DEVELOPMENT OF AN ANDROID BASED APPLICATION FOR UBIQUITOUS ENERGY MANAGEMENT IN THE HOME

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ABSTRACT:

In most developing countries, the supply of electrical energy required for the effective running of the home is grossly erratic, inadequate and expensive. As such, the need to efficiently manage this supply when available is not out of place. However, the burden of ensuring that this erratic energy supply is adequately utilized without wastage lies on all stakeholders. Over time, several technologies have been developed in a bid to ensuring that this expensive and scarce resource is adequately utilized at home. However, these technologies have not been able to optimally manage the energy utilization in the home; they have also not been able to provide users with desired flexibility, and they are most times expensive to acquire. In this project, we develop an Android-based Mobile Application that enables users to ubiquitously regulate electricity consumption in their home. The application provides users with the ability to switch ON/OFF connected devices that are in the home, thus helping in reducing power wastage and cost of power consumed by users. The hardware enables the home appliance to be connected to it via sockets. For the brain of the hardware, we adopted an ESP-8266 Wi-Fi module which acts as both the microcontroller and the wireless access point that connects the hardware to the internet. Based on testing results, the project was able to achieve a response time of 1sec under normal network conditions. Similarly result on deployment show about 12.567%energy saving and users adjudged the system to be more convenient.

KEYWORDS: *Android, Energy, ESP-8266 Wi-Fi module, Internet, Microcontroller.*

1. INTRODUCTION

Over time, Home Energy Management Systems (HEMS) have been seen as systems installed in a home to enable users to monitor energy usage in a bid to reducing energy consumption and minimizing energy utilization. This definition, however, has been reformed to accommodate the energy needs of the users. Recent definitions, encompasses both hardware's, software, and other firmware's that aid the easy transmission of information relevant to the energy consumption of the home and other control functionalities of such system. According to Amoo et al [1] HEMs is any system committed to the monitoring, optimization and control of energy utilization by domestic load. From this definition, it is obvious that the main objective of any HEMs is to optimize consumer cost by managing consumer demand [2]. Conceptually, HEMS is a subset of the broader field of Energy Management Systems (EMS) which has been in operation for a long time in the energy sector. However, HEMS being a more recent concept focuses on the need of energy users to control appliances in and around the home more efficiently [2, 3]. This concept is closely related to Home Automation (HA), which include the regulation and automation of lighting systems, heating- ventilation and air conditioning (HVAC) systems, home equipment's such as washers, ovens and refrigerators and security systems [3].

The development of labor-saving machines [4, 5], began in the 1900s. During this period, advances in power distribution systems, resulted in the development of many home appliances. These contributed to the demand for automation in the home as there was the need to regulate the energy consumption of these equipment owing to the high cost associated with energy supply [6].

The birth of the digital revolution came with the development of three generations of HA systems. The first generation used wireless technology with a proxy server in automation (they deployed Zigbee technology). While the second generation HA system utilizes Artificial Intelligence (AI) to control devices, and finally the third generation HA system uses robotic aids that interact with humans to get things done around the home [5-6]. Recently there is a drive to develop efficient smart homes that are secure, run on green energy and leverage on the omnipresent nature of the internet in realizing energy efficient and secure home. This inspiration forms the underpinning for the Internet of Things (IoT) [7].

Also, advances in the development of smart devices have also been instrumental in this drive as over 85% of adults have smart devices that are connected to the internet. This invariably provides a viable market for HEMS systems developers and energy producing companies [8-10]. In most developing countries, android smart devices are currently the most popular devices on the market [11]. This is attributable to their relatively low price when compared to other smart devices like iPhones, Samsung etc. Also, these devices are easier to operate owing to the ease associated with direct manipulation of their interface using touch gestures that closely relates to actions such as swiping, tapping and pinching [10, 11]. This paper, therefore, leverages on the aforementioned in developing an application that runs on Android devices for ubiquitous regulations of energy utilization in the home.

To be able to realize the set objective of this work, the remaining section is organized as thus: Section II presents an overview of the state of the arts in the field of HEMS, while Section III we adopt a top-down approach to realize the objective of our work by developing and discussing relevant block diagram and flow diagrams of operation for the proposed system. Also, in Section IV, we give a quantitative analysis of the system design and results generated from the developed system as against other systems. Finally, in chapter five, we conclude and make statements on our finding. We also make recommendations for improvement on the already developed system.

2. OVERVIEW OF THE STATE OF THE ARTS IN HEMS

Over the last decades, HEMs have evolved across several technological boundaries with the advent of digitization and miniaturization [2]. During this period, there has been a large-scale deployment of HEMS installations meant to connect the consumers of electricity to the distribution company for the purpose of regulating energy delivery to consumers. This systems, however, has several challenges, one of which was the market pricing method. As connecting consumer to the wholesale power market created room for price violation and system instability [12]. These problems created by these HEMS installations, were, however, ameliorated through the invention of Time of use (TOU) and critical peak pricing (CPP) techniques which reduced on-peak demand of energy by users through price forecasting. A typical set of this system is shown in fig. 1 with relevant parts.

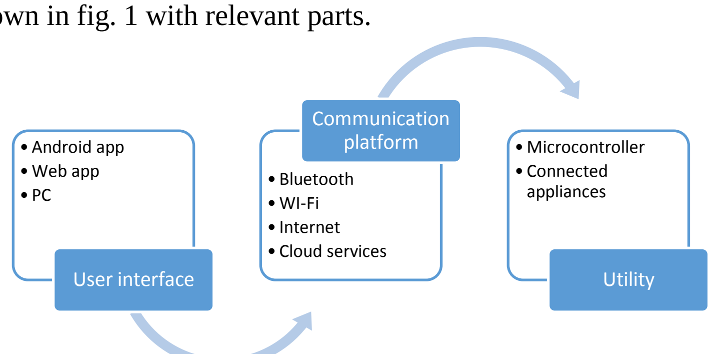

Fig. 1 Major Sections of typical HEMS

The different sections of this system have undergone a transformation with technological advancement. There have been transformations in the technologies behind the design of the user interface and the communication protocols for both front and back end selections of the system. We thus present an overview of the evolution in the different sections.

Communication Protocols for HEMS: While appliances developed in the last decades relied on hard-wired connection for communicate with the outside world, the evolution of several wireless technologies and the advancements in Internet have led to developments of several appliances with their own inbuilt communication transceivers leveraging on technologies such as: Infra-Red, IEEE 802.11b, Bluetooth and GSM/GPRS. These advancements, have also contributed greatly to changing the face of home automation systems. We thus present a critical analysis of some of the recent research and development efforts in the field of HEMS[13]. In 2011, Piyare et al [14] developed a home automation system utilizes a cell phone and leverages on Bluetooth technology which is not expensive and secured. However, a major limitation of this system was the length of time required to discover and access devices within. Also, the system could not realize real-time access and was not energy conservative [15].

The energy conservation challenge of the previous system in [14, 15] we ameliorated leveraging on Zigbee technology which is a low-cost, low-power, wireless technology. But, this still falls short of transmission range and hindered access due to the line of sight [16]. To further improve on HEMS, El Shafee et al [17] and Johri et al [18], proposed a two-component system as in fig. 2. The web server section which control, and monitors users' home and the hardware interface module, that provides the required interface to sensors and actuator of the HA system.

Fig. 2 A proposed home automation system layout [17]

The proposed system provided access to remotely monitor and control home appliances. However, it required that a physical personal computer be on and operational at all time for the entire system to work. Similarly, Kotiyal el al [19] presented a different approach to home automation. In their case, an Arduino Uno served as the controller for the system. While, system information were sent from PC via Wi-Fi and were decoded by the Wi-Fi module (an ESP8266) integrated to Arduino Uno. The automation system had the ability to be operated from a central host computer via the Internet. It could alsobe remotely accessed via a hand held PC with a Windows Mobile-based application. However, it still suffers from the same drawback as the former.

Furthermore, technologies such as Z-Wave emerged for HA systems, and are amongst the most widely accepted. With its inherent advantages such as cross-compatibility, unique network ID and mesh protocol. It, however, suffers the limitation of not been able to thrive for communication between more than four devices [20].

In an effort to ameliorate many of the shortfalls in the previous systems, Yuksekkaya et al developed a GSM controlled wireless automation system. The system utilizes a PIC16F887 microcontroller which is SMS based for controlling home appliances [21]. The system, however, was expensive as it incurred additional costs for the SMS. Similar systems were developed by Alheraish [22] and van der Werff et al [23] and both suffered the challenges of the aforementioned. Figure 3 gives a view of a layout of the GSM HA system. Table 1, presents these communication protocols, their merits, and demerits

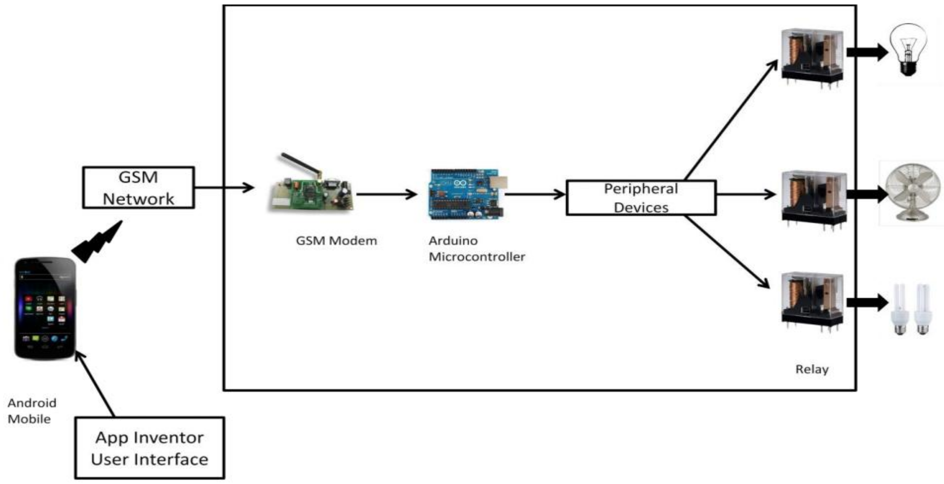

Fig. 3 Layout of a GSM-based home automation system [23]

Table 1. Comparison of Communication Technologies used in HEMS

S/N	Technology	Year released	Range (outdoors)	Cost	Standard/Proprietary
1.	Bluetooth	1998	~ 100m	Cheap	Standard
2.	Zigbee	2004	10m	Cheap	Standard
3.	Wi-Fi	1997	92m	Expensive	Standard
4.	Z-Wave	2001	100m	Cheap	Standard
5.	GSM/GPRS	1991	30km (around GSM mast)	Expensive	Standard
6.	X10/CEBus/INSTEON	1975 - 2005	~ 30m	Cheap	Proprietary
7.	EnOcean	2008	300m	Expensive	Proprietary

Overview of Internet services used in HEMS: The following are some services online that make the development of HEMS smooth and standardized:

Databases: This is the way in which data is stored in an ordered manner online. It allows for easy modification and accessing of data. Examples of databases include MySQL, PostgreSQL, Oracle, Microsoft SQL Server, etc.

Cloud services*:* Is an internet based on demand service from a provider's server. Popularly cloud services for HEMS include Ubidots, Cloudino, Firebase, etc.

Instant messaging protocols: These protocols enable real-time communication between devices connected to the Internet. Examples include XMPP and MQTT. Servers that support these protocols are able to push data to subscriber IP addresses when they receive certain information. However, these services are not yet common and are expensive. Many servers run the more common HTTP/HTTPS protocols.

Similarly, several microcontrollers have over time been used in various HEMS systems and they display advantages in some areas and limitations in other as in table 2.

Table 2. Comparison of major microcontrollers used in HEMS

Microcontroller	**Availability**	**Cost**	**Memory**	**Support**
PIC	Available	Cheap	Flash memory	Small community
AT89S52	Not available	Expensive	Flash memory	Small community
Arduino	Available	Cheap	Flash Memory	Large community
Raspberry Pi	Not available	Expensive	RAM	Growing community
ESP8266-12E	Available	Cheap	EEPROM	Growing community

2.1 Proposed System Design

The proposed system seeks to provide remedies to the following challenges of current HEMS: flexibility changes, excessive power demand for operation, poor response time and difficulty associated with maintaining the system. We adopted a top-down approach for the design and development of the systems. This approach was adopted as it minimizes debugging efforts and reduces development time. We developed the higher levels of abstraction of the system and then by stepwise refinement we added the core functionalities required for the realization of set goals. Figure 4 shows a flow diagram and the critical path diagram of the system. We thus presented an overview of the component realization of the system.

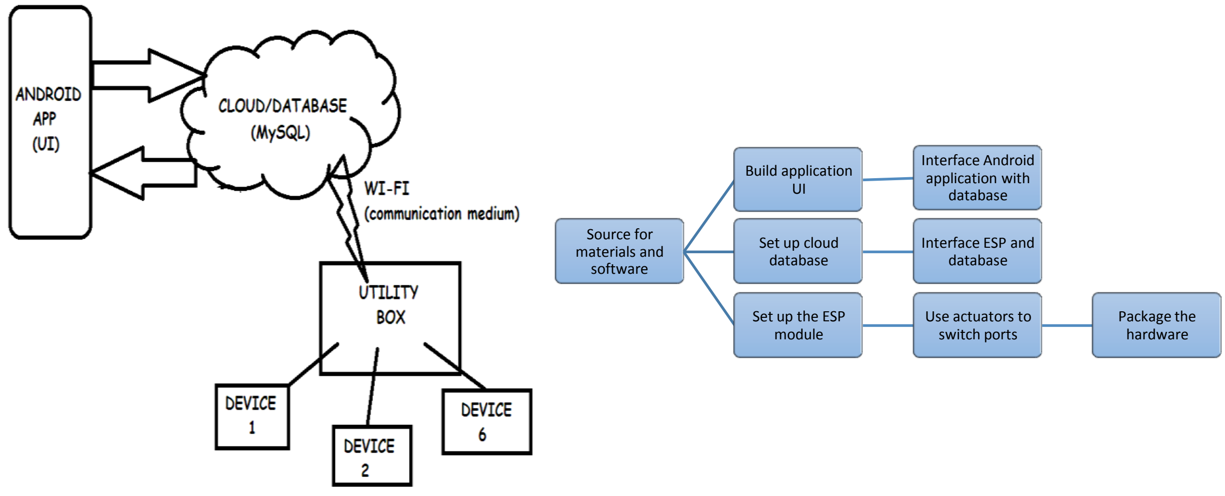

Fig. 4 Flow diagram and the critical path diagram of the system

2.2 Hardware Design and Implementation

The main pieces of hardware involved in the design are the ESP8266 module for carrying out controller functions and connecting the hardware to the database via Wi-Fi, relays, and voltage regulators. Other components used include a display for showing the circuit voltage, an LED for showing details of connected hardware to the database, and connecting wires. The complete circuit diagram is shown below.

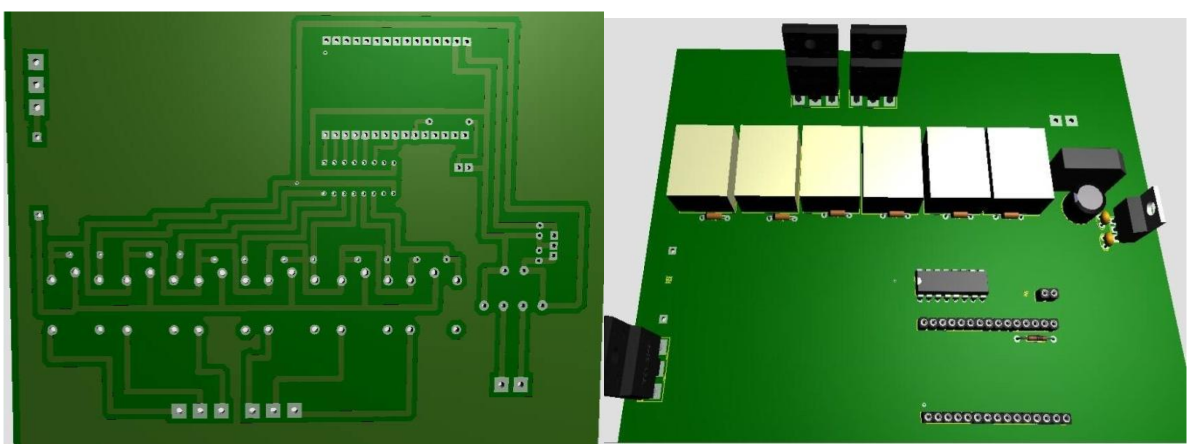

Fig. 5 PCB designs of hardware and complete circuit diagram of hardware

The program ESP8266 was programmed on the official Arduino IDE and then uploaded to the ESP module. The system algorithm is presented below:

- Initialize the socket pins as output pins and set the pins to a default low.
- Switch the sockets to their previous states before the power went off. If there are no previous states, turn off the entire sockets.

- Store the current states of the switches
- Start internet connection and waits till a secure connection is made
- Turn on the Network Pin Led bulb.
- While there is a secure connection to the server.
- Send the present states of the switches to the server and Get the new states of the switches from the server.
- Control the switches based on the new states gotten from the server.
- Store the new states of the switches.
- Put the system to modern sleep for two seconds. Go back to step 4.
- If the system could not connect to the server.
- Turn off the Network Pin led bulb.
- Attempt to connect to the server for three trials.
- If the connection was unsuccessful after three trials.
- Disconnect the system from the Access Point.
- Wait for two seconds. Go back to step 4

Android User Interface (UI): The Android UI for the system was designed for Android Studio 2.3. Some libraries were used to facilitate the functionality of the app. One of the important ones is Volley. This is a networking library that enabled us to make HTTP requests to our website asynchronously (that is, in the background while other tasks are running).

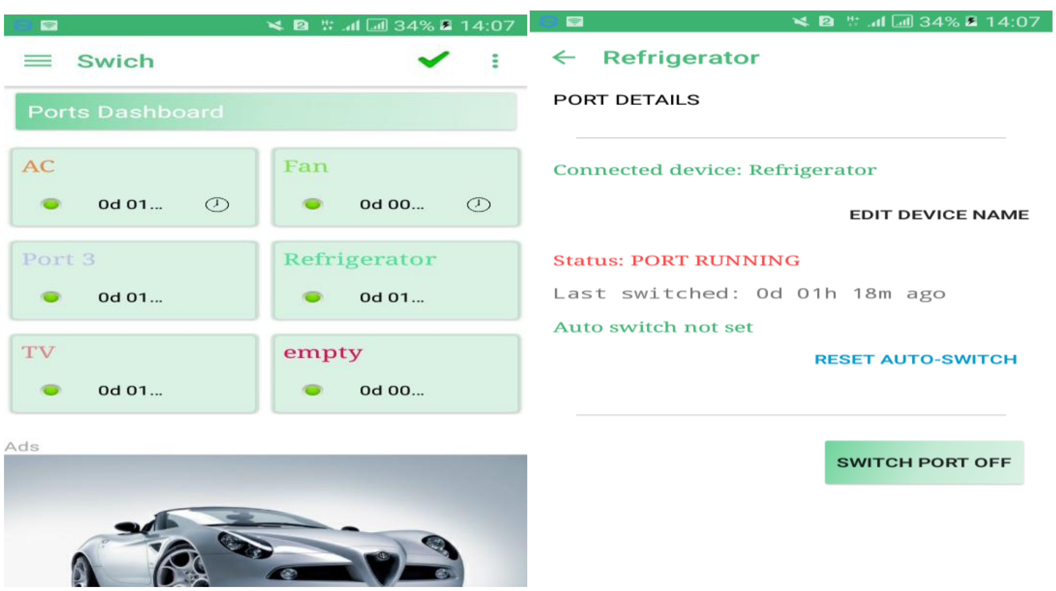

Fig. 6 Android user interface for project

It was realized that while the general code for making an HTTP request can easily be written from several examples, the program for making some project-specific requests (such as requesting port states, requesting last port switch times, switching a particular port, etc) had to be prepared from scratch. In order to do this, we devised codes for the six ports (1 to 6) and the two possible states they could be in (ON or OFF). So a request, for instance, made to the update.php to change the state of '3' to '0' means a request to switch port 3 OFF. Server and database structure: The database comprises two tables, Ports and

Power. The structures of the two tables are shown below. Some sample data for both tables are given in tables 4 and 5 respectively.

Table 3. Structure of Ports table

Column	Type	Null	Default
ID	int(11)	No	
state	int(11)	No	
time	timestamp	No	CURRENT_TIMESTAMP
switch time	timestamp	No	0000-00-00 00:00:00

Table 4. Structure of Power table

Column	Type	Null	Default
ID	int(11)	No	
last_time	datetime	No	

The Ports table as in table 4, is used to store the states of the six ports in the hardware, the last switch time and the present time for automatic switching. ID contains the index of the port, while the state column contains either 0 or 1, representing whether the port is OFF or ON respectively. The column for the last switch time set to update automatically by setting its default value to be CURRENT_TIMESTAMP. So anytime a change is made to a particular port row, the time is automatically updated to the current time. Similarly, the Power table as in table 5 keeps the record of the last time a request was made by the ESP module to the database. This is necessary in order to know whether the hardware has access to the database, and to be able to relay this information to the user anytime the android app is refreshed. During refresh, if the difference between the current timestamp and the value stored in this table is greater than 10 seconds, a toast appears in the app to notify the user that there is a problem with the connection at home.

Testing: The design was tested severally before packaging. After each testing, the design was updated to improve the performance. Initial tests resulted in large response time in the hardware after the user sends a request from the android app. Asides network issues, this was caused by some unhealthy programming of the ESP module. The program was refactored (precisely, the ESP was made to stop searching for Wi-Fi networks when a connection has already been achieved, and in the interval of time that no information is transferred between the module and the database) and the performance improved greatly.

Results: The performance values of the project after final testing are as follows:
Average response time: A mean response time of less than one second was obtained under relatively good connections both on the user Android device and at home for the ESP module.

3. CONCLUSION

The developed system was able to match the outlined objective of the research. It is more flexible and offers more friendly management of energy in the house as the Android user interface is standard and easy to understand. Also it is very efficient as it offers a mean responses time of less than 1sec, improved energy conservation of over 12.567% under normal network condition and has been adjudged to be very convenient by users. Finally, our system utilizes a generic database which has not been customized for home automation and hence cannot be scaled easily. This is one of the novelty of this works. We therefore recommend and increase exploration of this database to facilitate the building of a more robust production database that will cater for several users.

REFERENCES

[1] Amoo, A., Ranalkar, S. 2016. “*Home energy management system*”, Michigan Technology University.

[2] Cesar, R. 2014. “*Home energy management system*”, Michigan Technological University.

[3] Wikipedia. Home Automation. Retrieved November 15, 2017, https://en.wikipedia.org/wiki/Home_automation

[4] Taillade, N., Beg, S. M. 2000. “Multimedia networking for intelligent homes”, *Proc. International Symposium on Information and Communication Technologies*, Petaling Jaya, Malaysia. Pp. s1-1.1 - S1-1.4.

[5] Man, L. R., Ching, L. H. , 2016. "Sustainable Smart Home and Home Automation: Big Data Analytics Approach", *International Journal of Smart Home*, 10 (8), pp 177–198.

[6] Brush, A. J., Bongshin, L. 2011. “*Home Automation in the Wild: Challenges and Opportunities*", Microsoft Research.

[7] Olafusi, M. 2017,“*Individual Control Home Automation System*”, November 10.

[8] Baig, I., Muzamil, C., Dalvi, S. 2016. “*Home automation using Arduino wifi module ESP8266*”.

[9] Dae-man Han et. al. 2010. Smart home energy management system using IEEE 802.15.4 and zigbee, *IEEE Transactions on Consumer Electronics* .Volume: 56 , Issue: 3 .

[10] Rihan, M., Salim, M. B., Gupta, A. K. “Control of appliances in automated homes”, *National Conference on Cyber Security, Data Mining and ICT for the society*, G. G. University, Bilaspur. 2006.

[11] Wikipedia. Android (Operating System). Retrieved November 15, 2017, from https://en.wikipedia.org/wiki/Android_(operating_system)

[12] Roozbehani, M., Dahleh, M, Mitter, S. 2010. "On the stability of wholesale electricity markets under real-time pricing," *Decision and Control (CDC*), 2010 49th IEEE Conference. Pp. 1911 - 1918, 15-17.

[13] Kanma, H., Wakabayashi, N., Kanazawa, R., Ito, H. 2003. “Home appliance control system over Bluetooth with a cellular phone”, *IEEE Transactions on Consumer Electronics*. Vol. 49(4), pp. 1049 – 1053

[14] Piyare, R., Tazil, M. 2011. “Bluetooth based home automation system using cell phone”, *IEEE 15th International Symposium on Consumer Electronics*, Singapore. Pp. 192 – 195.

[15] Gomez, C., and Paradells, J. "Wireless home automation networks: A survey of architectures and technologies," *IEEE Communications Magazine*. Vol. 48(6), pp.92-101, Jun. 2010.

[16] El Shafee, A., Hamed, K. “Design and Implementation of a Wi-Fi based home automation system”, World Academy of Science, Engineering and Technology *International Journal of Computer and Information Engineering*. Vol 6(8), pp. 1074-1080, 2012.

[17] Johri, E., Bhangale, P., Thaker, V., Ghodke, S., Shah, V. “Remote controlled home automation using Android application via Wi-Fi connectivity”, *International Journal on Recent and Innovation Trends in Computing and Communication*. Vol. 3(3), pp. 1489-1492, 2015.

[18] Kotiyal, B., Baig, I., Muzamil, M., Dalvi, S. “*Home automation using Arduino Wi-Fi module ESP8266*”, available at http://aiktcdspace.org:8080/jspui/handle/123456789/1558, 2016.

[19] Withanage, C., Ashokl, R., Yuen, C., Otto, C. “A Comparison of the popular home automation technologies”, Engineering Product Development Pillar Singapore University of Technology and Design. 2014.

[20] Yuksekkaya, B., Kayalar, A., Tosun, M., Ozcan, M., and Alkar, A. “A GSM, Internet and speech controlled wireless interactive home automation system”, *IEEE Transactions on Consumer Electronics.* Vol. 52(3), pp. 837 – 843, 2006.

[21] Walko, J. "Home Control", *Computing & Control Engineering Journal*. Vol. 17(5), pp.16,19, Oct.-Nov. 2006.

[22] Shimi, S. L., “Home Automation and Energy management using Android app*”, International Journal of Engineering and Technical Research*. December 2015.

[23] David, N., Chima, A., Aronu, U., Edoga, O. “Design of a home automation system using Arduino”, *International Journal of Scientific and Engineering Research*. 2015.