Microcontroller-Based Power Monitoring and Switching Device for Appliances over a ZigBee Network

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***Abstract*—Microcontroller-Based Power Monitoring and Switching Device (PMAS) for Appliances over a Zigbee Network aims to develop a system that can provide aid to its user in consuming power more efficiently. This study aims to create a system for monitoring electrical consumption of home appliances through an Android application. It will also be focusing on the recording of electrical data so that its user may be able to track how much power they are consuming over a certain period of time. The microcontroller in the power monitoring and switching (PMAS) adapter will read and measure electrical data, such as voltage, current, and power. This data will then be transmitted to a hub that will be utilizing a ZigBee network, connected in a star topology. This gateway sends and receives data to and from the web server database, which the Android App accesses to display the information to the user through text and graphs. The app also has switches that can turn the adapter on or off. This study provides users with an easy to install and non-intrusive system to monitor and control the power consumption of home appliances using an Android app.**

***Index Terms*—Android Applications; Pic Microcontroller; Power Monitoring and Switching Device; Zigbee Network.**

I. INTRODUCTION

Modern civilization is built on the necessity of electricity and the luxury it provides. This manifests mostly in the electrical appliances present in most of today's homes. Due to the fact that the usage of electricity is deeply rooted into the daily life of the average person, power consumption has greatly increased. It has become easy to overlook the unnecessary expenditure of power. Since 87 percent of the 21 million households in the Philippines uses electricity, control over which of their home appliances are powered on or off at various points in time can greatly lessen power usage [1].

Developments in wireless personal area networks modernized industrial control, health monitoring, and smart homes technologies. The first widely accepted standard in WPAN technology is ZigBee. It has the ability to have network communications that are low-power, short-ranged, mesh networking, multi-hopping and secured. It is also useful for devices like home appliances and industrial apparatuses since they are able to possess the capacity to have multi-type and multi-point sensor information as inputs [2].

The work done in Wireless Micrometered Air conditioning and Lighting Control and Monitoring System [3] wirelessly controls the lights and air conditioning within the classrooms while simultaneously monitoring the electrical current and temperature of the said room. These are all connected to a single base station computer that controls and monitors the rooms lighting and air conditioning. They developed air conditioner specific features for their thesis, like a remote thermostat control, schedule database and fault detection for the air conditioners and lights. They track power by measuring current and assuming a 220V AC source. Their system is dependent on retrofitting the light switches and the power boxes of the air conditioners. In order to reduce the wastage in electricity of air conditioners and lights within the classroom between class hours, appliances are retrofitted to work with the system and control is done through the base station.

The work done in Analysis and Characterization of Wireless Smart Power Meter [4] develops a low-cost smart power meter capable of measuring VRMS, IRMS, real power, and reactive power. The features of the proposed research include matching by device rate of consumption and usage patterns to assist users in monitoring the connected devices, as well as condition monitoring to detect harmonics of interest in the connected circuits, which can give vital clues about the defects in the connected machines. This study only focuses on monitoring of usage.

The work done in Wireless Control and Monitoring System for Classrooms using ZigBee [5] uses ZigBee in mesh topology. The ZigBee modules in this network support monitoring and controlling inside a specific area, a classroom. The ZigBee network has a base station which is wirelessly linked to sensors placed around the classroom. These sensors monitor the different equipment within the classroom. A PIC16F877A microcontroller is used to interface between the output of the sensors and the ZigBee module. The base station will be given the information about the schedule of classrooms for it will be used to schedule the turning on and off of facilities in that classroom.

The work done in Home Based Power Outlet Usage Monitoring System [6] presents a system capable of measuring the amount of power consumed by appliances plugged into power outlets. It features individualized power monitors, capable of measuring instantaneous wattage and VA (volt-ampere). These values are aggregated and sent to a central database through powerline communications. In this central database, a web-based client software reports and plots appliance consumption. The system makes use of a modified version of the X10 protocol to send data to the database. The research also limits itself to sending recorded power consumption data only upon requests from the server.

The work done in AC Power Meter Design based on Arduino: Multichannel Single phase Approach [7] makes use of an Arduino to measure power. It also concerns itself with the power measurement of common electrical appliances. Its method of measuring the power is by simultaneously gathering voltage and current readings of the appliance. It is not a simple ammeter that assumes the voltage to be a single and stable value. Their hardware consists of the Arduinos being connected to a computer through a USB connection. It also makes use of an LCD screen to display these data.

The work done in Integration of NFC Technology on Household Appliances [8] monitors the usage of appliances through the use of NFC and MyRio. It focuses on the payment system, and provides pre-paid and post-paid options.

Our work develops a PMAS adapter that can be controlled through an android app. The adapter can be installed without any intrusive alterations to the appliances. adapters aren't tied to a specific room only. They are designed to work with any type of room. Easy to install hardware sends data at regular intervals. The PMAS app can display graphs showing power consumption over time. The hardware is a plug and play install type and the monitoring can be done from the users android device.

II. PMAS IMPLEMENTATION

The design of the system, shown in Figure 1, is composed mainly of four parts: the adapters, the central hub, the web server and database, and the Android App. An appliance will be connected to the PMAS adapter. The adapter is responsible for the reading of the voltage and current values of the appliance attached to it. It is composed of a microcontroller that measures the input voltage and current. Data and control information will be transmitted from the PMAS adapter through a ZigBee module to the PMAS Gateway. The PMAS gateway, composed of a ZigBee and an internet module, will receive the data from the adapters and process them before transmitting it to the web server and stores information on the database. The web server is accessed by an Android application to acquire the data from the PMAS adapters stored in the database. The data about the power consumption is displayed on the Android application. The mobile app also shows a graphical display of the data, indicating the power consumption of the device. The app also serves as the main controller for the switch installed in the adapters.

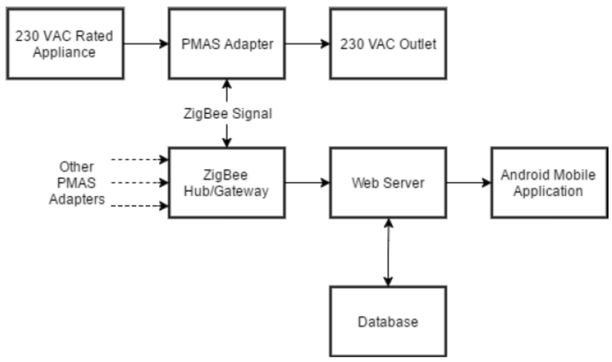

Figure 1: System Block Diagram

A. PMAS Adapter

Generally, the concept for the PMAS adapter is designed to consist of a voltage and current sensing component and as such will allow the microcontroller to measure electrical parameters such as the voltage and the current. It also features a relay for active switching controlled by the microcontroller.

The PIC18 microcontroller family introduced in 2000 by Microchip Technology features an optimized microcontroller for C programming language unlike its predecessors. The specific microcontroller utilized as part of the hardware is the PIC18F2550. Designed for low power applications and universal asynchronous receiver/transmitter (UART) communication interface, it is ideal for the integration of the microcontroller to the PMAS adapter for its analog measurement and wireless communication capabilities.

The main purpose of the PIC microcontroller is to receive scaled electrical signals, process and interpret the data gathered, and collectively communicate them to a ZigBee hub to transfer data to the server and receive control data for the relay. The PIC will be receiving electrical data from the voltmeter circuit and the current sensor circuits discussed below. Using the UART communication protocol for the PIC, the PMAS adapter is able to have a ZigBee integration for wireless communication.

PIC Microcontrollers are not capable of having a large AC voltage as an analog input. To compensate in measuring AC outlet high-voltage, a differential amplifier is designed using an LM358 Operational amplifier. The differential amplifier will scale down 230 Vrms AC outlet voltage to a lower AC voltage. Figure 2 displays the differential amplifier. The gain can be computed from the resistor values utilized, as the feedback resistor at 22kohms is divided by the sum of the resistances along the line connected to the negative input (V-) of the operational amplifier The resulting gain is 1/91 or 0.01099 which converts the 230 Vrms or 325.27 Vpeak input voltage to a 3.57439 Vpeak AC voltage.

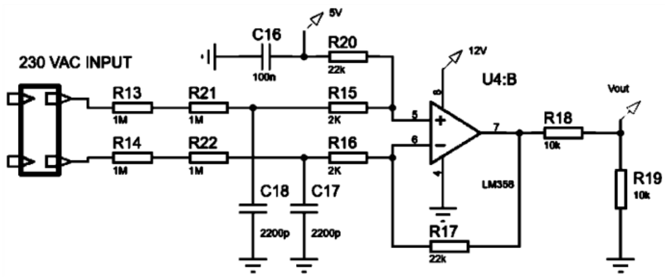

Figure 2: Differential amplifier used as a voltage scaling circuit

The current sensor implemented in the PMAS adapter is the ACS712. TheACS712 is a fully integrated, Hall-effect-based linear current sensor IC. An ACS module was utilized where the output and input pins are already designated, as well as the inclusion of a filter capacitor for noise reduction and a bypass capacitor for the 5V DC input [9]. The schematic layout of this module is illustrated in Figure 3.

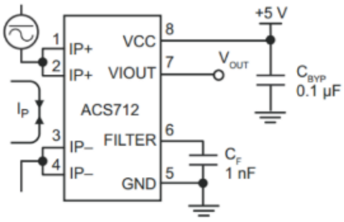

Figure 3: Schematic layout of ACS712 module [8]

The ac input to the ac output connection is generally a direct path. The Hall effect current sensor is electrically isolated, meaning there is no loss in voltage. Other than that and the relay, the peripherals displayed on the right side of the AC ports are all connected in parallel to the AC line.

Proteus was utilized to layout the design and implement the circuit components, such as the ACS712 Hall effect based current sensor, the voltmeter, voltage regulators, and the microcontroller unit. The ZigBee module was also integrated to the design as part of the wireless capabilities of the adapter. More specifically, the ZigBee module chosen was the XBee ZigBee (S2C.

B. Zigbee Wireless Network Layout

An XBee module is a device created by Digi International that uses a communication protocol called the Zigbee Protocol. The XBee Series S2C is a variant of the product line of the XBee family [10]. This variant has an indoor/outdoor range of up to 60 meters or 200 feet. It also has an outdoor RF line-of-sight range of up to 1200 meters or 4000 feet. The XBee module support two modes of serial interfaces which are known as the Transparent mode and the Application Programming mode (API). In Transparent mode, the modules act as a serial line replacement thus it can be said that data is passed through the module. In API mode, the module will contain data entering and leaving in frames that define operations or events within the module. Also, in API mode, the module can facilitate an operation such as identifying the source address of each received packet. In this study, API mode will be utilized by the XBee modules because it can send RF data to multiple destinations in which it is needed so that the coordinator can send data to different PMAS devices. Also, it can send remote configuration commands to manage devices in the network when in API mode.

Five XBee modules will be used to implement this network, four for the ZigBee routers while one for the ZigBee coordinator. The employed topology to be used in the ZigBee network is a star topology, as illustrated in Figure 4. The ZigBee routers, which are connected to the adapters, will be connected to the ZigBee coordinator. The ZigBee coordinator will then connect the ZigBee network to the database of the whole system. This creates communication between the database of the system to the constructed ZigBee network.

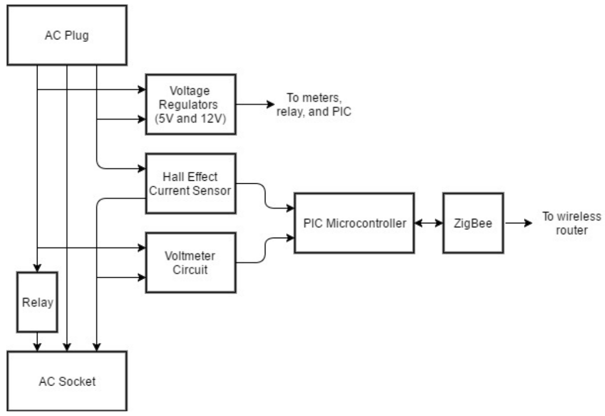

Figure 4: ZigBee network layout

C. PMAS Gateway and Web Server

The PMAS Gateway is an Arduino-based device that processes the data received by the ZigBee coordinator from the four PMAS adapters. The PMAS gateway is the device that connects the PMAS network with the internet. The ZigBee modules connected in the PMAS adapters send data through ZigBee networking protocols to the ZigBee module attached to the PMAS gateway. This gateway is composed of a Gizduino, with an Ethernet Shield and an XBee shield attached to it.

The ZigBee modules that will be used in employing this network are the XBee, which is created by Digi International. Five XBee modules will be used to implement this network; four for the ZigBee routers while one for the ZigBee coordinator. The employed topology to be used in the ZigBee network is a star topology. The ZigBee routers, which are connected to the adapters, will be connected to the ZigBee coordinator. The PMAS gateway, where the ZigBee coordinator is attached, connects the ZigBee network to the web server and database of the whole system.

The web server, written mostly in PHP, allows the interaction between the PMAS gateway, the database, and the mobile app. The PMAS gateway receives data from the PMAS adapters, processes it, then transmit it to the web server through the internet. The web server stores this data in the database, also allowing it to be viewed by the mobile app. This also works in the opposite direction, wherein the mobile app sends data to the web server, the web server updates the database, which is then read by the PMAS gateway. The gateway transmits this data to the appropriate PMAS adapter. Figure 5 shows the interactions with the web server.

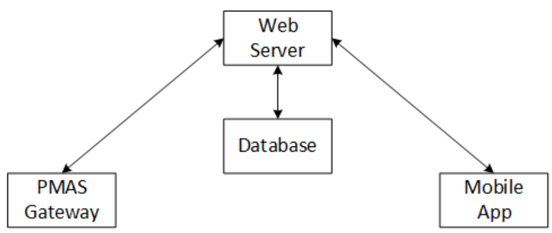

Figure 5: Diagram for Web Server Interaction

D. Android Application

There are two major programs that can be used for Android Development. These are Eclipse and Android Studio. The codes written for Eclipse and Android Studio are interchangeable, so online tutorials done in Eclipse is applicable in Android Studio. Although they are similar in most ways, Android Studio was chosen over Eclipse due to the fact that it is a freeware developed by Google itself and is constantly being updated and continually adds support for newer versions of their Android OS. Additionally, the project files generated by Android Studio cannot be opened by Eclipse but Eclipse project files can be opened in Android Studio. This means that online sample projects made using Eclipse can be opened in Android Studio.

The eXtensible Markup Languange is the coding language used for creating the visuals of Android Apps. These XML files can be found under the resources folder of the Android project. Single screen apps usually only have one XML file, but depending on the application, there can be multiple XML files.

In the PMAS app, there are a total of 10 XML files. These include the XML files for the main screen, settings screen, about screen, and a few more that were auto generated by Android Studio for the navigation pane of the app. The XML file labeled content main contains most of what the user will see. These are the graphs and data regarding the power consumption of their appliances. It also contains the switches for the PMAS adapters.

Its main layout is made using nested layouts with LinearLayout being its parent view. Its child views are a TextView for the device list label and a ScrollView to contain the switches, graphs, data, and refresh buttons of all of the PMAS devices. The ScrollView is a necessary child view because the content that is to be presented to the user is too long to fit into the screen size of any single phone. Another LinearLayout is nested inside the ScrollView so the individual PMAS device's data can be seen vertically segmented into their own spaces. These spaces are in a RelativeLayout format so that the elements under each of the PMAS devices can be positioned relative to each other.

The graph is shown through the use of a WebView. The same is true for the kWh, power, time, voltage, and current values displayed by the app. The refresh button was added so that if the app were to start when the phone is without an internet connection, the user can merely tap the refresh button for the data to appear once they are re-connected to the internet. Each of the elements that will be called upon in the Java code needs to be given id names and, in the case of RelativeLayouts, the elements should be written in a specific order. There is also a vast amount of different XML attributes that can be toggled for each element like width, height, paddings, margins, colors, among others.

A navigation pane can also be added in such way that the XML files will be auto generated by Android Studio. These are the app_bar_main and nav_header_main. The initial code written in these XML files are of a sample navigation pane that can be edited to match what the specific app requires. The user input.xml is a separate XML file that is called upon when the user would like to label their PMAS adapter names. This is done by long-clicking the device name which triggers a dialog box to pop up asking for the new label. The final output of the XML file is the GUI of the Android application and can be seen in Figure 6.

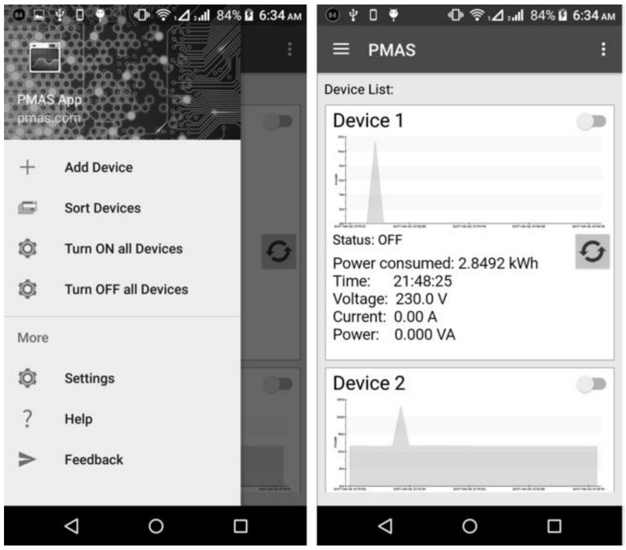

Figure 6. XML Output and Final GUI

Report functionality has been added that gives the user the ability to monitor the power of each device in either a monthly or daily basis. Two buttons were added to the top right corner of the main screen to add the monthly and daily report. These can be seen in Figure 7. Bar graph is used for displaying the average power of each device in either a monthly or a daily basis. For the monthly report, the graph shows the average power per day for the whole month. The daily report will show the average power per hour for the whole day.

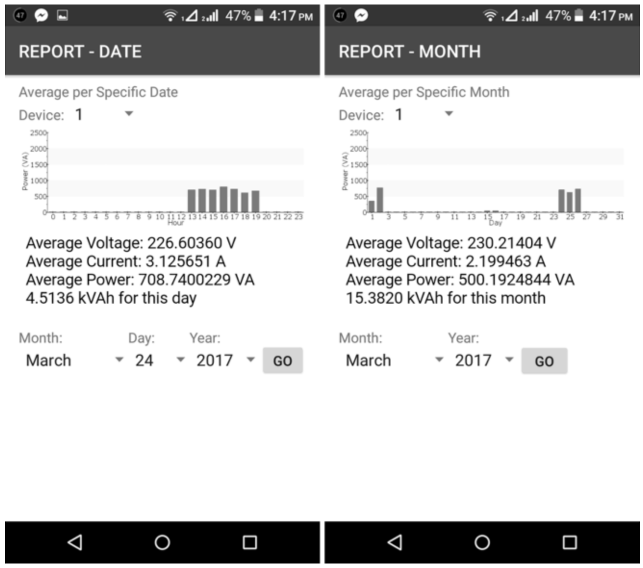

Figure 7: Monthly and Daily Report Activities.

III. PMAS Testing

For this study, data was gathered by measuring the current and voltage values simultaneously using two multimeters and comparing them with the values stored onto the database by the PMAS adapter. The data gathering was conducted over four different appliances: a hair dryer, an induction cooker, a microwave, and an air conditioner. These appliances were chosen because these are the devices that can be commonly found in condominium and apartment units.

The data gathering is composed of 3 main parts. Setup 1 measures the voltage, current, and power consumption of an appliance under normal circumstances, meaning that there is no PMAS adapter connected to it. Doing this establishes a frame of reference regarding to how the appliance consumes power over a certain period of time. The second setup takes into account the PMAS adapter and measures the accuracy of the voltage and current values read by the device itself and compares it with the voltage and current values measured through the use of the external ammeter and voltmeter. The third setup was conducted similarly to the second setup but with the PMAS adapter replaced with another unit of the PMAS adapter. Doing this confirms that the construction of the hardware can be replicated along with all of its functionality. This confirms that the study is repeatable. It can be seen from the data gathered in the tables that the current values have relatively higher deviations compared to those of the voltage values for both PMAS adapters. Still, given these factors, the average percent deviations of the power values are all still within acceptable ranges. For both the PMAS adapter 1 and 2 readings, the highest deviation recorded still belongs to the air conditioner with all of the other appliances having percent deviations of around one or two percent.

Table 1
Average Power Reading On Multimeters without PMAS Adapter, with PMAS Adapter 1, and with PMAS Adapter 2

Appliances	Average Power from Multimeters (VA)	Average Power with PMAS Adapter 1 (VA)	Average Power with PMAS Adapter 2 (VA)
Air conditioner	614.97	649.90	642.74
Hair dryer	1,137.50	1,191.95	1,194.87
Induction cooker	817.74	826.58	834.27
Microwave	1,111.80	1,121.21	977.98

IV. CONCLUSION

The PMAS adapter was designed to serve as a voltage and current measuring device. The measurements are stored in a database where the power and kVAh reading is computed. The PMAS adapter has an interior size of 4 x 3 x 2 inches, making the device compact and easy to use.

The overcurrent protection of the PMAS system lies within the code of the microcontroller itself. Once the PIC reads a current value above the specified overcurrent value, it will immediately turn off the relay.

The user can see the voltage, current, power and kVAh readings on the Android application in the form of text and as graphs. It also has switches for all the PMAS devices. Each of these switches can send a signal to the web server telling it to switch the PMAS adapters' relays either on or off. Additionally, the Android App can display the average values of a certain device over the course of either a specific date or a specific month. The PMAS adapter uses low power devices, such as the ACS712 current sensor, the ZigBee module, and the relay to have the device consume less power. Four fully functioning PMAS adapters and a PMAS gateway were built. The Xbee modules inside each of the PMAS adapters are all transmitting and receiving data to and from the PMAS gateway; forming a star topology.

The readings of the PMAS adapters are stored on the database which the Android app utilizes to display the readings to the user.

Basically, a mobile app-controlled wireless power monitoring and switching system using ZigBee based specialized adapters has been constructed.

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