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To cite this article: Dar Hung Chiam et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 495 012019

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Wi-Fi Enabled Modular Sensing System For Smart Home Applications

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Abstract. Advancement of sensory systems and internet connectivity has enabled the mass growth of Internet of Things (IoT) in 21st century. The concept of smart home applies IoT protocol by connecting all electronic appliances onto a server host wirelessly for home activities monitoring, management and control. All-in-one Wi-Fi enabled smart home devices comprise of multiple sensors for home environment control. However, some built-in sensors are not always in use all time, and it incurs the cost of production. Hence, a portable Wi-Fi enabled Modular Sensory System (Wi-MSS) is proposed in this paper aiming to give flexibility to users in customizing their own smart home sensory devices while enabling the automation of electronic appliances by following users’ rule and condition setting. Wi-MSS comprises of a Wi-Fi host with multiple analog-to-digital micro-USB ports for sensory plug-in. In addition, an interactive interface is created in the cloud service for information management and data visualization in Wi-MSS. The data is visualized in an interactive way enabling users to analyse their behaviour on using home appliances through Internet and mobile phone.

1. Introduction

The recent development of Internet of Things (IoT) has applied multiple sensory system and internet connectivity to various applications especially smart home system [1]. IoT enabled us in building smart homes, smart environments where most of the monitoring, control and decision making can be automated. IoT applications can be categorized into two categories, i.e. ambient data collection and analytics, and real time reactive application [2]. The first category of IoT system collects information, processes data offline, makes simple action and acts as a predictor for future data. Second category of IoT application is based on real-time reactive system, for example autonomous vehicle. Combining these two category into one device will increase the flexibility and scalability of the product [3].

The concept of smart home applies IoT protocol by connecting all home appliances together via a host server for home activity monitoring, management and control. However, the mobility of center processing unit sitting at one corner of the house reduces the flexibility of controlling mechanism [4]. Hence, smart home devices connecting via mobile phone for ease monitoring has become the trend nowadays as it enables users to monitor all appliances at anywhere at any time via internet. A billion of information is retrieved from home appliances to a mobile phone and subsequently, the information should be presented interactivly for data visualization and analysis. Data collected from smart devices such as smart phones can be used to analyze human daily behavior and activities [5]. Through data visualization and analysis, the behavior of a user can be retrieved. The user behavior analyzed can be used for the smart home appliances for the intelligent control and learning [6].

In the existing market, smart home devices such as D-Link Wi-Fi smart plug [7], Digi XBee Smart Plug [8], Belkin WeMo [9] contain multiple sensors to monitor home appliances’ power consumption, lighting control via network and feedback to user about the user’s power usage behavior inside all-in-one system. On the other hand, Icontrol Network Pipers [10] is an all-in-in Wi-Fi-enabled smart home security and automation hub to detect motion, temperature, humidity, light and sound. Lowe’s Iris smart home monitoring and control system enables wide range of smart devices and appliances from home...
security sensors to a smart sprinkler system [11]. However, all the above-mentioned devices embed with sensors inside the smart devices and it reduces the flexibility of customization. Redundant sensors are somehow increasing the cost of production as if they were placed at the wrong corner of the home.

In this paper, a portable Wi-Fi Enabled Modular Sensory System (Wi-MSS) is proposed for smart home activity monitoring, management and control. The proposed modular device enables users to customize their own sensors through multiple micro-USB ports associated with a Wi-Fi module. It aims to reduce the wastage of unused sensors which are embedded inside a device. In our proposed device, five types of modular sensors such as current transducer, motion detector, temperature, humidity and light dependent sensors are built into micro-USB modules. Those sensors can be interchanged easily by the users with the proposed Wi-MSS. Subsequently, users can customize its automation procedure with plug-in sensors by setting up rules and conditions for home appliances activation. In addition, those sensors will collect and deliver data to mobile phone for data visualization and monitoring. The data collected can be used for user behavioral analysis as well as electrical appliances behavior analysis. It is believed that this is a green initiative by reducing the abusive waste of electronic sensors, automating the on-off process of devices when under usage and understanding the user behavior on how they utilize their appliances at home daily.

Figure 1. The overall block diagram of the proposed Wi-MSS for generic smart home application.

Figure 2. The functionality of multiple Wi-MSS control via Internet and cloud computing.

In Figure 1, a detailed block diagram of proposed Wi-MSS for smart home monitoring is demonstrated. Inside the Wi-MSS module, the major electronic components are Real Time Clock (RTC), Current sensor (ACS 712), SD card module, 240 V\textsubscript{AC} to 5 V\textsubscript{DC} power converter, Wi-Fi module ESP 8266, Logic Shifter, Arduino Nano, micro-USB ports, which can be connected to various kind of sensor modules (temperature, humidity, motion and light dependent resistor) and relay. After the completion of hardware, a user interactive interface is designed for data visualization, management and control as shown in Figure 2. Subsequently, hardware and software integration is implemented with a few case scenarios at home environment for data analysis and evaluation. In this paper, Section II discusses about three-stage design methodology for Wi-MSS. Section III reveals the products and its verification of Wi-MSS. In the final section, a conclusion and future work is drawn about the benefits of Wi-MSS.
3. Figure 3. Three stages of Wi-MSS design including hardware prototyping, software integration and data logging verification.

2. Design Methodology of Wi-MSS

Three stages of design methodology for the proposed Wi-Fi-enabled modular sensing system is illustrated in Figure 3. Stage 1 consists of hardware design and prototype construction using ESP8266 Wi-Fi module, Arduino Nano board, ACS 712 current transducer and some other electronic devices to form them into a modular size. Stage 2 involves the software design using cloud server and ESP8266 as a stand-alone server. Software design also includes the algorithm functional design for Wi-MSS. Stage 3 is carried on to verify the integration of modular sensory system and cloud as well as ESP8266 server in home environment. The detail of the project implementation is demonstrated in the following sections.

2.1. Stage 1 -- Hardware design of modular sensory system

In the first stage, component sourcing and purchasing from internet, such as element14 and RS components are surveyed and investigated. The accurate components with correct specification is ordered for the hardware construction. Once components are received, a series of test and evaluation will be done to ensure the components are in proper function. Subsequently, the assembly of the components will be started off by following the circuit schematic as shown in Figure 4. In addition, relay switch connections will be designed to enable AC current flow. The usage of ESP 8266 Wi-Fi module is further studied for wireless communication. The server feature of the ESP 8266 Wi-Fi module is explored. The internal memory of ESP 8266 is 1-Mb flash memory.

2.2. Stage 2--Software design of data analytic display using Fusionex Giant

In stage 2, once a single unit of Wi-MSS is completed, a user interface is created on the cloud, where it can be access from anywhere with network. In this project, Fusionex Giant is used as the cloud platform to collect power information from Wi-Fi module. The collected data is demonstrated in an interactive graphical format, followed by the data visualization and analysis. A complete set prototype is subsequently built to test the functionality and verify the output of different sensors. Multiple units of the proposed Wi-MSS are duplicated after the verification of functionality of first prototype. Testing will be done again to ensure the two cells of Wi-MSS works accordingly.

2.3. Stage 3--Verification of modular sensory system inside home environment

In this stage, several real-case scenarios of the applications of the proposed prototypes are set up for smart home system evaluation. The prototypes functionality will be tested in real situation. For example: the temperature sensor will be installed and temperature data will be monitored together with a functional thermometer. This is to make sure that the data collected by the Wi-MSS is correct and at the same time to test its accuracy as well as robustness. An improved version of software or hardware will be upgraded if it is required.
3. Results & Discussion

The implementation of stage 1 is completed with the finalized circuit diagram as shown in Figure 4. The Wi-MSS circuit diagram consists of input AC adaptor, output AC plug, ACS 712, AC-DC converter, RTC, Relay, Nano Arduino, SD card, micro-USB port, LM 1117, ESP module and Logic shifter. Figure 5 (a) shows the Wi-MSS prototype testing with a load 55W rated fan.

![Wi-MSS prototype testing with a load, 55W table fan.](a)

![The complete overview of Wi-MSS prototype construction.](b)

**Figure 5.** (a) Wi-MSS prototype testing with a load, 55W table fan. (b) The complete overview of Wi-MSS prototype construction.

There are ten components in Wi-MSS shown in Figure 5(b). All labeled components are described as follows:

1. Power source which supplies power to Wi-MSS system and serve as an adaptor for electronics devices.
2. Current transducer uses to capture current flowing to the load for power consumption calculation and monitoring.
3. Relay receives a signal from the microcontroller to activate the load.
4. Power module or converter which convert AC source to DC source to power up the electronics module.
5. ESP8266 Wi-Fi module acts as a master controller. It transmits data to internet through Wi-Fi and it has built-in sleep mode function.
6. Real-time clock enables the record of clocking system for day and night power consumption analysis.
7. Logic shifter converts 5V to 3.3V for different module communication.
8. Micro-USB connector is a modular sensing system for various types of sensors enabled, such as IR sensor, LDR, motion, temperature and current.
9. SD card module logs all captured data in certain period before transmitting to internet for visualization.
10. Arduino Nano acts as a slave controller. I2C protocol is used to communicate with master controller. It obtains more ADC and GPIO pins for data collection and capturing.

The harvested data of the 55W fan is collected and uploaded to the Fusionex Giant cloud for display as shown in Figure 6(a). Our data is uploaded to “data.sparkfun” database. At this stage, we download the data stream manually from the database in CSV format. The CSV file is then uploaded to Fusionex analytics for data visualization and analysis. Figure 6(b) shows the collected one hour power data of the
55W fan. The fluctuation of the power at the beginning of the graph shows the switching event during the test. Figure 7 shows the switching test on interval of 10 seconds carried out.

Figure 6. (a) Captured data is transferred via wireless connectivity and displayed on a screen using Fusionex Giant, (b) One hour data logging on a load, 55W table fan.

The sensors data are collected and saved on SD card. The sensors data will be uploaded to sparkfun database on each interval, for example, 5-minute interval in order to save the power consumption of micro-controller. On the Fusionex Giant, the sensors data will be displayed using graphical method (graphs or charts), depending on the type of data. Each sensor can have multiple displays (For example, 5-minutes, hourly, daily, monthly graphs). Fusionex Giant is adopted for the current development due to the ease of data analyzing tools provided in the software.

Multiple Wi-MSS can upload their data individually onto the same server. The devices will be named separately and the sensors data will be uploaded to Sparkfun database as usual. At Sparkfun database, the data are categorized into user-defined parameters before sending it to Fusionex Giant. At Fusionex Giant, the user behavior can be observed. For example, user’s total power usage per month is displayed, this data shown on Fusionex Giant graph can be further split into multiple displays of individual sensors power consumption. Users can easily know their electricity consumption behavior using this graphical method.

Besides, human behavior study will also be conducted on the power data collected. The devices behavior can be analyzed by comparing to efficient devices available in the market. Users can harvest their electrical appliances health status easily. Based on the electrical appliances’ health report, users can easily decide whether they should do maintenance on the devices or to purchase a new one to replace the existing device. Figure 8 shows the final prototype of the proposed Wi-MSS module, where all the electronic components are arranged into a 60*35*75mm casing with the Wi-Fi module outside of the body. This version of prototype consists of all the ready-made modules and can be upgraded to even compact design using printed circuit board in future.
Figure 8. Complete prototype of the proposed Wi-MSS.

4. Conclusion

In this paper, a new portable Wi-Fi Enabled Modular Sensing System (Wi-MSS) was proposed for smart home applications. The customization feature of Wi-MSS allows the inclusion of only the required sensors for specific purpose. This reduced the incurring costing of extra features while at the same time increase the flexibility. The captured data was transferred to mobile devices for data visualization and user behaviour analysis. In addition, Fusionex Giant was adopted as the software tool to display the big data logged from the multiple IoT devices. To enable the real-time IoT function, “data.sparkfun” database acted as the medium to harvest data received from the Wi-Fi transmission for database collection. Subsequently, the visualization of real-time data was plotted in Fusionex Giant. It enabled users to analyse their behaviour on how the usage of power consumption daily for every household devices. It could educate the behaviour of users to save energy if they could visualize their behaviour in an interactive graph. In the future, artificial intelligent would be applied to analyse the data automatically and deliver tips of saving energy to user’s handheld device.

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