NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Development of Internet of Things (IoT) Based Energy Consumption Monitoring and Device Control System

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Article Info

Received 26 May 2020
Revised 16 June 2020
Accepted 17 June 2020
Available online 31 August 2020

Keywords: *Internet of Things (IoT), Energy monitoring system, Arduino Uno, Atmega328, Home Automation*

https://doi.org/10.37933/nipes/2.3.2020.9

https://nipesjournals.org.ng

Abstract

Internet of Things is an amplification of existing internet facility to provide communication, connection and internetworking amongst several devices and physical objects also identified as "Things". The recent explosion in urbanization over the past few years has necessitated the need for sustainable, efficient, and smart solutions for monitoring energy consumption and management. The conventional domestic energy consumption monitoring systems are incapacitated to automatically monitor, bill and manage energy consumption of IoT homes. Hence, to address this shortcoming, this paper presents an IoT based energy consumption monitoring and controlling device using Atmega328 Microcontroller. The proposed system is able to monitor, bill, control and monitor energy consumption of individual and all appliances. Furthermore, the system is able to compute the total energy consumption and billing which is automatically sent to consumers. The proposed system exhibits an average overall performance accuracy of about 95%. This shows that the proposed system is promising for energy consumption monitoring and management.

1. Introduction

Internet of Things (IoT) is the network of physical objects or "things" embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data [1, 2]. IoT allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration between the physical world and computer-based systems, and resulting in improved efficiency, accuracy and economic benefit [3]. "Things," in IoT sense, refers to a wide variety of devices that collect useful data with the help of various existing technologies and autonomously flow such data between other devices [4]. Internet of Things is not the result of a single novel technology; instead, several complementary technical developments provide capabilities that taken together help to bridge the gap between the virtual and physical world [5]. The IoT objectives are represented in Figure 1.

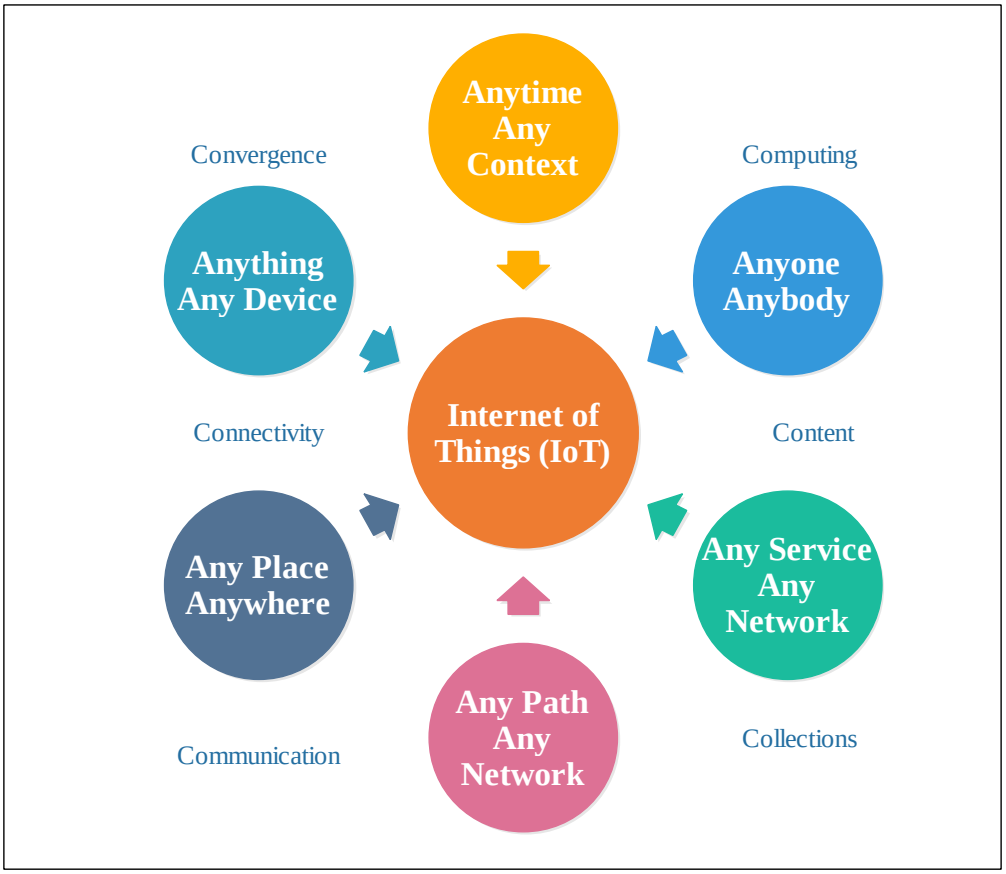

Figure 1. IoT objectives

Electricity has become one of the basic requirements for human life, being widely used for domestic, industrial and agricultural purposes etc. Energy monitoring is an important technique for determining the energy efficiency of various device [6]. The recent explosion in urbanization over the past few years has led to energy provision crises because energy produced is less than what is required [7]. The optimum solution of this trending problem is to monitor and control the power consumption. In power system, the number of appliance consuming energy are growing speedily and thus the energy requirement [8]. The need for energy monitoring is becoming a very important task to households, industries, agricultural industries and others due to its insufficiency and cost [9]. Monitoring energy efficiently and conserving it intelligently is a necessity in today's world. With the rapid increase in residential, commercial, and industrial consumers of electricity throughout the world, it has now become imperative for utilities companies to devise better, non-intrusive, environmentally-safe techniques of gauging utilities' consumption so that correct energy management can be achieved [10]. Without electric energy it's almost impossible to survive today and hence important to save and conserve electric energy. To avoid the loss, we need to monitor the power consumption and losses, so that we can efficiently utilize and manage the generated power [11].

Several IoT based energy meter monitoring devices have been proposed in [12, 13, 14, 15, and 16] to overcome the shortcomings of conventional energy monitoring devices. However, these proposals are characterized with some shortcomings. A smart, efficient and reliable energy monitoring and management device (system) should be capable of:

i. Monitoring and measuring both individual and collective appliances consumption rate.
ii. Switch on and off (control) appliance at set times.

iii. Automatically generate billing (consumption rate and cost)
iv. Ability to automatically send generated bills to consumers at stipulated time via the internet.
v. Ability to save consumption history for further analysis

In this paper we considered energy monitoring and appliance control for IoT based smart home. An illustration of a smart home is exemplified in Figure 2.

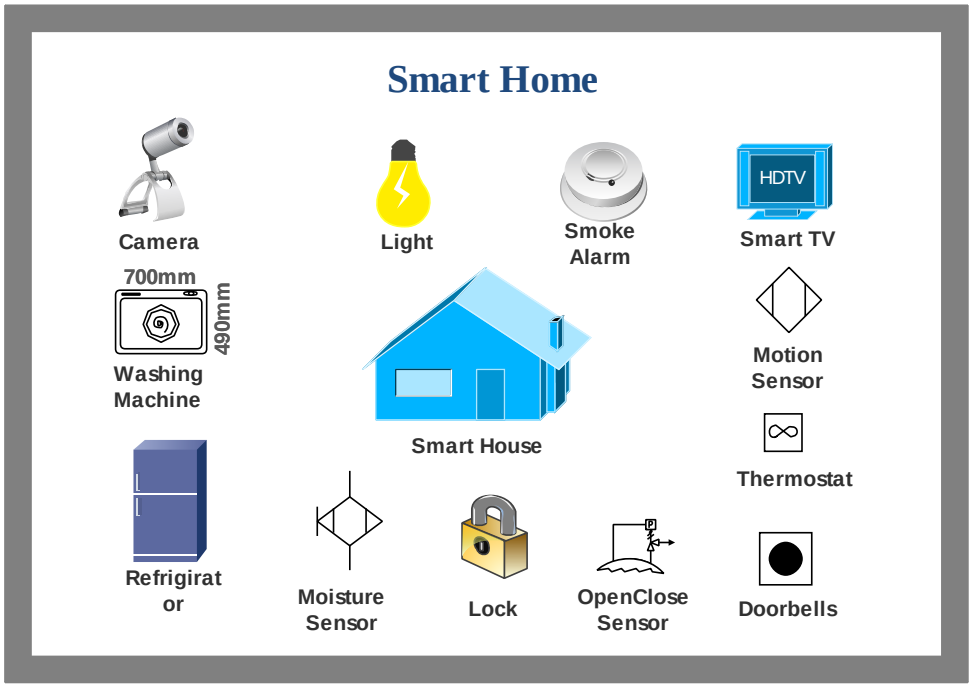

Figure 2. An illustration Smart Home with IoT Devices

2. Related works

Many researches have been conducted in the area of IoT based energy consumption monitoring. [17] proposed smart home system that uses CoZNET method to eliminate the effect of noise created because of the presence of WSN and WIFI networks. The performance of the proposed system was validated for both energy consumption by the devices and the noise created by the presence of WIFI and WSN networks. Simulation results showed that the proposed method is drastically affected by noise. This is a serious drawback of their proposed method. Additionally, the system proved to be less effective in decreasing the amount of energy consumed by appliances used in a smart home.

[16] developed an IOT based energy monitoring and control device using Arduino microcontroller. The proposed system has the capacity to measure the power consumed by each electrical appliance in the smart home and send the information to the server and even as it continues to remotely control the electrical appliances. The system can compute the amount of power consumed by each electrical appliance generate the bill on a dedicated website. The drawbacks of their method are that the number of electrical appliances that can be monitored is restricted to just two appliances. Moreover, the developed device can only compute the power consumed through current sensing. The implication of this is that measurements of the amount of electricity consumed might not be totally accurate.

[7] present a concise study on energy management and challenges in smart cities. The authors went ahead to propose a uniting architecture for promoting energy efficiency and scheduling of IoT-based

smart cities. Furthermore, they explained how energy is garnered in smart cities so as to prolong the lifespan of run-down power devices and its associated problems. Simulation results showed that their proposed method effectively reduced energy consumption through enhanced scheduling of energy and wireless power transmission in smart cities. The limitations of their technique include: the complexities of the method and the impracticability of such in developing countries.

[18] proposed a smart low-cost home automation system which is designed using IoT. The system has the capacity to control every home appliances and electronic machines and monitor their energy consumption through a website. The technique provides a surveillance system that allows both the consumers and energy merchants to detect the abnormalities of the power distribution system by inspecting the metering system. The shortcomings of the proposed system include: absence online billing system, and performance metric to know how efficient and robust the proposed system is. [15] proposed a framework for building energy monitoring and analysis system based on the Internet of things. The framework has some instruction for monitoring building energy consumption further to attain real-time monitoring and control, and reduce the power consumption level of intelligent building. The system was not implemented, so its performance in real life cannot be ascertain.

[12] in their work discussed web service and open database connectivity and front-end communication. Simulation results show that the intelligent city energy management system based on the Internet of things can meet the needs of the "intelligent city" construction. The proposed system incorporates energy information at remote locations and achieves energy consumption management. It provides a basis for the analysis and energy reduction valuation in urban cities. The system was only simulated but not implemented.[19] developed an Arduino based IoT metering system for on-demand energy monitoring. The performance of the technique was assessed using some case studies and experiments. Experimental results show that the system is effective in monitoring energy consumption with insignificant errors. Limitations of the work are lack of automation and inability to communicate over long distance.

[13] proposed an IoT Based Digital Energy Meter for Remote Monitoring which consists of voltage and current measuring circuits and it is interface to the Arduino microcontroller that is already programmed for calculating the amount of power utilized by the consumer. However, the system has no ability to monitor the energy consume by individual appliance.[14] proposed and IoT Based Energy Meter Billing and Monitoring System that uses Internet of things (IoT) for transmitting the customer's electricity consumption and bill information that is calculated using PIC microcontroller. However, the system does not have storage device that can be used to store data about the energy consumed by individual appliance. Hence, there is a need to design a system which can overcome these aforementioned shortcomings of the proposed systems. The conventional energy monitoring system only provides feedback to the customer on total energy consume in a house hold. The consumer has no way to track their energy usage on a more immediate basis. The consumers are growing exponentially fast and load on power providing divisions is rapidly rising. In the existing system, individual energy monitoring cannot be done and it is one of the major drawbacks for an energy crisis [20]. Therefore, there is need to propose a more efficient system that have the capacity to overcome the shortcoming of the conventional system.

The objectives of this research are to design and implement an IoT Based Energy Consumption Monitoring and Controlling Device. Also, to interface the monitoring device to capture individual energy consumption. And to test and evaluate the performance of the proposed system. This work developed an Internet of Things (IoT) Based Energy Consumption Monitoring and Controlling Device that is capable of determining the energy consumption of each appliance with multiple electrical load control system using Wi-Fi through android phone and also provides feedback to the

customer on total energy consumed in a house. This provide a platform for home automation system using Wi-Fi through Android Mobile which is the most helpful procedure to monitor home appliances inside or outside home. It is the most convenient way of using modern technology in day to day life, the best way to provide adequate security without too much physical effort and integrates the control for any number of appliances into a single control unit. This proposed system will help in energy monitoring and consumption control.

3. Methodology

This section introduces the approach employed towards the realization of set objectives. The solution framework and block diagram are represented. The details of the circuit and its implementation stages are presented. The systems performance metrics are presented and highlighted in this section.

3.1 Block Diagram of the System

The block diagram of the proposed system is presented in Figure 3. The block diagram depicts the behaviour and interfacing features of the main system. The ATmega328 being the heart of the system is interface with the required components: the transmission and switching unit consisting of relays and sensing and transmission unit.

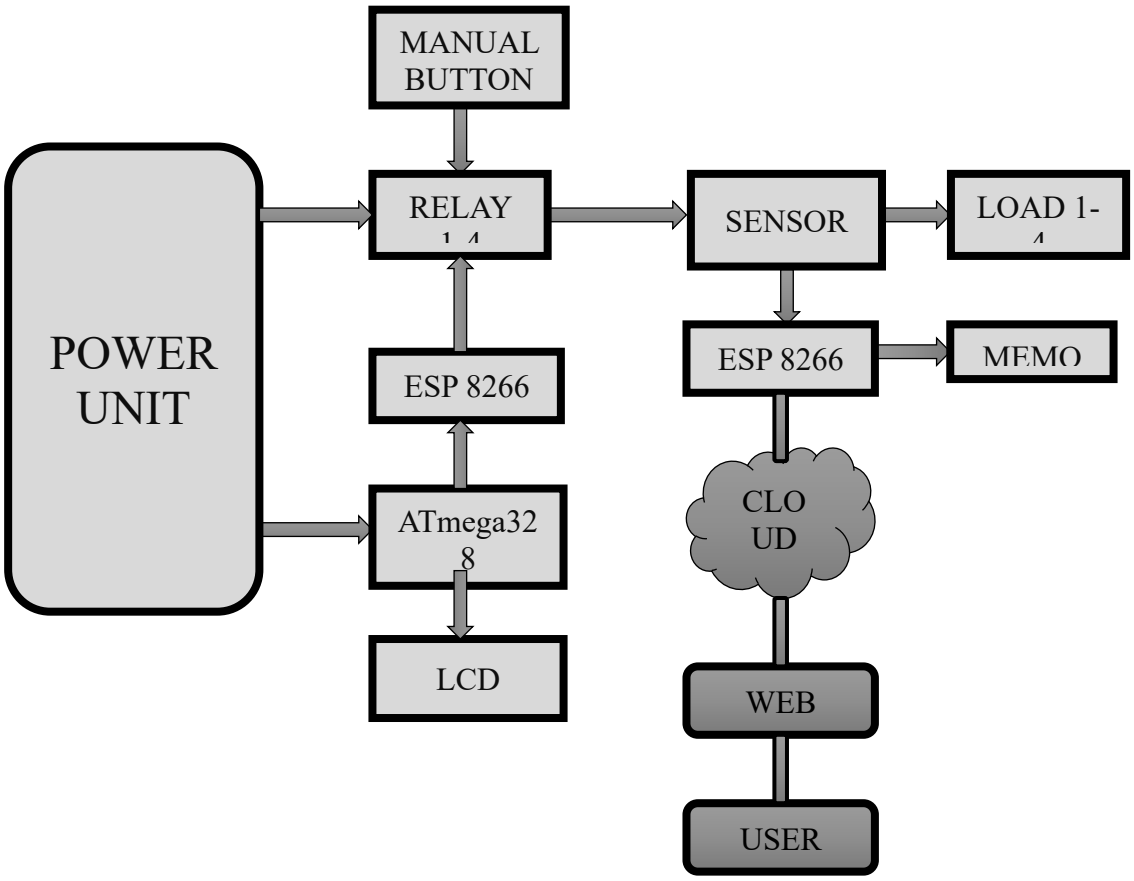

Figure 3. Proposed system Block diagram

3.2 System Circuit Diagram

The internal circuitry and configuration of the proposed main system is presented in Figure 4. The LCD is connected to the data pins of the Arduino (D2-D7), using serial connectors. The connection of the current sensor to the relay to the analog pins (A0-A3).

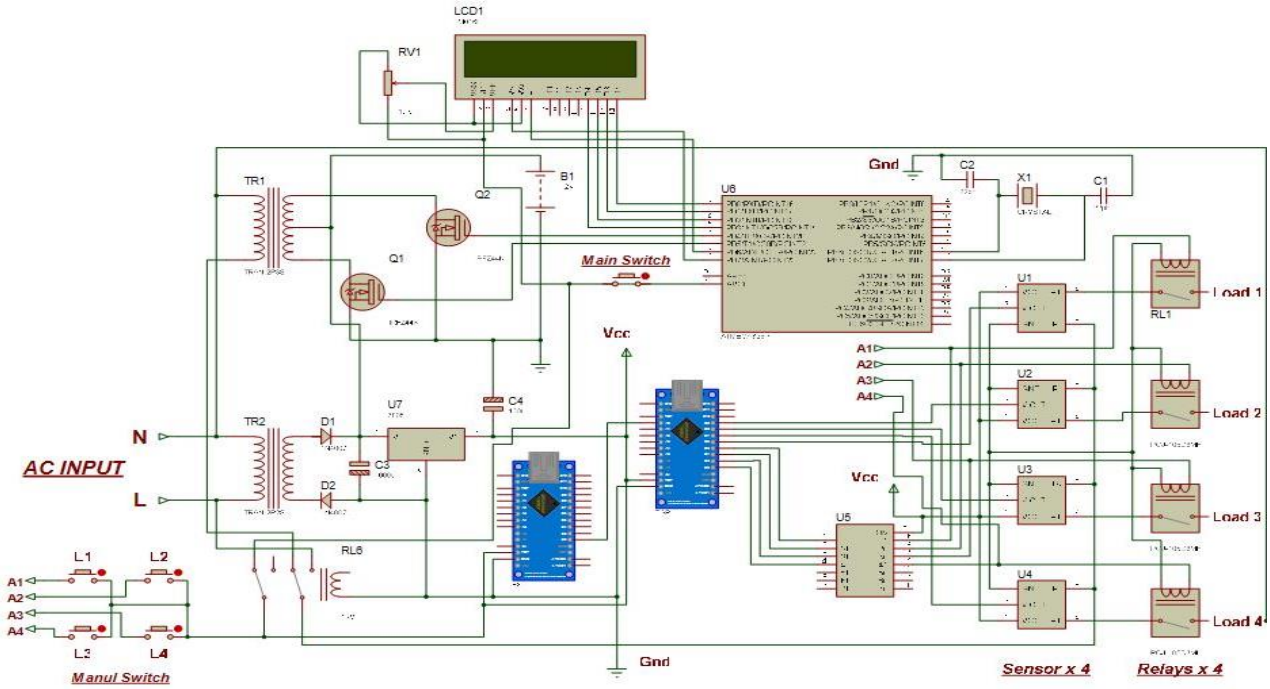

Figure 4. Circuit diagram of proposed system

The paper explains the basic structure and system design for IoT based energy consumption monitoring and controlling device. The proposed system also explains the basic blocks and components used in this system. It's a complete case study for the proposed system design. The system is very much helpful for reduction in energy wastage. In this system consumer can do power management by knowing individual appliance energy usage. Using this system, we can provide real time monitoring system. Figure 5 illustrates the Functioning Device.

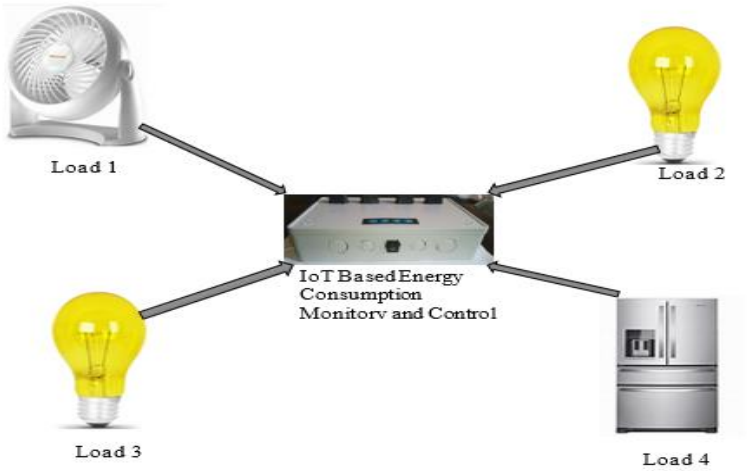

Figure 5. Representation of the Functioning Device

3.3 Software Design (Programming)

The Arduino Integrated Development Environment (IDE) is a cross-platform application written in Java which is derived from the IDE made for the processing programming language and the wiring project. It includes a code editor with features such as syntax highlighting, brace matching, and automatic indentation, and is also capable of compiling and uploading programs to the board with a single click. The Arduino IDE comes with a C / C++ library called "Wiring", makes many common input/output operations much easier [21].

4. Tests, Results and Discussion

This section presents description of proposed system test performed. An illustration of hardware connection for experimental test is presented in Figure 5. The proposed device is connected to four different appliances and consumption rates were monitored for both individual appliance and all appliances. This is to verify the performance of the proposed system.

4.1 Test Results and Analysis

Table 1 presents energy consumption (E_{kwh}) of four (4) different electrical appliances over a duration of four hours. So, user can analyze and visualize the data and send control command to controller to control the device using push button available on mobile application or web dashboard. Figure 6 illustrates a plot of energy consumption per hour and power in watts.

Table 1: Energy (E) consumption for different for four (4) different loads

Load	Power in Watts (P_w)	Energy E in Kilowatt-hours $E_{kwh}=P_w*T_h/1000$
Load 1	7	0.03
Load 1	15	0.06
Load 3	60	0.2
Load 4	100	0.4

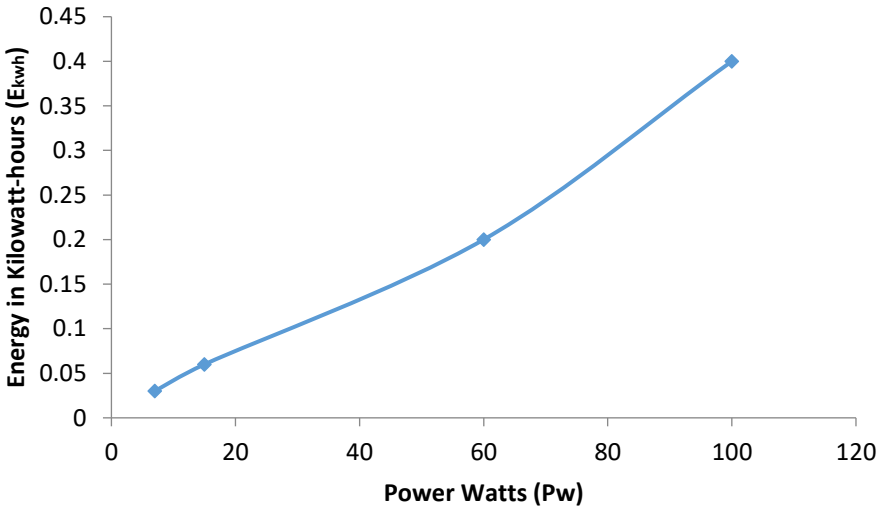

Figure 6: Graph of Energy (E_{kwh}) vs Power (P_w) consumption

Table 2 shows the energy consumption (E_{kwh}) for load 1 measure over time in hours (T_h). So, user can analyze and visualize the data, and send control command to controller to control the device using push button available on mobile application or web dashboard.

Table 2: Energy (E) in Kilowatts-hours of Load 1

Load	Usage Hours (T_h)	Energy E in Kilowatt-hours $E_{kwh}=P_w*T_h/1000$
Load 1	2	0.01
Load 1	4	0.02
Load1	6	0.04
Load 1	8	0.05

Table 3 shows the energy consumption (E_{kwh}) and power for load 2 based on time analysis at variable time (T_h). So user can analyze and visualize the data, and send control command to controller to control the device using push button available on mobile application or web dashboard.

Table 3: Energy (E) in Kilowatts-hours of Load 2

Load	Usage Hours (T_h)	Energy E in Kilowatt-hours $E_{kwh}=P_w*T_h/1000$
Load 1	2	0.03
Load 1	4	0.06
Load 1	6	0.09
Load 1	8	0.1

Table 4 shows the energy consumption (E_{kwh}) and Power for load 3 based on time analysis at variable time (T_h). This makes it possible for the user to analyze and visualize the data.

Table 4: Energy (E) in Kilowatts-hours of Load 3

Load	Energy E in Kilowatt-hours $E_{kwh}=P_w*T_h/1000$
Load 3	0.1
Load 3	0.2
Load 3	0.4
Load 3	0.5

Table 5 shows the energy consumption (E_{kwh}) and power for load 4 based on time analysis at variable time (T_h). The user can analyze and visualize the data using the control command to control the device using push button available on mobile application or web dashboard.

Table 5: Energy (E) in Kilowatts-hours of Load 4 (100w)

Load	Energy E in Kilowatt-hours $E_{kwh}=P_w*T_h/1000$
Load 4	0.2
Load4	0.4
Load 4	0.6
Load4	0.8

The graph of Usage Hours vs Energy in for Tables 2-5 is presented in Figure 7. The consumption of individual appliances power consumption rates is measured and recorded. The measurements

were taking at an hour interval for a period of four (4) hours. The energy usage for every load is computed and recorded.

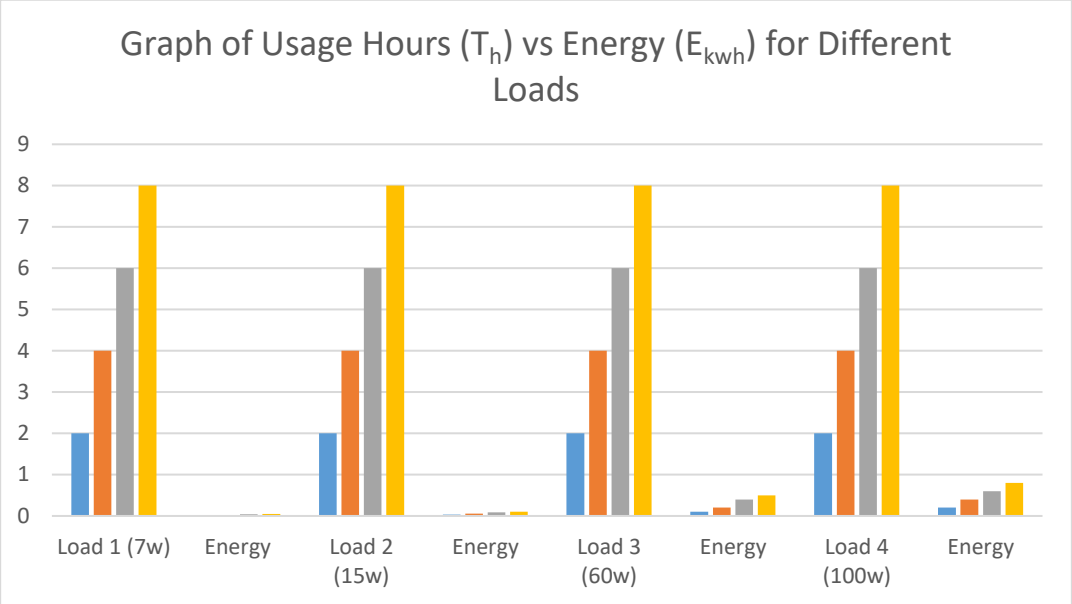

Figure 7. Graph of Usage Hours (T_h) vs Energy (E_{kwh})

Figure 8 shows the web page application for the user interface with the system. Here connection to http server is created which is the part of the IoT platform.

Figure 8. Web page application for the user interface system

From the experimental results, it is evident that the proposed system is an effective IOT based energy monitoring and control device using Arduino microcontroller like what is obtainable in many of the work cited in previous section [7, 13, 15, 16, 17 and 18]. However, unlike the work of [17], the results generated by this method is not affected by noise. Moreover, this present work proved to be very effective in reducing the quantity of energy consumed by appliances in a smart home. This proposed system also overcome the challenges associated with the work of [16] where the number of electrical appliances that can be monitored is limited to two appliances.

Also, the limitation inherent in the work of [7] has been surmounted in this proposed method as the approach is simple and practicable in developing countries. This proposed work has online billing module unlike the work of [18]. The proposed system also complements the work of [15] which was not implemented. The drawback of the technique used in [13] was addressed in this work as the system can compute the amount of power consumed by the user.

5. Conclusion

The coexistence of several networks with different characteristics and energy efficiency in today's smart home environment is top amidst multiple challenges towards the realization of automated home energy management system. This paper presented an architecture for a smart home automated energy and billing aware metering system. The proposed automated smart home energy monitoring and billing system used Atmega328 Microcontroller and internet of things to manage and control energy consumption of smart home appliances. The proposed system is equipped with user friendly website design for easy usage.

The hypothetical evaluations and experimental results indicated that the proposed system is an outstanding method for monitoring power consumption and sending the measurements through IoT which considerably surmount the numerous challenges associated with the conventional technique of energy consumption monitoring. The proposed model has the potential to function automatically in a very efficient manner with minimum manpower requirement and at very low cost. The future applications of this research work are very great considering the amount of time and resources it saves. This work can be used as a reference or as a base for realizing a scheme to be implemented in other projects of greater level such as home security system, as it creates a platform for the user to interface between himself and his household.

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