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DEVELOPMENT OF A WEB-BASED SMART POWER EXTENSION DEVICE FOR DOMESTIC APPLICATIONS

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ABSTRACT

With the development of science and technology, the energy demand in the world increases day by day and it is an important fact to save that energy. Everything today is becoming smart devices by various concepts and smart plug is such one topic. Features like power monitoring, consumption of power, mobile controllable ability and web control can be found on such kind of devices.

The following project was about development of a Smart Power Extension Device for domestic uses. This device has the ability to measure real-time power measuring, automatic turn on or off at a given time, remote control via the internet of things (IoT) and protect equipment and user from high voltages. As an external remote controlling device for this smart power extension device, developed a web page and a mobile application for both android and IOS operating systems that are connected to an internet of things (IoT) cloud server.

This article reviews extant literature relevant to the design of smart devices in the globe providing existing devices with their limitations. Then the paper discusses the status of the new device, how the innovation and smart thinking can be applied while achieving the intended objectives. Finally, the results of the smart device highlight how IoT concept can help save energy in domestic level and the improvements are needed to be done to make the smart device a perfection.

Key Words: IoT, Power Management, Smart Concept

1. Introduction

Global energy demand for the year 2021 was predicted to increase by 4.6%, offsetting a 4% contraction according to 2020 (IEA, 2021). This growth of the demand is due to the increase of the global economy which is expected to rebound by 6% in 2021. Electricity continues to position itself as the “fuel” of the future, with global electricity demand growing by 4% in 2018 to more than 23000 TWh (Tera Watt hours).

In Sri Lanka, 85.95% of the country’s energy generated from fossil fuels i.e., 86 TWh (Ritchie & Roser, 2020). These fossil fuel resources are scarce, and these resources are imported, a significant part of Sri Lanka’s import expenditure. As a developing country, Sri Lanka’s demand for electricity is going to increase in the future. According to the Sri Lanka Sustainable Energy Authority, the total number of electricity consumers in the grid has increased by 4% in 2017 when compared with 2016. When the number of electricity consumers increased, the electricity demand also increased, thereby the average selling price. Therefore, it is important to secure its energy future by focusing on effective energy consumption by using smart technologies (Singh, 2017).

Nowadays, electricity is an essential ingredient in everything we do (Musleh, Debouza, & Farook, 2017). From giant power plants to small houses, power is the backbone of all those things. With the improvement of technology, power consumption has been the most growing problem around the world. This problem can be overcome by starting monitoring and reducing power consumption from smaller places like small houses. The Smart Home Control is exploring the potential for enabling technologies in vulnerable and investigating the potential for off-the- shelf enabling technologies. These smart home control systems can initialize by installing smart light bulbs and by smart power extensions. A smart power extension is a networked power code which is plugged into a normal electric power outlet. Any electric appliances and devices which is plugged into the smart power extension can be wirelessly and remotely controlled via a mobile (smartphone) app (Nicholls, Strengers, & Tirado, 2017). The use of smart power extensions can minimize the energy waste by controlling it remotely because it will not take much time as it takes to do manually. Even though this is a very small energy waste when summing up this small waste globally it is a huge amount and by controlling the energy waste from the smallest place the global energy consumption can be reduced.

According to Moore’s law, the capacity of technology doubles every 18 months and in the last couple of years, there have been great strides made in assistive technology. Due to this rapidly improving technology and ever-continuing disruption, accessibility focused mobile two applications and smart devices for people with disabilities (Mehrjerdian, 2019). Smart power extensions are a great help for people with disabilities because they can control the devices from the place they are and by not moving an inch of their position.

With the growth of the population, people tend to work more according to their needs and wants which leads them to a complex lifestyle. So, to monitor and control the power consumption in their houses they intended to seek an easier, time saving, efficient way (Win, Innocent, Mathieu, Cecile, & Aung, 2017). With power monitoring, people can identify what are the devices that consume the highest power when using and can make a plan to reduce that consumption by an effective way and can identify the faulty devices which consume more power than the rated values. The development of a smart power extension that can control remotely like using technologies like IR, Bluetooth will provide a lot of convenience to the user. It will be more convenient if the device can be controlled within a long-range like through Wi-Fi. Now the society lives a smart life, everyday objects like smartphones, smart TVs, tabs can be used to control the smart devices through the internet with the technology IoTs (Internet of Things).

This smart device is an invention for domestic purposes which have the capability of measuring real-time power monitoring, power consumption, power surge protection and mobile control ability. This concept will help the busy scheduled people to monitor and manage their power consumption remotely which will help manage their precious time. An Android OS and iOS running mobile applications will use to monitor and control the smart device for activities like power monitoring, switching (On/Off) and automatic timing. A web page is implemented to control the smart power extension device through the internet from anywhere in the world. The device will be connected to a cloud when power is given and through the cloud, we can send signals to control the devices on and off ability and timing option and by receiving signals we can monitor the current, voltage, power consumed by a particular device and time stamp of the switch (On and off time and date). On the device itself, there is an OLED (Organic Light Emitting Diode) display to check power and one button switch will be there to control the display to access various functions. The display will update the current, voltage and power values every one second.

Hence, this paper promotes IoT thinking among Sri Lankans to design and develop smart devices to save energy. The paper, first, provides a literature review of other researches and works done and then the discussion of the innovation and design approach of the device. Finally, the discussion is on the results of the developed smart device with the use of IoT concept.

2. Literature Review

With the scarcity of renewable and non-renewable energy sources and the increase in demand for power, we are now facing a huge energy crisis. Therefore, various organizations and groups try to implement systems to reduce power consumption (Shajahan & Anand, 2013). According to (Alahmad, Wheeler, Schwer, Eiden, & Brumbaugh, 2012) in the USA residential energy consumption is around 21% of the total electricity usage and out of it, 41% is wasted. The real-time monitoring (RTM) devices available in the market only monitor and display the power consumption and do not give the control parameter to the users. There are several RTM systems in the market like Ambient Energy Orb (Orb), Aztech In-Home Display (Aztech), Cent-A-Meter, EML 2020H, The Energy Detective (TED), Wattson and Power Cost Monitor (PCM). These devices do only monitor and display energy consumption only. As (Colon, 2019) states, there are many smart power extensions and power strips in today’s market like Belkin WeMo Insight Smart Plug, iHome iSP6X Smart Plug, iHome iSP6X Smart Plug and Geeni Spot Smart Wi-Fi Plug. But there are several pros and cons to those devices like cost, accessibility techniques and protective techniques.

HEM (Home Energy Management) can be categorized into three categories i.e., control devices, user interface and enabling technologies. Control devices allow the users to actively control the energy usage with various techniques like automatic or human-in-the-loop. Under control devices, there are three subcategories i.e., centralized, device level and on-board. Previously mentioned smarts plug, and power strips fall on to device level category where user can control a single device or function. To improve the control of multiple devices with various smart devices, enabling technologies must be used. Enabling technologies are sensors, data acquisition devices and communications (LaMarche, Cheney, Christian, & Roth).

According to (Alahmad, Wheeler, Schwer, Eiden, & Brumbaugh, 2012), there are many real-time monitoring (RTM) devices in the market where they only monitor and display the energy consumption only. Nowadays most of the smart devices are controlled by microcontrollers. The main difficulty is to find the most suitable microcontroller for the Smart Power Monitoring Device. There are many microcontrollers in the market such as PIC and ATmega and small single-board computers such as Raspberry Pi. ATmega microcontroller is best suited as the brain of our Smart Power Monitoring Device According to research (Aftab, Chau, & Khonji, 2017), (Hadwan & Reddy, 2016) and out of ATmega48P, ATmega88P, ATmega168P and ATmega328P, the ATmega328P is fulfilling the requirement of this smart power monitoring device. Since this system is working with the sinusoidal voltages and current, a microcontroller with the capability of four analog to digital conversion is appropriate.

To calculate power consumption, ACS712 current sensor is best suited due to its compact size and high accuracy and sensitivity and it appears on multiple number of other applications and voltage step down module (230V AC to 5V AC) for measure voltage on the system (Ahmed, et al., December 2015).

Most of the smart devices nowadays are based on the IoT technology. The concept of IoT was proposed in 1999 by the Auto-ID Laboratory of MIT (Guoqiang, Yanming, Chao, & Yanxu, 2013). The Internet of Things (IoT) is the network that connects everyday objects like smartphones, smart TVs to the internet where the devices are intelligently linked together enabling new forms of communication between things and people, and between things themselves (Kortuem, Kawsar, Sundramoorthy, & Fitton, 2010). According to (Hilton, n.d.), it is to be expected that the number of electrical devices connected to the internet will increase from 100.4 million (2011) to 2.1 billion by the year 2021, growing at a rate of 36%. Different home appliances like lights, home security systems, entertainment systems are connected to the internet where they can be controlled remotely and not only control, but to monitor the amount of energy consumption (Chen, Gao, & Chen, 2011).

Smart power extensions are one of many devices which are used to control and monitor various functions. Each one of the devices will be compared to each other to find the best suitable device for a particular task. When comparing smart power extensions, can categorize into several factors like cost, power consumption, power efficiency, communication technology etc. when considering the communication technology, the most critical criteria are data rate, range of transmission or the power consumption. There are several techs like Bluetooth, Zigbee, IEEE 802.15. Wi-fi, LoRaWAN, SigFox and Z-wave etc (Musleh, Debouza, & Farook, 2017). NB-IoT is a newly introduced technology in 2016 to complement the high Quality of Service (QoS) along with low latency (Alliance, 2016).

The main drawback of Bluetooth is that it has a limited operational range (up to 10m). Therefore, Bluetooth is not very practical for a smart power extension because its unable to cope with mobility and can only be controlled if the device is in a particular range. When considering the Zigbee, it is suitable for low data rate applications and also it needs complicated application layer gateways to access the Internet. Wi-fi is a local area wireless technology that uses 2.4 GHz radio waves to communicate and has the ability to transmit data at higher rates over a wide range.

Table 1: Comparison of the wireless technologies

Protocol	Bluetooth	Zigbee	Wi-Fi 802.11
Data Rate	1 Mbit/s	20,40,250 Kbit/s	11,54 Mbit/s
Range	10m	10~100m	>100m
Network Topology	Ad - hoc, small networks	Ad-hoc, peer to peer, star, or mesh	Point to hub
Frequency	2.4 GHz	2.4 GHz	2.4GHz and 5GHz
Power	Low	Very low	High
Typical Application	Inter-device wireless connectivity	Industrial control and monitoring, sensor networks, building	WLAN connectivity

Source: Author constructed

According to Table 1, it indicates that Wi-fi is the best wireless connectivity technique when compared with Bluetooth and Zigbee. Wi- fi has the capability to transmit data at a higher rate in a wide range with strong anti-jamming capability. Using Wi-fi as the communication technology reduces the wiring troubles because no cabling is required. Also accessing the system becomes possible anywhere at any time (as long as the device is in reach of a network) where device's exact physical location is not essential for the connection (ElShafee & Hamed, 2012).

Controlling of the smart power extension through Wi-fi is done by a mobile application. Mobile application development platforms have been passed several evolutions in the past like when Blackberry, Bada and Symbian failed to grasp the market demand while IOS and Android won the market demand (Dalmasso, Datta, Bonnet, & Nikaein, 2013). Mobile applications are developed on several platforms like Android OS, IOS, RIM Blackberry, Windows, and Palm. But (Tracy, 2012) states that RIM Blackberry, Windows and Palm platforms were considered not very good for an initial application. As (Butler, 2011) states, android based smartphone sales are higher than the iPhone iOS smartphones as of September 2010. This shows that there are more android based devices than iOS-based devices. When considering publishing android apps, we have to pay a small fee (US$25) to register (Google, 2019) whereas to publish an iOS app we need to pay an annual fee of US$99 (Apple, 2017).

In general, within the global market there are various devices with various separate functions like remote control, power monitoring, automatic timing, voice control etc. but there are no such devices with the combination of all of these functions. There are devices with a combination of two or three functions. This Smart power extension device consists of all the above functions along with web controllability through IoT technology by comparing many other findings done by other authors and by selecting the best components and features among those.

3. Methodology

The main aim is to create an IoT based real-time power monitoring smart power extension which can control and monitor several functions through a smart device or within the device itself which directly helps to minimize time waste and power consumption. The sensors and modules will acquire required data and transmit them via a communication network to a cloud database and from which it can be accessed by an informational interface (figure 1).

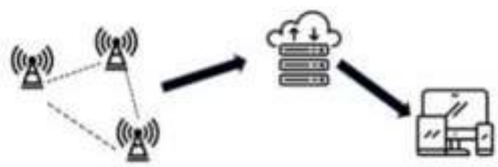

Figure 1. Concept Map

The device is designed by including several functions like power consumption monitoring, mobile control capability, power surge protection and timer. As a control unit, an Atmel ATmega328P microcontroller is used. Microcontroller directly connects to current sensors (ACS712-5A) and voltage sensors to measure the power usage which was connected to the power extension device. The microcontroller's internal counter is used to control the automatic timing feature. 128bit by 64bit OLED LCD display unit is used to display power consumption data and automatic timing data on Smart Power Extension Device. And finally, ESP8266 Wi-Fi module is used to connect the microcontroller to the internet. To improve the smartness of the device, the development of an android based, and iOS based mobile applications proposed where through the app the user can control and monitor the smart power extension through various smart devices like smartphones, laptops etc. and a web page to control it through a computer (figure 2).

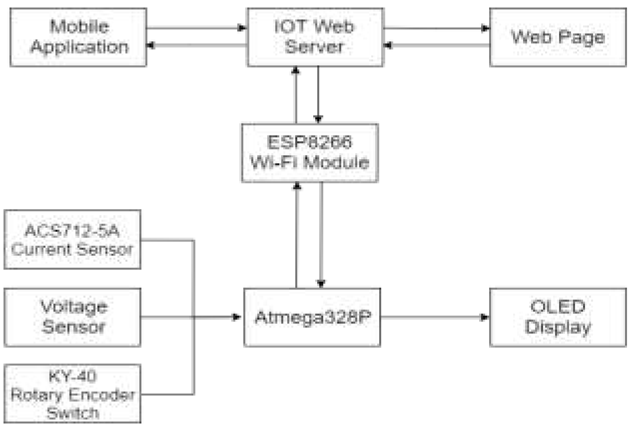

Figure 2: Smart power extension device process

The Wi-Fi module is communicating with the aREST cloud via MQTT commands and for the cloud server, the Digital Ocean cloud server used (figure 3). ESP8266 board act as a web client that accepts incoming commands from the cloud.arest.io website and process those commands via the library thus can control those commands through the mobile app and web page.

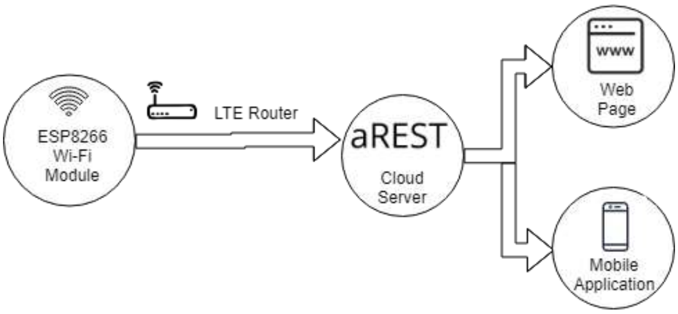

Figure 3. IoT cloud data base

A customizes PCB unit was designed using Eagle CAD software which were planned to build the circuit using Atmel microcontroller. Design was planned by checking the modern standards and with the minimum material cost (figure 4). Customized PCB unit designed using Eagle CAD software and proposed to use NodeMCU development board as the IoT controller when considering the limited space available inside the sun box.

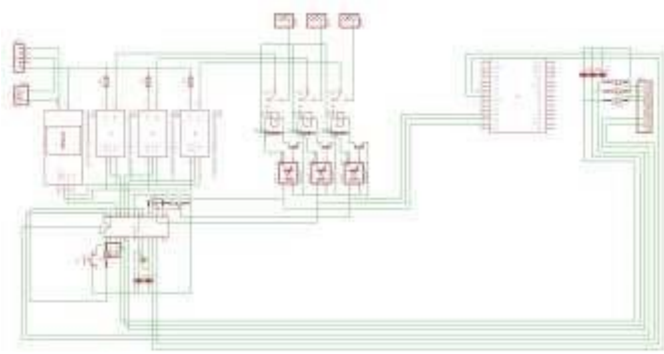

Figure 4: Final schematic diagram

With the successfully tested customised PCB unit, developed the final project design. Some standard results were taken before going through with the final design. Standard Strength - 50N, Standard Material - Poly- Lactic-Acid material (PLA). The reason for using PLA was because it is a natural product, it is also long-term biodegradable. Also, PLA is a great starting filament to use for the majority of 3D printers.

ESP8266 Wi-Fi module can be controlled via several communications protocols like through local area network (LAN), Static IP connection, Cloud-based connection. Through Cloud-based connection GPIO pins of the module can be controlled in three methods i.e., activating GPIO pins by entering the link on the web browser, by mobile application and by the web page.

4. Results/Analysis and Discussion

Since the smart power extension device is works with AC signals (sinusoidal waveforms), it is quite a challenge to read input wave and calculate an average numerical value. This can be eliminated by calculating the root mean square (RMS) value for AC current and voltage reading by obtaining thousand samples at a onetime.

A. Monitoring Current Sensor Readings

Figure 5. is showing the net input of analog reading values of ACS712-5A current sensors vs time. The power calculation required for the RMS value of the current was done using a unique programming algorithm, the designing team succussed to calculate the RMS current value (figure 6).

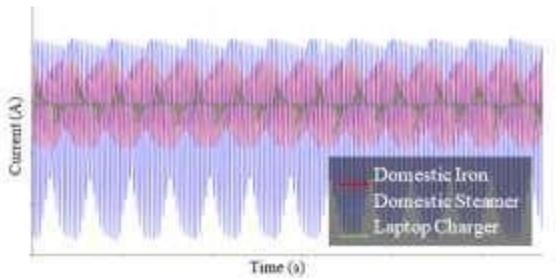

Figure 5: Graph of analog reading of current values

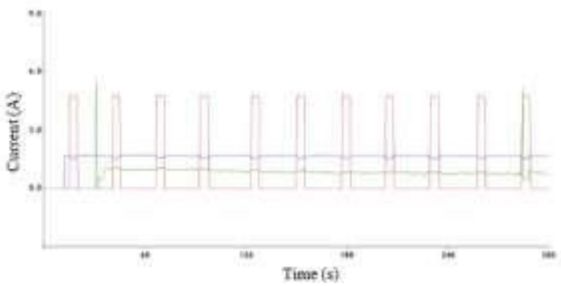

Figure 6: Sensor outputs from current sensor

B. Monitoring Voltage Sensor Readings

Figure 7 is showing the net input of analog reading values of voltage sensors vs time. The power calculation required the RMS value of the voltage was done using a unique programming algorithm, the designing team succussed to calculate the RMS voltage value (figure 8).

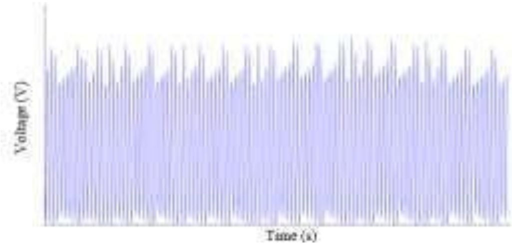

Figure 7: Graph of analog reading of voltage value

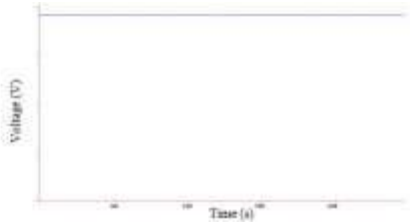

Figure 8: Graph of calculated voltage value

C. User Input Control

KY-40 Rotary Encoder Switch is used for inputting the user command. From the rotary encoder switch, the user can surf the smart power extension menu easily. Rotary encoder readings were read by using inbuilt external interrupts in the ATmega328P microcontroller unit. Other than that rotary encoder's switch used as a switch to the system. Any switch has a bouncing effect which was directly affected the microcontroller reading. Therefore, implemented a mechanical debouncing method to reduce the debouncing of the switch (figure 9).

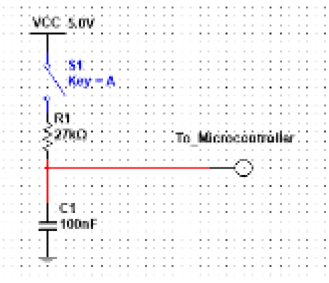

Figure 9: Mechanical debouncing

D. Display Unit

The display unit fulfils the Human Machine Interface (HMI) of this device. Display unit is directly connected to the microcontroller unit via I2C communication protocol.

E. Final Smart Power Extension Device

The final smart power extension device exterior is 3D printed by using PLA material to get a fine finishing. The main reason to use PLA is that PLA has better mechanical properties and can withstand to a temperature of 180-2200C without deforming its properties. Other than that, the interior of the smart power extension device is also custom made by using steel plates, PCB, and wires.

F. IoT Protocols

The MQTT commands receive from the mobile application and web page is process through the aREST cloud server and activate the corresponding GPIO pins of the smart power extension device. Android Studio, XCode and Visual Studio Code used for the development of the android app, iOS app and web page respectively. The thing speak IoT platform which runs with MATLAB analytics used to monitor the exact moment (exact date, exact time, which GPIO pin) got activated. Relay Activity on Time Base.

5. Conclusion

The Smart Power Extension Device can monitor voltage, current and power consumption of all three devices separately and displays those parameters on an OLED display which were installed on the device. A rotary encoder switch is used to access these variables and control the display menu. By the menu separate current, voltage, power can be obtained and there is an overall power consumption parameter too which shows the total power consumption. Android and IOS-based mobile applications are developed to control the devices on and off ability. Since the mobile application is password protected, only authorized persons can access the device. Also, from the mobile application, an automatic timing function can be activated where the user needs to enter the required on and off time in seconds and after the entered time the device will switch on or off. A web page also developed and hosted to control the device through a laptop or computer. The device is programmed to connect to a cloud when power is given and through the cloud the device can be controlled. The network developed for the communication module is based on the IoT cloud base concept to complete the scope of the communication while meeting the overall objectives.

This paper provides the broader application of smart concepts to save energy within domestic level. However, this design is developed for a voltage with 5A current and currently in Sri Lanka the domestic power supply is 13A current. Thus, there is a need to improve the device for 13A while have the ability to find the power factor. Subsequently, developing the webpage and mobile applications more user friendly while interpreting more data for analysis and more secure. Finally, the design of the device should design more ergonomically for a smooth use by the consumers.

The main outcomes of the project are,

- Power consumption and monitoring
- Minimizing the time consumption taken to control plugs manually
- Automatic timing function
- Mobile application with a user-friendly interface
- Web controllability

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