The Designing and Implementation of a Smart Home System with Wireless Sensor/Actuator and Smartphone

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***Abstract*—This paper presents the design and implementation of a prototype system that employs standing techniques for smart home sensing and control for a future home environment. Smartphones currently show great potential in sensing, processing and communication capabilities. The prototype provides solutions for communications between home users, electronic equipment and a Smartphone. The home equipment is linked wirelessly via Wi-Fi technology to a household server, which can be controlled through the smart phone using an iOS application. In particular, the main objective of this work is to design a system named Wireless Sensor Actuator Mobile Computing in a Smart Home (WiSAMCinSM) that makes multifunctional contributions to assisting elderly people in their daily lives. Part of this system has been tested within the laboratory; firstly, through a WI-Fly Serial Adapter using Tera Term technology, and secondly, through WI-Fly and iPhone using the Ad hoc network. The prototype system consists of a Smartphone, Microcontroller Unite (STC89C52RC), WiFly-RN370 and seven sensors, as well as an iMac and a Personal Digital Assistant (PDA). The prototype system has been implemented based on the Smartphone and commercially available low cost sensors, actuators and logic converters. Results show great potential in employing the information and evaluation of high quality prototypes for the functions of data acquisition.**

Keywords–smartphone; sensors/actuators; smart home; WI-Fly.

I. INTRODUCTION

It is widely known that embedded sensors and actuators within mobile computing in the smart home can be useful in improving elderly people's daily lives [1]. Today, elderly people are the fastest growing segment of the population in developed countries, and they want to live as independently as possible; but, these lifestyles come with risks and challenges. The ageing population has continued to grow since 1950; the world percentage of elderly people has increased steadily from 8% in 1950 to 11% in 2009 and is expected to reach 22 % by 2050 [2]. It has been noted that the continuing decrease in the mortality rates for the elderly, means that the proportion of older people in the population will continue to increase [2].

The smart home is equipped with wireless sensors and actuators to recognise environment-sensing data and to control electric devices. The technology will be converted to a digital system mapping the movement of the body within the environment surrounding it. This will then be transmitted to the Microcontroller Unit (MCU) to perform certain applications, for example: monitoring, appliance control, and processing, most of which require and utilise software information. This is in addition to the automatic transmission by means of an algorithm located in a different address [3].

All phones also come with the ability to communicate over the cellular networks, and most have built-in short range communication capabilities such as Bluetooth and Wi-Fi, that can allow them to communicate with and control appliances in their surrounding environment [4]. Khan et al. [5] found that over the last decade, the mobile computing service has been commonly accepted and has become an integrated digital method of assistance, not only for key computing and communication mobile devices, but also for other purposes, such as predicting the global environment, controlling greenhouses and for social networking.

Smart phones are now the preferred mode of interaction with many appliances because the phone is always available and can provide a better user interface with its improved hardware. Precedents exist for people using their phones to control their environment remotely [4].

The model in this study is the wireless Sensor Actuator Mobile Computing in Smart Home (WiSAMCinSH), which consists of various appliances to monitor occupant activity and can also be used in other circumstances to control the devices that are used indoors. The system is equipped with a number of wireless sensors and actuators that can make decisions and acquire data according to the behaviour of the house occupant. The Smartphone technology is used to receive information from wireless sensors in real time. It is believed that information collected from sensors can engage with a large proportion of data to indicate possible human behaviour. That kind of information can be gathered and transferred to the Smartphone or a personal computer for

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storage and analysis using advance computation and data processing methods.

The rest of the paper is structured as follows: Section 2 describes the background, with respect to wireless sensor/ actuator and mobile computing in a smart home. Section 3 introduces the prototype system used in formulation of the method of smart home design. Section 4 presents the system design by describing the prototype for human mobile computer interaction in a smart home and how it can integrate with other equipment such as wireless sensors, actuators and the MCU, using a wireless network. Section 5 outlines the appliances and technology used with sensor implementation. Section 6 defines two techniques to set up configurations of the test plan using Tear Term and smartphone. Section 7 considers an evaluation of the results while Section 8 provides the conclusion and future work.

II. RELATED WORK

Alam et al. [6] reviewed collective information on various technologies used in the smart home, and defined the smart home as "an application of ubiquitous computing that is able to provide user context-aware automated or assistive service in the form of ambient intelligence, remote home control, or home automation". Ding et al. [7] used a survey to assess the effect that various sensor technologies have on sensing environments and infrastructures mediated in the smart home, where appliances are located on elderly people and placed in the home infrastructure.

Recent studies by Makonin et al. [8] and Kononen et al. [9], which involved integration between mobile computing and computational intelligence, provide an opportunity to assist inhabitants dynamically with interaction in smart home technologies. These devices and patterns of usage are the main concentration of new projects. There is therefore a need to understand more about integrating, locating and implementing these technologies to help occupants in constructing additional resources to enable decision making.

Tag4M and Wi-Fi were used to measure temperature, humidity, light and pressure in a room environment in the smart home. The use of hardware and software techniques presented a condition for the monitoring of the ambiance in the room. The results illustrate that gathering data using Wi-Fi Tag might be a preferable method in wireless application [10].

Data are gathered from the sensors and actuator network to monitor the environment and activity of regular living; and these are then communicated through a base station, finally being saved in a central database [11].

Suryadevara et al. [12] and Majeed [13] have recently developed a well-being function for the elderly in the intelligent home, with the support of devices using ZigBee [12] and wireless sensor. The well-being function is used to compute the run time of the system design as a related procedure throughout. It takes the sensing action period from the specific records of the workstation system. This index was instantaneously detailed in the database for upcoming information processing and estimation of the uncommon behaviour of the occupants.

Rather than use a massive amount of monitoring devices, Gaddam et al. [14] have experimented with a limited number of expensive wireless sensors of high quality, to deal with the challenges of the prototype system and reliability. They suggested a microcontroller with wireless radio frequency communication, for example ZigBee; which allows for the data collected from sensors and transmitted to a base station to be installed on a PC. Some experiments have been done by linking wireless sensors to electronic equipment such as: a kettle; microwave; bed; and TV; to determine the reliability and performance of the system design. The results showed that for longer distances reliability decreases and also, the effect of Wi-Fi noise caused communication to become unreliable.

In 2012, Jiang et al. [15] carried out a number of investigations into the methods used to monitor the home environment, including: pressure, temperature, humidity, and electric power. The method it was hoped could solve any problems that arose and give warning alarms instantly to the mobile agent. The authors found that the prototype system includes three aspects, namely, (i) the mobile agent is not causing any delay in the network, (ii) there is a decreased latency in the data stream, and finally, (iii) the technology of WSN support is used to resolve the difficulty of knowing whether a location is inhabited.

Makonin et al. [8] presented a method called a Smart Intervention (SI); this function involved: residents requirements, home, context, and measurements. The devices used in this module included: sensors, actuator and wireless network. Formula (1) below has been used in experiment to control the light in the middle of the night when the occupants get out of bed. It was found that this system design has the benefit of permitting the functionality to be extensible and flexible in the smart home, and it can be developed for many other numbers of reasons.

$$H's = SI\ (Hs, H, O, Ctx, Aut, E) \qquad (1)$$

where Hs is the state before measurements, H is the home, O is the occupant, Ctx is the context-aware, Aut is the automations and E is the evaluation for accuracy and ability.

III. METHOD EMPLOYED IN SMART HOME

Through the benefits of the application of sensors such as actuators, wireless adapters, and processor units, many previous developments in the smart house have been replaced. As mobile computing becomes more universal, there will be an increasing number of computerized devices in our environment that are capable of being controlled [16].

Framework theories for human and mobile computing interaction in the smart home, particularly for elderly

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people, are nonexistent, especially in the area of smart phone and wireless sensors and actuators. On the other hand, smart intervention is lacking in its description of human-home interaction. Because of this, there is a motivation to develop a method that can be used to support work with the system design used by residents in the smart home. Therefore, the main function of Smart Intervention (SI) can takes the following formula (2) [8] :

$$H's = SI\ (R, WS/A, Ctx, Aut, Hs, E), \quad (2)$$

where H's is the home state, R is the resident, WS/A refers to wireless sensor and actuator, Ctx is the context-aware, Aut is the home automation, Hs is the smart home and E is the evaluation for reliability, efficiency, and usability.

The electrical equipment in the smart home needs to be controlled by actuators in order to maintain it within a certain range of data collection, such as: temperature and light to execute the action of on or off immediately, or as scheduled by the resident's command. The smart home intelligence network is to detect serious conditions that can be picked up by the smart home sensors, when there is a likelihood of an event taking place. In addition, smart intervention can be used to elicit an interaction between the environment and the home equipment. For example, a better automatic action can be made regarding the data received from the environment in the smart home, such as regulating the light and fan. This can be done with the scheduled intelligent intervention which are in built, when the devices are correctly switched on or off by the occupants.

IV. SYSTEM DESIGN

Regarding the formula of the smart intervention in the previous section, we add one parameter to this equation namely; wireless sensors and actuators, to be engaged in this prototype system. The comprehensive system architecture from the communication, electronic devices and data management viewpoint is given in Fig 1. Different challenges based on the design and, related to sensing and control in detecting the wireless network, have been addressed in the related work.

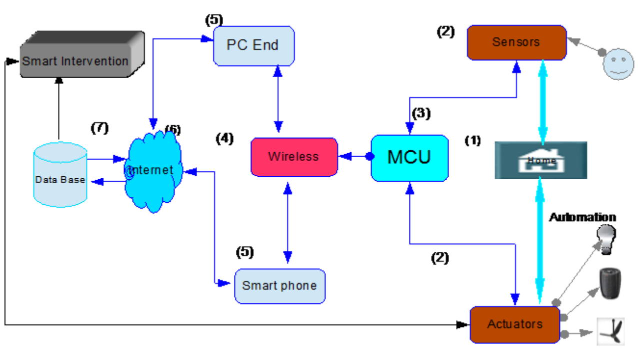

Figure 1: Block Diagram of General Architecture.

- The system design is based on a wireless adapter: WI-Fly-RN370, rather than other wireless technology, because this has the ability to cover up to 300m in an open area, as well as being able to connect with the smartphone and PC through Ad hoc or infrastructure networks.
- The service remains an open topic; new methods of methodical design, conceptual models, and common architecture are required. Complete technical solutions and technology need to be included in the scheming sensors so as to improve the computer system, and to work with the physical user intervention. This will enable us to explore a universal extendible smart home architecture that assists these models in working together and to show it alongside our prototype WiSAMCinSH.

Consequently, this study will attempt to provide sensitive architecture and technology solutions to common context, effectively collecting discrete sensor technologies under an ambient background. This will result in automated proactive and personalized service and optimization of context-aware decision making.

Through the benefits of the applications of sensors such as actuators, wireless adapters, and processor units, many previous developments in the smart house have been replaced. Working on developments to the prototype will ensure that newly created interfaces allow for features with which the user has interacted previously.

A. *Framework Layers for WiSAMCinSM*

This section shows the WiSAMCinSH architecture system consisting of four layers; as shown in Figure 2.

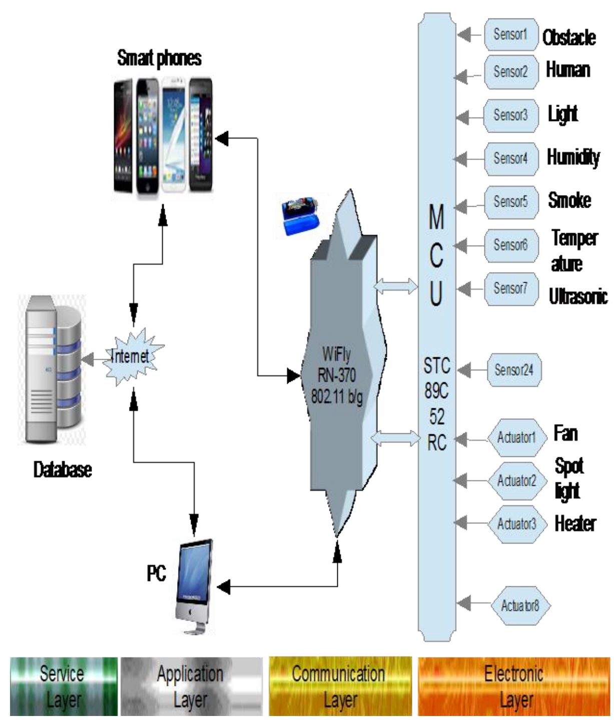

Figure 2 .Framework Layers in the Prototype System.

1) *Electronic Layer:* In the electronic layer, which is located in the lowest level, the sensors and actuators are organised in rooms in different places to gather raw data such as obstacle avoidance, human body activity, light levels, smoke, humidity, temperature, and ultrasonic distance measuring, as well as to control the appliances that the householder decides to use, for example a fan, light, or heater. This information is collected by MCU (STC89C52RC), which is connected to a WI-Fly adapter and can also be used to store an application program embedded with flash memory.

2) *Communication Layer*: In the communication layer, sensing information from different sensors is used according to their applications. This layer communicates with the application layer and then transmits the users' decision to the electronics section, and transfers information written or read to the successive interface consisting of an iPhone and computer control. This data is transmitted through a TCP/IP socket where an Ad hoc or infrastructure network has the ability to use wireless connections to several WI-Fly adapters.

3) *Application Layer*: The application layer is able to build platform interfaces with elderly people, for example a user can get data or make decisions using the smartphone, personal computers, or tablets. Moreover, the householder can send commands to a wireless sensor over the microcontroller unit, if any abnormal information is received. Reliability, satisfaction, effectiveness, efficiency, and usability are requirements for everyday use and this device is able to provide all these. In addition, there is a control program in the application layer that can be operated through the smartphone or PC to acquire the data from the sensors.

4) *Service Layer*: The database server and Internet in the service layer is where information is gathered from the sensors and actuators. This layer provides a computing service based on the database. Important and useful information from historical data can predict abnormal conditions, such as: very high humidity; natural gas or smoke using the smoker sensor; and so on. At the same time, the database system offers an opportunity for another user to share the information, for example, a healthcare professional can monitor the situation of their patient.

V. SYSTEM IMPLEMENTATION

The main model system is broken down into two main parts; hardware and software that are currently available in the laboratory.

B. Hardware Parts

- Wireless adapter (WiFly-RN370).
- MCU (STC89C52RC).
- Seven kinds of sensors.
- IPhone (Version iOS 6.1.3) and iMac version 10.7.5.

C. *Software Parts*

- C language for MCU.
- Objective-C for iPhone application.

1) *WI-Fly (RN-370):* The Wireless adapter is powered by: an external AC to 5V DC and two AAA batteries which run up to eight hours on full charge. The device is connected with only a RS-232 serial port interface of the DB9. It receives information from sensors over the MCU, and then sends it to end devices such as iPhone and PC. The data is also transferred over a reliable TCP/IP socket using an Ad hoc or infrastructure network. This has the benefit of low wireless construction and can be connected to any type of WI-Fly serial adapter. An overview of this set up can be shown in Figure 3.

There are different types of connections available to create Wi-Fi applications, for example: remote environment sensors, control and monitoring appliances, diagnostics, and mobile phone connections; such as GPS and sensors. Therefore, WI- Fly configurations can be set as peer-to-peer (Ad hoc) networking to an iPhone, by using an IP address which is (169.254.1.1) and Subnet mask (255.255.0.0), with the need to set the Service Set Identifier (SSID) and WI-Fly-GSX-a5 in a wireless mobile computing network [17].

2) *Microcontroller Unit (Logic Converter):* The Microcontroller Unit is connected to the computer in order to collect data from sensors, pre-process raw data, and direct data to the phone. It is also connected to a wireless module Wi-Fi to accept the wireless connection through the smart home server. The STC89Cxx series MCU is an important part of the system design as it is an 8-bit single-chip microcontroller. This chip is compatible with outlying device communication that monitors resident activity, and motion by gathering data from sensors, interfaced with the WI-Fly wireless transceiver, and embedded with 64K bytes flash memory to store data, which is shared with In-system Programming (ISP). It also has an, In-system Application (ISA) to assist the operators. These communication requirements are based on a microcontroller need to be adapted with a Universal Asynchronous Receiver Transmitter (UART) [18]. This is an appliance that transmits and receives raw information from the choice of MCU to support a low level programming language. C provides many different ranges of development tools and pins diagrams, as illustrated in Figure 4.

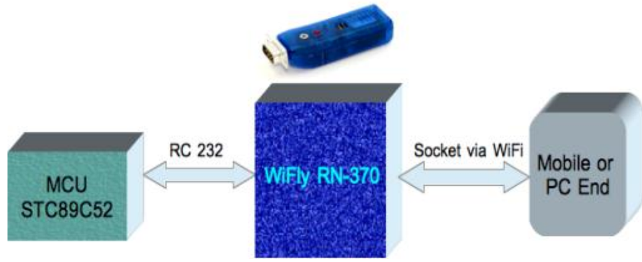

Figure 3 Overview of the WI-Fly Adapter Connection

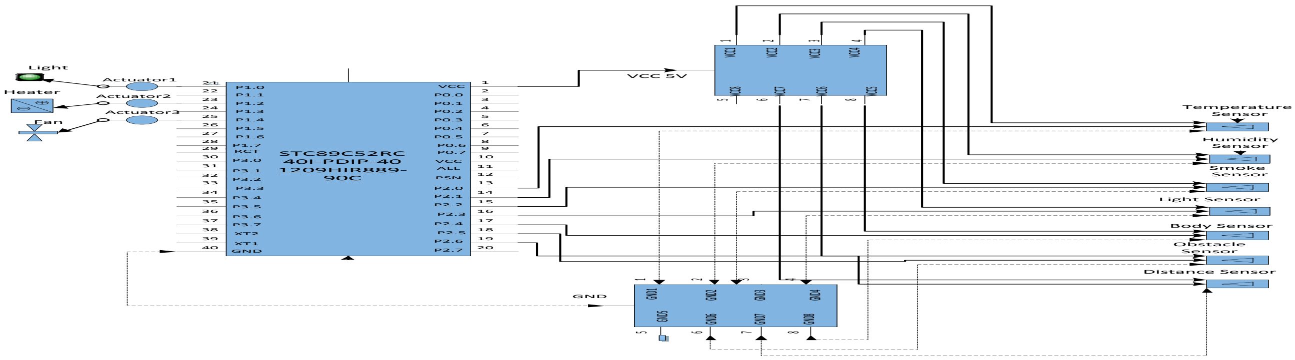

Figure 4 Microcontroller Units STC89C52RC-schematic pin diagrams of the system.

3) *Sensors Involved:* There is great demand for the use of sensors for several applications in the prototype. The most commonly used being: obstacle avoidance sensor, smoke sensor, human detection sensor, light level sensor, humidity sensor, temperature sensor, and ultrasonic distance measuring. These are the different types of sensors that have been used in the system design. The main idea of this function is to transfigure physical variables in reality to digital variables and real numbers, which are processed in the computing system.

The function of the temperature sensor DS18B20 [19] is to gather data from the room environment, when the software program runs in the MCU. The brightness sensor BH1750, is dependent upon the level of light in the home; the smoke sensor ZYMQ-2 is used to monitor whether there is any smoke or gas close to the sensor area; the humidity sensor HR202LM393 is used to sense the level of nearby humidity when environmental humidity is high; the obstacle avoidance sensor E18-D50NK has a detection distance between 3cm and 80cm with an adjustable resistor; the human body sensor DYP-ME393 reliably detects the human body when it comes to within seven meters of the sensing area; the last sensor is the ultrasonic distance measuring HC-SR04 [20], used to measure distance from 2cm to 4m when the function is working well.

4) *Smart Phones and PCs (End Use):* In this system, the implementation of an end-use like iPhone, Android, BlackBerry and Windows Phone as the platform for the prototype system means they can receive the gathered information from sensors and control the actuator. The smart phone platform can be programmed using Object-C to communicate over CFNetwork sockets. Zdziarski offers a code using a CFNetwork socket to connect between the web server and smart phone or among peer-to-peer networks such as Ad hoc connections [21].

5) *Software Structure:* The information gathered from the seven sensors are stored in the memory of embedded system STC89C52RC provisionally, then when it is running, the software program and compiler passes through the Test Program in Debugger (Keil uVision3) for the debugger instruction. At the same time the program language C also will run in the STC-ISP.exe, after selecting the hex file and the port from the PC to be ready for sending the collected data over wireless technology.

The iPhone SDK (Version IOS 6.1.3) and Apple iMac version 10.7.5 run with Xcode version 4.6.2 were used in this experiment. Objective-C and Cocoa Touch were the programs that were most used in the implementation of this part of the project, where Cocoa Touch is used by Object-C which offers the structure for iPhone application.

VI. TESTING PLAN

A. *Experiment Condition:*

Testing the prototype system firstly required connection of the seven types of sensors to the MCU as follows: obstacle avoidance sensor; human body; brightness; smoke; humidity; temperature and ultrasonic distance measuring; to the ports from P2^0 to P2^7 of STC89C52RC. This unit has the ability to gather data from 32 sensors; because it contains four sets of ports P1, P2, P3 and P4 - each with eight pin. The WI-Fly Serial Adapter is interfaced with the MCU by using connector Pin DB9; it is also connected through serial port communication RS232. This appliance is designed to work with an input power supply from 4.5 to 5 VDC. There are three cable interfaces (RXD, TXD and GND) between the WI-Fly and Microcontroller and five cable interfaces between the WI-Fly and computer.

B. *Steps:*

There are two techniques to setup configurations of the software as follows:

1) *Setup Configuration through WI-Fly Serial Adapter Using Tera Term:* This configuration is used through the Ad hoc Mode (point to point), with switch 1–ON. The Ad hoc Mode powers up the Wi-Fly device, which is only connected between two appliances that are Smartphone (iPhone) or PC, to gather the data or control a device through the serial interface as shown in Figure 5. This WI-Fly device needs to set the constructor default value as follows: Service Set Identifier SSID, which is WiFly-GSX-a5 to the IP address (169.254.1.1), IP net mask of (255.255.0.0), and TCP port (2000) [22].

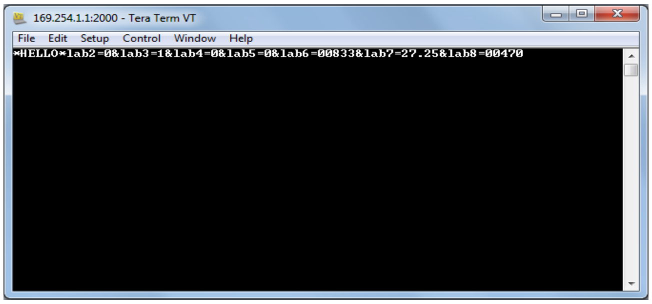

Figure 5. The value of the seven sensors using Tera Term screen.

Once the connection is linked with the Ad hoc mode, it might take up to one to two minutes to share an IP address with the computer. Next, click "OK" if the connection is successful. The program of Tera Term will show the message "HELLO". After that, the user can receive information from various sensors that were connected with the MCU and WI-Fly using program Tera Term. This also, displays the data regarding the environment and locations of the operator to the sensors.

2) *Setup Configuration through WI-Fly RN370 using iPhone:* To set [15] WI-Fly and iPhone using the Ad hoc Mode interface, it is not required to have the Access Point to set up the Wi-Fly network data together. The wireless appliance can accept information directly, and it is point to point communication.

Firstly, move Switch 1 Ad hoc to position "ON" in the WI-Fly and switch on the power supply. Secondly, the wireless network is connected with an iPhone via the WI-Fly. It is possible to build a wireless system with a Smartphone using Dynamic Host Configuration Protocol (DHCP).

The Smartphone will create an Ad hoc Mode using Service Set Identifier (SSID) and the associated WI-Fly holders of a number of IP addresses. In this case the client iPhone will be their IP address: 169.254.1.1. The sensing data is first collected by the MCU, and then sent to the Smartphone within the WI-Fly transceiver, as shown in Figure 6.

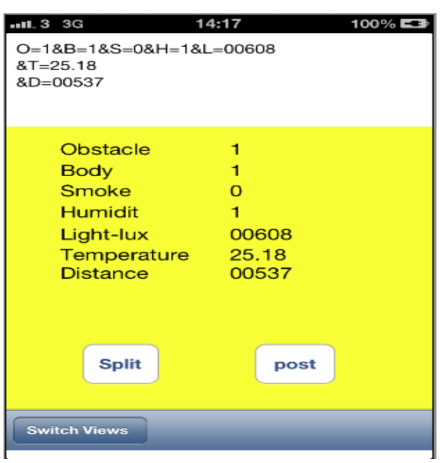

Figure 6. The value of seven sensors collected by iPhone.

VII. EVALUATION

The accuracy of the sensors' measurement is distinguished according to the performance of each sensor. The results will show how the accuracy can be faithful to the actual value. The most improved sensor has high quality of performance. To succeed, we must make a comparison with other evaluations and use real word results such as distance measuring meters to contrast with the ultrasonic distance sensor.

The results have been taken from some sensors, such as; obstacle, human body, brightness, temperature, and ultrasonic distance sensor; in order to further understand whether or not these sensors can work accurately according to their functions. The first experiment began with the temperature sensor to measure the room temperature. The results were measured at each hour from 9am to 8pm for three days. The results in Figure 7 show evaluation of the temperature sensor which took place for three days in the sensor system. The average measured temperature in the room during the three days in the morning and afternoon was recorded using temperature sensor (DSI-2B20). There was a rise in temperature between 20.5°C and 24.5 °C from 9am to 4pm. After that, the afternoon temperature shows a fluctuation between 4pm and 8pm with average temperature between 24°C and 24.5 °C. Generally, the graph illustrates that the average temperature is mostly high in the afternoon and low in the early morning.

A comparison can be made between the results of room temperature monitoring using the TC1046VNB sensor when the temperature rises up with a heater [10], and the result of this experiment for the same situation using the DS18B20 sensor. It can be understood that temperature increased when the heater began to warm up and started to drop when the heater was switched off.

For the ultrasonic distance sensor measurement Figure 8 shows the accuracy of measurement results between 5cm and 80cm by using an obstacle object to measure the distance between the sensor and the object. The sensor has the exact results between 5cm and 40cm. After that the sensor results vary from 45cm to 60cm, showing some errors with 0.9cm for each 5cm, then the measurement drops to 1.1cm, and starts to increase by 5cm up to 80cm. This sensor still needs more work to improve its accuracy and measuring of distance.

The third step was to identify whether the obstacle, human body and smoke sensors can be implemented for long distances using an ultrasonic distance sensor to measure the distance between the sensors and the object detection. The graph in Figure 9 shows how in this experiment the performance results of three sensors were initiated, from a distance of 5cm and then increased up to 80cm. The obstacle sensor can be interacted with the object from 5cm to 40cm with high voltage (1), than drops to (0) volt from 45cm to 80cm. However, the human body sensor can be attracted with the object between 5cm and 80cm with

TABLE I TEST AND EXPECTED RESULTS

Sensor Type	Function	Methods		Expected	Results
		Tear Term	iPhone		
Obstacle	Avoidance obstacle of object in line	✓	✓	0 or 1	1
Human body	Human body sensing	✓	✓	0 or 1	1
Smoke	Detection gas and smoke	✓	✓	0 or 1	0
Humidity	Humidity detection and raindrop	✓	✓	0 or 1	0
Light	Measure intensity of light	✓	✓	(0 - 1000) Lux	(0 - 753) lux
Temperature	Measure room temperature	✓	✓	(3 - 40) °C	(19.18 - 24.87)°C
Distance	Measure current distance	✓	✓	(0.2cm - 4m)	(0.2- 60) cm

(Note: √ represents acceptable)

high voltage (1). The smoke sensor was however not tested because there was no event related to this function in the room.

Another comparison was made [23], using light brightness sensors LDR to measure the light intensity during daytime. To evaluate the brightness sensor BH170 in this prototype system, the results were taken between 9am and 8pm with and without light in the room as illustrated in Figure 10 and 11, to show the performance of the light sensor to be used with LED light in the smart home and controlled by smart phone. In addition, the accuracy designates just how faithfully the sensor can measure the real world factor value.

Test results are shown in Table I. According to the information collected from the data, there are two methods of sensory perception. Firstly, the four sensors: obstacle, human body, smoke, and humidity express their results in a digital format, comprising factors of zero and one. Secondly, the temperature, brightness, and ultrasonic distance sensors produce results in an integer format.

VIII. CONCLUSION AND FUTURE WORK

A. *Conclusion*

This paper defined the different types of technologies and equipment related to the design system to control and to sense smart home appliance operated by Smartphone and personal computer. It was also used to sense unusual patterns during daily activities. This project offered a comprehensive wireless system from the Smartphone host user to the end appliance used by an elderly or a disabled person at home. Additionally, different aspects, such as methods elaborated in the smart home and methodology have been explored. Furthermore, four framework layers of architecture design have been explained according to their implementation in smart space. The module system has been integrated with some technology to build software and hardware systems, as well as requiring a user interface consisting of Smartphone and PC to be simple to use for elderly people. This investigation contributes to the following points:

- The system intends to implement smart home control at both a basic level, with active sensing, and at a higher level, which also includes user home automation.
- The system aims to create a convenient and inexpensive development within the area of home sensing system.

B. *Future Work*

The next stages will be setting the network connection wireless adapter with wireless router and server. After that, a MySQL database table will be created to receive the script language code, which will be run by PHP. And then, with the network the sensor data from the mobile can be sent to the server and saved in the database for computing tasks.

Moreover, extra works have been decided on for experiment and investigation in the next steps, such as using an ultrasonic distance sensor to make it more accurate to measure up to 4m, as well as assisting with the human body and obstacle avoidance sensors for monitoring issues. Home automation is a part of the research; therefore some appliances will be involved in the prototype, such as actuator to control the fan, LED light and heater using Smartphone to assist the occupant. Another future piece of work, will be computing algorithms to investigate reliability and usability which has been necessitated by information from various sensors and the control of electrical devices. Finally, other Smart phones such as, Android and BlackBerry will be involved in the system design.

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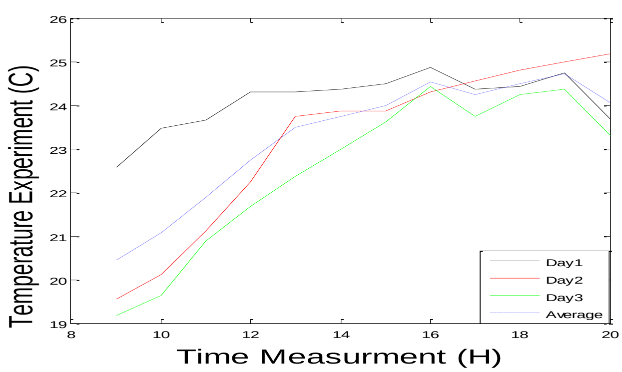

Figure 7. The evaluation of temperature sensor (DS18B20): (a) the temperature when the heater is on (b) the dashed line for average value

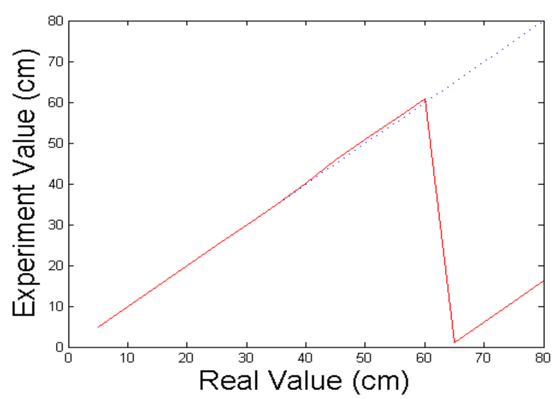

Figure 8. The ultrasonic measuring sensor and the dashed line is the real

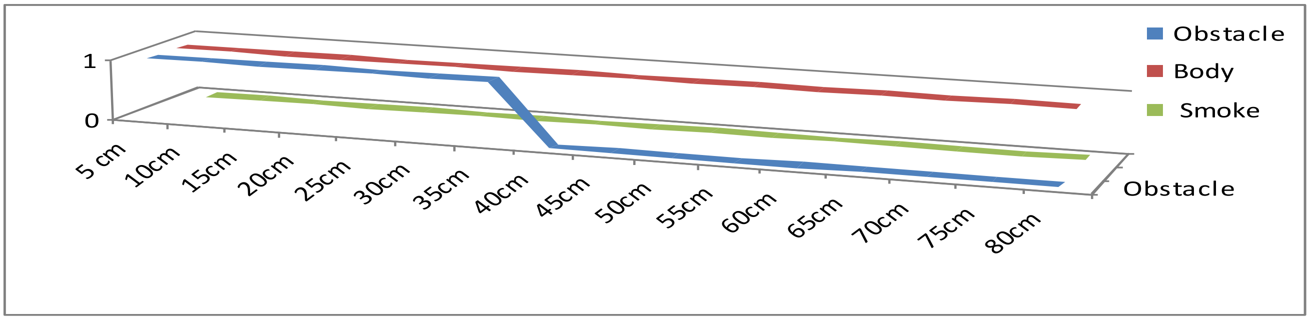

Figure 9. Illustrate the results of three digital sensors

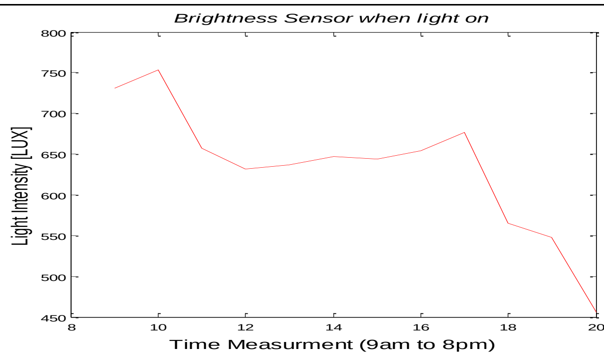

Figure 10. Graphical illustration of the brightness intensity during daytime with light

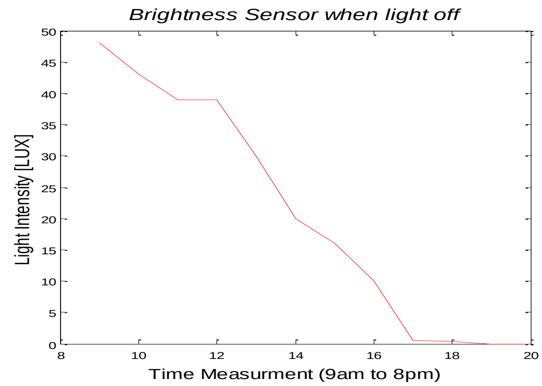

Figure 11. Light intensity during daytime without light.