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Prototype Design of Smart Home System using Internet of Things

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Abstract

Smart home control system (SHCS) can be integrated into an existing home appliances to reduce the need for human intervention, increase security and energy efficiency. However, it is still an open problem due to difficulties such as network distance, signal interference, not user friendly, increased cost and power consumption. This paper reviews various topics on smart home technologies including control system, smart home network, smart home appliance and sensor technologies for smart home. In this research, the proposed prototype of home automation allows users to remotely switch on or off any household appliances based on Internet of Things (IoT) with the enhancement of solar charger. This prototype uses four types of sensors i.e. PIR sensor, temperature sensor, ultrasonic sensor and smoke gas sensor for automatic environmental control and intrusion detection. The hardware, software, and test field design will be discussed in this paper.

Keywords*: Smart home, Internet of Things, Arduino, Solar Charger*

1. Introduction

Nowadays, more people are becoming aware to make their homes to be environmental-friendly. The smart home enables user to manage the energy consumed and increase savings by controlling lighting, window coverings, irrigation and monitoring usage. The portability and technologies of smartphone increased the users' interest in controlling their appliances from the smartphones. The automated appliance control enable users to execute tasks before arriving home. Smart home control system provide solution for assistive technologies especially to the disabled and elderly person using the mobile remote control apps. According to the report in [1], around 72% respondents said that self-adjusting thermostat and 71% said that doors that can be locked from a remote location, were the most important features when it comes to the most desired smart home devices. Figure 1 illustrates the smart home function and users' level of enthusiasm for the technology.

Smart home research became popular, however this system is rather not user-friendly to some group of people such as disabled and elderly due to its complexity and cost. The use of GSM communication results in additional charge for every message sent through the network. Moreover, the proposed system should have easy-to-use GUI interface to control and monitor. The use of a webserver is the best choice to overcome this problem as a single website can reach users across many different types of mobile devices, whereas native apps require a separate version to be developed for each type of device.

This research introduces a smart home control system that would improve the manually household operation. Less personnel is required while increasing the overall safety by integrating the automatic home appliances based on sensor reading and user manual button in a developed website interface. The automatic function based on the sensor information made the control system to operate effectively and efficiently. The concept of IP networking applications and devices in the house enables the home appliances to be controlled from everywhere from laptop, mobile phone, tablets or smart TVs, provided these devices has

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access to the internet. The website provide convenience to developers and users, especially for the disabled and elderly people. This research provides a password protected website to tackle the security issue. Besides, the battery problem can be overcome by adding solar charger to recharge the weak battery. This solar recharge controller can also be used as a backup resource during blackout.

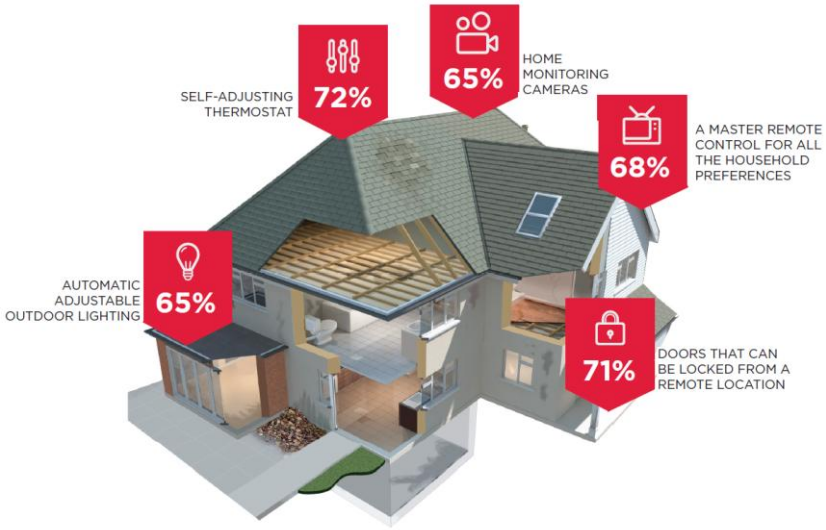

Figure 1. Top Consumers' Lists for Most Desired Smart Home Devices adopted from [1]

2. Home Automation System

2.1. Elements of Smart Home

Smart Home system is the control and management of integrated of many small systems at home. The small system can be a lamp switch, temperature monitoring, motion detection, home surveillance and other sensors. The sensors in these systems will be controlled by users using interface devices such as remote control, computer, and smartphone. By increasing the type of sensor to be controlled, the main system needs to be more specialized to integrate the sub-systems to become the Smart Home system. The networking of system can be wired or wireless depending on application. Table 1 shows the summary of Smart Home system elements.

Table 1. Summary of elements in smart home

Elements in Smart Home system	Example
Sensor	Temperature monitoring, fire detection, home surveillance
User interface devices	Remote control, computer, Smartphone, tablet
Types of networking	Wired-Fiber optic, coaxial cable Wireless-Bluetooth, WiFi, ZigBee, RF
Centralizing control	Micro controller, PLC, computer, FPGA

2.2. Home Automation Carrier Mode

The carrier mode of home automation carries signal for electric power transmission to home appliances. There are four types of carrier mode; power line systems, wireless systems, hardwired systems and internet protocol systems.

Power line communication is a transmission or carrying data through conductor. A modulated carrier signal is applied on the wiring system. Different types of power line communications have different frequency bands, depending on the signal transmission characteristics of the power wiring used. Since the power wiring system was originally intended for transmission of alternating current (AC) power, the power wire circuits were limited to carry on higher frequencies.

Wireless communication is an information transfer between two or more points without any physical connection medium such as an electrical conductor. It is the most recent of the three and is increasingly becoming more popular as costs per unit decrease. Solutions based on this technology are usually very easy to install and configure. The system can combine most of the benefits offered by hardwired technology, such as two-way communication and scalability, though with a relatively lower bandwidth.

Wired, or hardwired smart home is the most reliable and expensive carrier because it can perform over high-grade communications cable. Therefore, a systematic plan is needed before constructing a house. Hardwired systems can perform more tasks at a time causing them an ideal choice for larger homes. This system allows effective integration of households such as lighting, audio/video equipment and security system.

Internet Protocol (IP) control the devices under an Internet Protocol address, and creates a local area network (LAN) in the home. It has an internal web server and support configuration with a browser. Internet can provide possibilities for live video streaming and real-time control in the home. However, not all home appliances are equipped with access to the internet.

2.3. Wired and Wireless Home Automation Protocol

The major standards for wired carrier mode are INSTEON, KNX and X10. INSTEON standard uses mesh topology and is developed based on the X10 model, enabling simple devices to be networked together using the power line or RF. INSTEON power line devices can transmit data at 131.65 KHz with corresponding wireless devices at 904 MHz. INSTEON devices are peer to peer, thus a master controller or routing software is not needed. KNX is a standard for OSI-based network communications protocol for smart buildings. This standard is based on the communication stack of EIB with enlargement of the physical layers and configuration modes. KNX supports different types of communication media like twisted pair, radio frequency, power line, and IP. Lastly, X10 is one of the home automation standard. It uses power line wiring as carrier mode. X10 remains popular in the home environment because of inexpensive availability of new components. X10 transmit packets with four bit house code followed by one or more four bit unit code, finally followed by a four bit command.

The major standards for wireless carrier mode are Zigbee, Z-Wave, Bluetooth, WiFi, APC 220 Wireless Module. Table 2 shows the summary of home automation protocol. Based on Table 2, APC220 is chosen as wireless communication between two or more microcontroller due to its low cost and easily transmit transparent data with large data buffer one with more than 100 channels.

Table 2. Summary of Home Automation Protocol

Media	Protocol	Significance	Disadvantage
Wired	X10	Easy to install, lower cost, bitrate 20 bit/s.	Have noise
	KNX	Have high data rate (1200 bit/s)	Interference from AC signal
	INSTEON	Every devices have own unique ID	Not adopted to some Electricity
Wireless	Zigbee	Low power wireless protocol	Tight power and bandwidth constraint
	WiFi	Higher transmission rate(11Mbps)	High power consumption
	APC220	Easy to configure	Point to point communication only

2.4. Internet of Things

In the communication domain for smart home, two requirements are needed. The first one is how to make possible the communication of the equipment inside the house. The second one is to connect the smart house to the outside internet world. Internet of Things refers to a network of objects, where all things are uniquely and universally addressable, identified and managed by computers. It is a collection of technologies that makes it possible to connect things like sensors and actuators to the Internet [2].

A formal definition of the IoT is the following: "*The Internet of Things is an integrated part of the Future Internet and could be defined as a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual things have identities, physical attributes, and virtual personalities*

and use intelligent interfaces, and are seamlessly integrated into the information network." as stated in [3].

Current applications of the IoT are found in logistics, smart homes, large-scale platforms for sensor data and many more. The IoT research area is important in the smart home context because the contained devices share technology and functionality with it. As stated in [3], the unquestionable main strength of IoT is its impact on everyday' s life. They highlight areas such as smart homes, smart offices, e-health, and enhanced learning.

2.5. Smart Home Application Framework

The most open and interoperable way to provide access to remote services or to enable applications to communicate with each other is to utilize Web services. There are two classes of Web services: Simple Object Access Protocol (SOAP) and Representational State Transfer (REST). REST based Web service utilizing standard operation such as GET and POST requests that return Javascript Object Notation (JSON) responses to communicate between the remote user and the micro Web server. JSON is a lightweight data-interchange format. It is easy for human beings to read and write. It is also simpler for machines to parse and generate messages than using XML. For example, the author in [4] highlighted the process to turn ON the light, which need to send HTTP POST request to the resource using the server.

2.6. Related Works on Smart Home

From the invention of embedded smart home many decades ago until today, numerous researchers and developers envisioned, designed and developed ubiquitous applications, to transform physical environments into smart spaces. The purpose of smart home project includes HVAC (Heater, Ventilation, and Air Conditioning), lighting, energy monitor, and security. Many researchers used ZigBee and SAANet protocol to develop their smart home project [5, 6]. Meanwhile, the authors in [7] designed smart home by using OSGi technology as home network subsystem. OSGi technology is a set of specifications that defines a dynamic component system for Java. Table 3 shows the summary of related works on smart home.

3. Prototype Design of Smart Home Control System

The previous generation of smart home control system was dependent on human, remote control or PC utilization for switching functionalities. This basic capability already provided significant improvement over manually home appliances system, but its usefulness was greatly reduced due to infrared limited use for indoor.

3.1. Hardware Design

In the proposed design, the evolution process was based on mobile control system. The SHCS configuration consists of a website platform and an Ethernet based micro web-server. The SHCS configuration consists of the following components based on developed system as shown in the Figure 2.

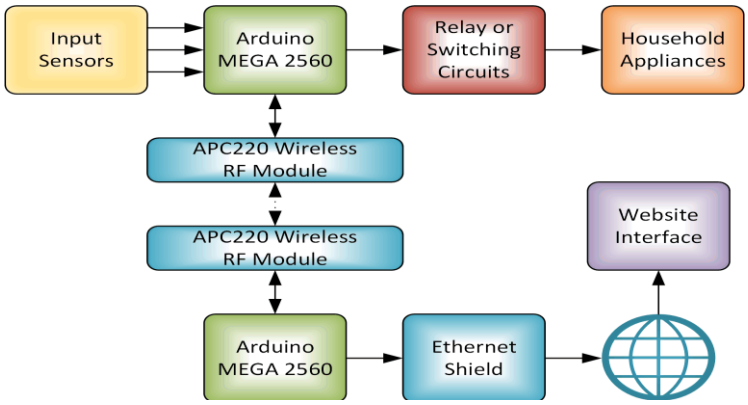

Figure 2. Block Diagram of Smart Home Control System

Table 3. Summary of Related Works on Smart Home

Ref	Methods	Advantages	Disadvantages
[8]	-Proposed context-aware middleware method by providing user's preference smart home. -Acquire 6 inputs: pulse, facial, room temperature, body temperature, location and time. - Used OSGi as home network protocol.	- Middleware allows agents to get information easily, reason about it using logics for any changing events. -Automatic control service without the need of user pressing any button remote -A better home service can be estimated by analyzing the user-pattern history	-Neural networks cannot be retrained. Adding data later is almost impossible to an existing network. - Handling of 6 data in middleware is rather a complicated tasks.
[9]	-Built within PUC system; enables users control households in their environment through a remote user interface. - Introduced Windows smart phone interface.	-Allow remote control interfaces on user smart phone devices -Single smart phone user making it easy to personalize the interfaces.	- A full mapping table is needed to remote controls for all home entertainment system. -Long hierarchical list design is worse in the small screen
[10]	- OSGi method provides portal services and maps the broadband network with local network. -Used IDS and firewall to avoid any infection.	-Equipped with firewall and virus protection software. -Provide secure communication for users.	-Applicable for internet users only
[5]	-Smart home appliance communication is based on Zigbee and SAANet protocol.	-Zigbee wireless communication reduced the cost.	-Facing obstacle for different data recognition between different types of devices. -Have distance limit
[11]	-Consist of three main component; RFID tag, sensor network, home server and service robots.	-Enable households to be controlled by actuators connected to the home server. For example, the robot just needs network address to switch the devices. -Services robot helps the user for the daily chores.	-Increased in cost because of expensive sensors used. - Database for decision-making is huge and the algorithms is too complex. -Not satisfactory performance of the robotic system.
[12]	- FL based smart alarm is developed. - Developed fuzzy neural network (FNN) for learning purpose. - Bluetooth connection between smart home controller and home appliances.	-The uncertainty of observation is reduced from FNN learning. -Exact solution is given at lowest calculation time.	- A complete analysis for the smart home environment is not possible. - Problems of changing hardware and software components.
[13]	- Consist of controller, terminal device and signal converter. - TI DM6446 as CPU, DSP and ARM processor - Mobile phone scheme are CGI, javascript, CSS, and separate WM/WMLscript	- Communication Wrapper converted the diverse communication protocol to a uniform style - Enable control of infrared devices by using ASK wireless signal; convert the wireless transceiver command to infrared	- The looking style of user interface is unfit for different screen whether adopt C/S or B/S mode.
[14]	Zigbee wireless communication is used for application that requires low development cost and low power consumption	-Low cost system -Reprogrammable system	-Implementation includes GSM,WIFI and Zigbee -Result in high cost

3.2. Software Design

Figure 3 shows the overall process of the system. First, user need to configure the IP address of SHCS and key in the IP address at the web browser. For the SHCS prototype, it is connected to the university's network router which is a dynamic and private IP address. Next, user need to key in the password to access the main page. The website is kept in idle mode and refreshed in every 1 second (configurable) so that it can be updated with the current sensor reading. Lastly, a command string is decoded if the user enter a command key. The command is interpreted in microcontroller and HIGH or LOW output is produced to the relay circuit. The relay circuit enables a low voltage Arduino to control the high voltage home appliances.

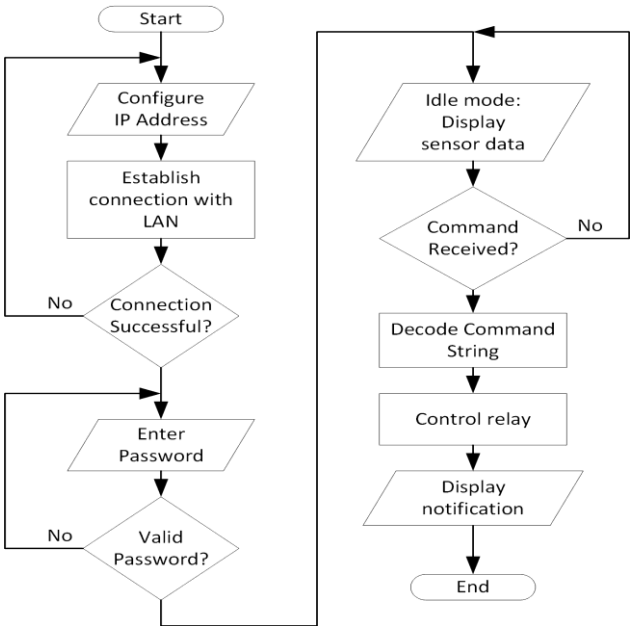

Figure 3. Flowchart of the System Operation

4. Prototype Implementation of Smart Home Control System

4.1. Hardware Implementation

Arduino is an inexpensive single-chip computer or microcontroller. Arduino do not function in isolation, means that it can accept input from one or more devices and provide output to other devices within a given system. The Arduino can be powered via the USB connection or with an external power supply. The external power can be connected from an AC-to-DC adapter (wall-wart) or battery. For this project, an external battery is supplied to the Arduino. Three sensors were used in this prototype, i.e. gas sensor, PIR sensor, temperature sensor and ultrasonic sensor. Figure 4 shows the primary test field of SHCS that has been developed to monitor the temperature, user location and switch the electrical loads. This process is achieved using internet with Android application interface. Mechanical CAD design is drawn using Solidworks and is shown in Figure 5.

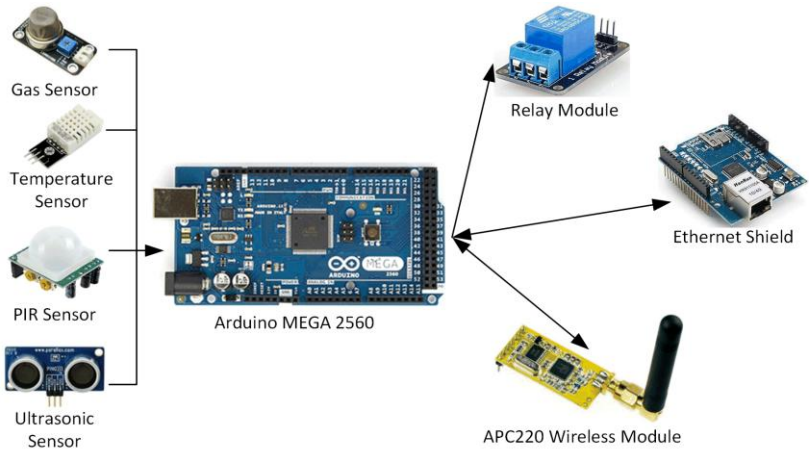

Figure 3. Hardware Implementation

The ON/OFF user command for SHCS prototype composed of six lamps, fan, blind and gate. Gas sensor is located at the kitchen to detect the gas leakage, while PIR sensor is placed

at room, temperature sensor at hall and ultrasonic sensor at front gate. These devices at right side (room, toilet, etc) is communicated wirelessly with the left side (kitchen, dining hall). Figure 6 shows the prototype implementation.

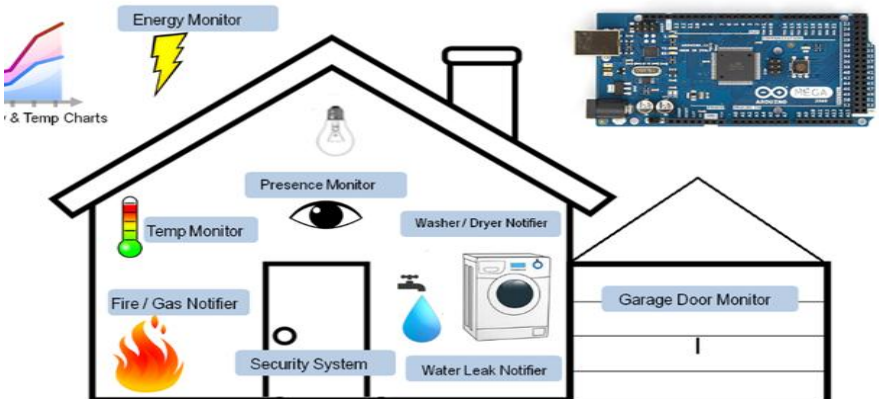

Figure 4. Test field of Smart Home Control System

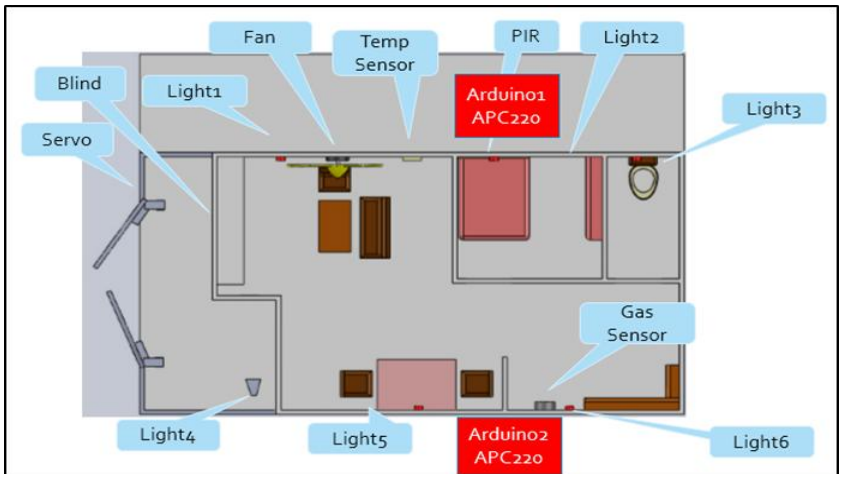

Figure 5. The top view of test field

Figure 6. The Prototype of Smart Home Control System

4.2. Software Implementation

Website Graphical User Interface (GUI) is the interface for the user with the electronic devices in order to use the system. In GUI, user can control the home appliances either to turn it on or off at any time. The website also displays current gas and temperature reading. Notification is shown when the PIR sensor detects a human motion in the room and ultrasonic sensor detects a car at main gate.

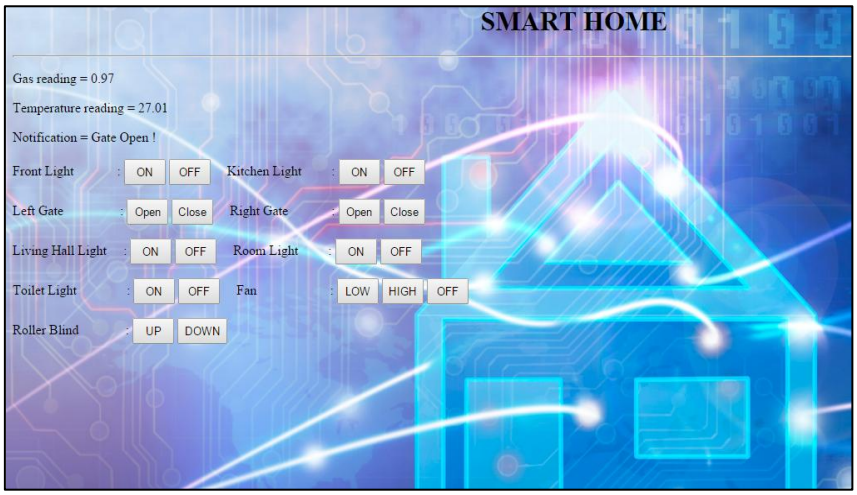

Figure 7. Website GUI for Smart Home Control System

Users can use the application without any complexity on understanding and learning the command language. Exchange of data between applications on the Internet is achieved by using HTML format. HTML provides a simple way of how data can be represented in textual form where meta-tags enclose the data item. HTML is a markup language that defines a set of rules for encoding documents in a format that is both human- and machine-readable. Figure 7 shows example of HTML in Arduino IDE to design various buttons/controls in the website GUI.

5. Conclusion

This paper has presented the prototype design and implementation of smart home control system. First, it provides a comprehensive literature review on smart home system elements, carrier mode, wired and wireless protocols, and application framework. Next, the hardware design is presented using Arduino Mega 2560, APC220 Wireless, Ethernet shield, and three sensors. The flowchart of the system operation was discussed in the software design. Lastly, prototype implementation and test field design were discussed in more details. The prototype uses six lamps, one speed-controlled fan, one window blind, and one security gate. The actual implementation of a smart home webservice was also presented. The home appliances are successfully integrated with the smart home control system through relays. Further research includes the performance evaluation of the developed prototype.

Acknowledgements

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