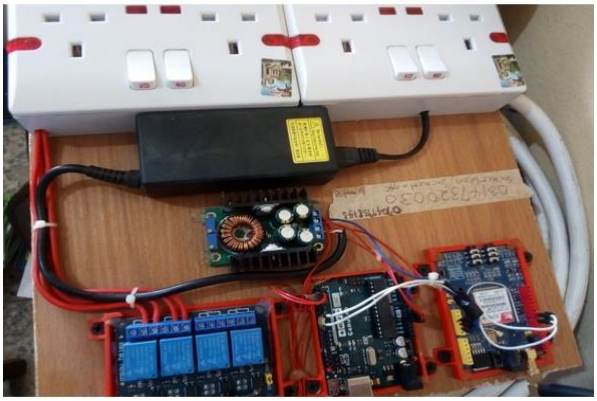

Fig. 7: Developed GSM home automation system

The command presented in Table 1 was verified with the design prototype within three selected areas in Olabisi Onabanjo University, engineering Campus and the network performance of the service providers in responding to the design prototype accessibility was also examined. It can be inferred that the developed system function as intended with the MTN, Glo, Airtel and 9Mobile networks but the performance varies with the signal strength of the network service providers. Also, the performance evaluation indicated that for all the four prominent networks, the Airtel is the best and the most reliable due to its wide-range of network coverage and strong signal strength in all the three areas follow by MTN and Glo. However, the 9Mobile network is intermittent due to inaccessibility of 9mobile telecommunication mask and tower within the area (that is only available in the city which far from the campus). Besides, cases of message delay were reported in Glo and 9Mobile networks.

Table 3: Test data interpretation

Design	5	4	3	2	1	Aggregate	Mean	Description
Compare to other HAS instruments I have used, I noticed that the GSM-HAS is more reliable, accurate and dependable.	6	3	1	0	0	10	4.5	Good
The developed system (GSM-HAS) is user-defined compliance	8	2	0	0	0	10	4.8	Excellent
The GSM-HAS does not delay or crash with GSM network	7	2	1	0	0	10	4.6	Excellent
The control command or text message is secured without data loss	8	1	1	0	0	10	4.7	Excellent
The Arduino Uno feedback mechanism on home appliance status is unmatched	7	2	1	0	0	10	4.6	Excellent

Furthermore, the test data presented in Table 3 show that the respondents are much satisfied with the design prototype based on their rating. In terms of network accessibility, usability, communication, functionality, interactivity, and control and SMS notification, the developed system was rated on a scale of "Excellent". Moreover, the design prototype was integrated with a password-protected encryption system to secure the home appliances control schemes and inhibit unauthorized access of an intruder and only the master or homeowner can access the GSM home automation system via the smartphone. The overall system design is shown in Fig. 5.

Conclusion

In this study, the development of GSM based automation system using Arduino Uno microcontroller was presented. The increasing concern of energy wastage and abnormal billing system in residential building has stimulated the interest of this research. The proposed framework uses four-tier architectural features to facilitate SMS message, data processing, GSM/GPRS communication, and switching control. In this study, an Arduino Uno, GSM SIM900 module as an SMS gateway, 4-channel relay, and smartphone were integrated into GSM home automation system to enhance easy monitoring and controlling of electrical appliances, minimize energy cost, and save energy use.

Furthermore, the integration of GSM shield in the developed system has substantially improved household appliances control and energy management in the residential building by eliminating the limitation of limited coverage areas and signal crashes or delays that are associated with other wireless communications such as Bluetooth, Internet-of-Things (IoT), ZigBee and Wi-Fi. A designed prototype has been developed and tested within three areas of Olabisi Onabanjo University, Engineering Campus, the result shown that the developed system was adept and suitable to reduce the problem of energy wastage and also improved the remote control of home appliances. In terms of accessibility, usability, sending and receiving SMS messages, controlling and SMS notification schemes, the system was rated "Excellent "by the respondents. In contrast to other existing designs, the developed system has an advantage of a password-protected system that enhances data security of the system against an imposter. With the GSM based home automation system, the homeowner can get personalized communication of actions on energy usage status and also prevent abnormal billing system.

Acknowledgement

The authors would like to appreciate various authors whose literature provided detailed information that assisted in the preparation of this manuscript. Also, various comments and suggestion received from the co-researchers that have added value to this work are also appreciated.

Conflict of Interest

The authors declare that there is no conflict of interest related to this work.

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