DESIGN AND DEVELOPMENT OF INTELLIGENT HOME AUTOMATION SYSTEM (IHAS) FOR ENHANCED ENERGY PERFORMANCE

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DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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ABSTRACT

With the growing distresses on carbon emission and sustainable energy concepts, the whole world appreciates the movements towards sustainable energy consumption. Statistics point out that over 50% of total electricity generation is consumed by three sectors, namely residential, commercial and public services. Among them, the residential sector alone consumes over 25% of total energy consumption which can possibly be attributed to heating, ventilation, air-conditioning (HVAC) and lighting used for occupants' comfort. However, over 65% of global electricity generation is based on fossil fuel and natural gases, residential electricity consumption is accountable for a substantial extent of global carbon emission, consequently the present climate calamity.

Researchers across the globe have figured out that the theories on sustainable energy consumption should start with our own home. It is required to focus on reducing the energy consumption by home HVAC systems, lighting systems and other appliances while keeping residential comfort level untouched. Home automation systems have shown their success towards the goal amidst several drawbacks.

This research, proposes an intelligent home automation system (IHAS) with a real-time sensor network. The system has the ability to perform user preference based automation on the premises based on user comfort, safety and energy efficiency. The proposed system consists of a wireless sensor network, intelligent controller and device control interface. The sensory system monitors the environment and the identified information transferred to the intelligent central controller, which makes the accurate decision on most efficient configurations for the home appliances. It includes HVAC system, lighting systems and multimedia systems thus optimizing power consumption and improving user comfort. Finally, the device control interface delivers the obtained control decisions to the appliances through the default control interface.

The developed non-interactive user identification system will recognize individual users within the premises and track their activities to obtained individual user preferences related to the comfort and multimedia devices. Based on those preferences and real-time ambient conditions measured through climatic sensor systems, the central controller will decide the configurations for the home appliances.

The entire work includes the design and fabrication of different hardware systems and firmware implementations based on 8-bit and 16-bit microcontrollers. The central controller was developed on a single board computer which is powered by 32 Bit ARM Cortex A11 CPU. Fuzzy inference systems were used to implement the intelligent control algorithms of different control application of the proposed system.

Key Words: Home Automation, Intelligent Control, Sensor Systems, Mechatronics

DEDICATION

I dedicate my dissertation work to my family and my teachers. A special feeling of gratitude to my loving parents, Mr. Alfred Basnayake and Mrs. Malani Basnayake and my siblings Mr. Christie Fernando and Mrs. Dyamini Basnayake, whose words of encouragement and push for tenacity ring in my ears.

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LIST OF ABBREVIATIONS

Abbreviation	Description
AC	Alternative Current
ADC	Analog to Digital Converter
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning
BAC	Building Automation Controller
BAP	Battery Assisted Passive
BMS	Building Management Systems
bps	Bits per second
CCS	Centralized Control System
CLF	Compact Fluorescent Lamp
CPU	Central Processing Unit
CT	Current Transformer
dBm	decibel-milliwatts
DC	Direct Current
DSC	Digital Signal Controller
DVD	Digital Versatile Disc
EEPROM	Electrically Erasable Programmable Read-Only Memory
FL	Fuzzy Logic
GA	Genetic Algorithms
GPIO	General Purpose Input Output
GUI	Graphical User Interface
HMI	Human Machine Interface
HVAC	Heating, Ventilation, and Air Conditioning
I/O	Input Output
I^2C	Integrated Circuit
IC	Inter-Integrated Circuit

ID	Identification
IHAS	Intelligent Home Automation System
IOT	Internet Of Things
IR	Infra-Red
ISM	Industrial, Scientific and Medical
ISO	International Organization for Standardization
KB	Kilo Byte
LCD	Liquid Crystal Display
LDR	Light Dependent Resistor
LED	Light Emitting Diod
Mbps	Megabits per second
MEMS	Micro-Electro-Mechanical Systems
MIMO	Multi Input Multi Output
MIPS	Mega Instructions Per Second
MISO	Multi Input Single Output
MSPS	Mega Samples Per Second
NI	National Instrument
NN	Neural Network
NTC	Negative Temperature Coefficient
OS	Operating Systems
PCB	Printed Circuit Board
PIR	Passive Infrared
PV	Photovoltaic
RAM	Random Access Memory
RC	Resistor Capacitor
RF	Radio Frequency
RFID	Radio Frequency Identifications
RH	Relative Humidity

RMS	Root Mean Square
SAR	Successive Approximation
SBC	Single Board Computer
SD	Secure Digital
SIMO	Single Input Multi Output
SISO	Single Input Single Output
SMD	Surface Mounted
SoC	System on Chip
SPI	Serial Peripheral Interface
TQFP	Thin Quad Flat Package
TTL	Transistor-Transistor Logic
TX	Transmitter
UART	Universal Asynchronous Receiver Transmitter
UID	Unique Identifier
USART	Universal Synchronous Asynchronous Receiver Transmitter
USB	Universal Serial Bus
UV	Ultra Violet

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1 INTRODUCTION

Smart home technology, also often referred to as home automation or domotics provides homeowners security, comfort, convenience and energy efficiency by allowing them to control smart devices, often by a smart home app on their smartphone or networked device. One of the most touted benefits of home automation is providing peace of mind to homeowners, allowing them to monitor and control their homes remotely and automatically [1].

The home automation can be performed on user preferences. For example, as soon as you arrive home, your garage door will open, the lights will go on and your favourite tunes will start playing on your smart speakers [2].

Together with the development of energy conservation concepts, home automation systems have gained enormous attraction. The residential buildings (domestic buildings) are among the leading consumers of electricity in many countries. A substantial percentage of energy consumed by buildings can be attributed to Heating, Ventilation and Air-conditioning (HVAC) systems and lighting systems used for comfort.

To develop convenient and energy efficient automation system for the residential applications, as the initial stage, it is vital to develop a multi-sensory system with good performance to take the measurements on own environment conditions which are going to control and which parameters are will be affected for the system. And then it needs to develop an efficient controller to make decisions on the environment parameters accurately. Therefore, the main aim of this research is to develop an intelligent home automation system to improve user comfort while maintaining the enhanced energy performance in the building. The proposed automation system consists of an enhanced real-time multi-sensory system, intelligent controller and building appliances control interface which can be integrated into the existing buildings without doing any infrastructure modifications to the building. The controller has the ability to perform user preference based automation on the premises to improve the user comfort, safety and energy efficiency.

When developing an intelligent home automation system, there are several areas to be focused on. Development of sensing systems, development of appliances interfaces, development of intelligent controller and communication systems are some of those areas. Figure 1.1 shows the development process of the intelligent home automation system in this research.

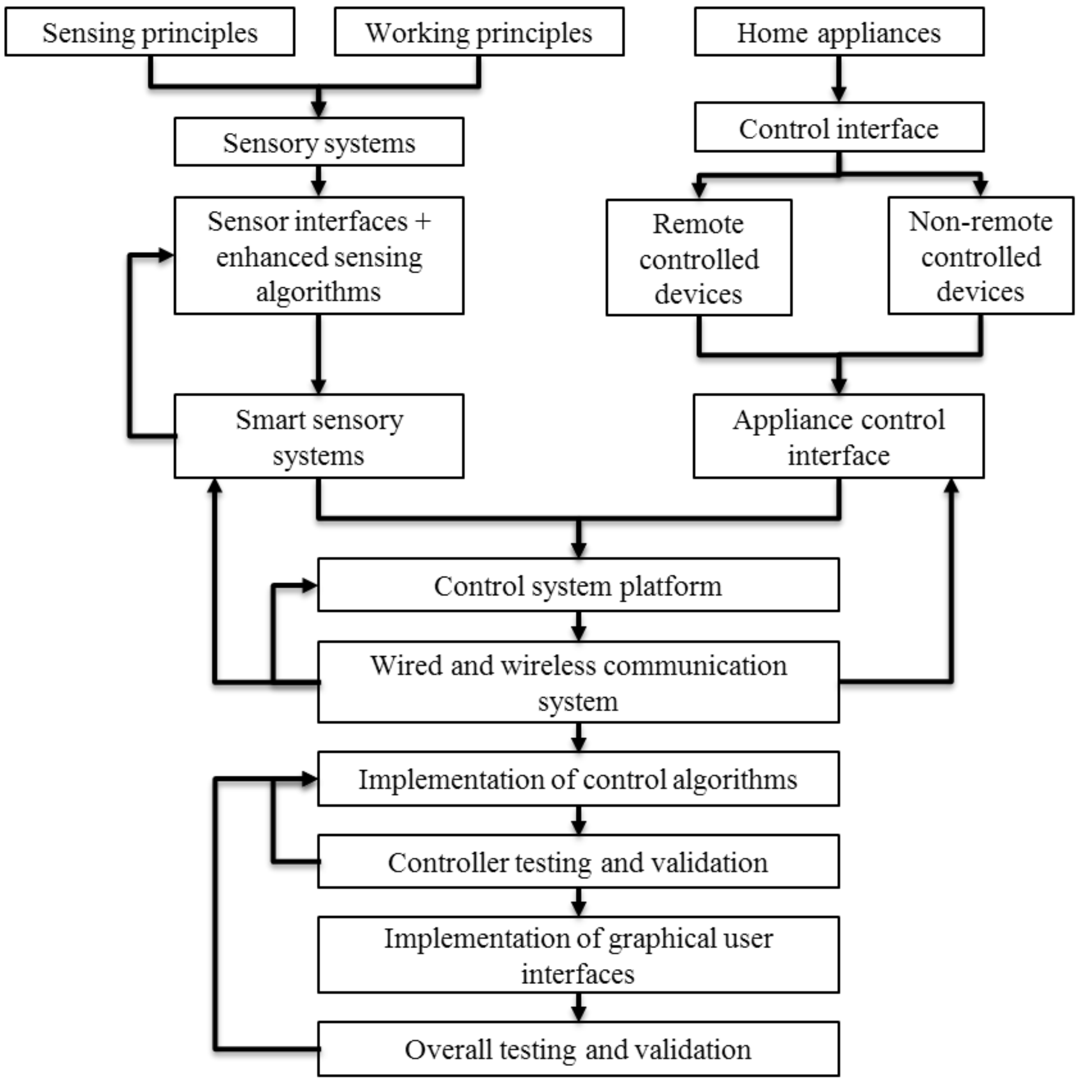


Figure 1.1: Development process of intelligent home automation system (IHAS)

When developing the home automation systems, it is vital to conduct a literature review regarding home automation systems focused on the historical background, technology developments, applications areas and related systems to identify current stage of development regarding them. Hence, in this thesis, the second chapter consists of the details about the conducted literature review. According to the literature, some of the important areas were identified to proceed the research as shown in Figure 1.1.

The third chapter of this thesis consists of the details about the proposed design and working principle of the proposed automation system. The fourth chapter of this research is about the design and development of the proposed system as prototypes, firmware and computer-based graphical user interfaces to validate the design. The overall design and implementation of the proposed system have described under the five subchapters including the introduction to the design, implementation of the sensory system, appliances control interface, centralized controller, control algorithms and implementation of the wired and wireless communication system.

After the development of sensory systems and automation control systems, they were tested and validated to use them in residential building application. Details about this work is described in the fifth chapter of the thesis.

Finally, the sixth chapter of the thesis discusses the results of the developed systems, further improvements and research findings related to this research.

2 LITERATURE REVIEW

2.1 Introduction

Home Automation Systems (HAS) can be identified as control systems which are used to produce a comfortable, reliable, Energy efficient, and safe environment in the residential buildings. Home automation systems include centralize controls for lighting systems, HVAC (Heating, Ventilation and Air Conditioning) systems, utility appliance control, security systems and others as shown in Figure 2.1. The main objective of Home automation systems is to enhance user comfort while keeping energy consumption at an optimum level in domestic scenarios. Generally, Most of the home appliances are control by different types of independent control panels come with the particular appliances. Those control interfaces are often not connected with each other. The purpose of a modern home automation system is to interface of all the home appliances into a single control interface and make centralize control. This unique control interface can be programmed to operate automatically for different tasks appropriate for the residents and the living premises [3].

Figure 2.1: Application areas of smart home automation system

The goal of home automation is not only to improve the comfort but also to optimize the consumption of resources such as electricity, gas, etc. Preserving resources has become a part of an individual's daily life due to current prices of energy sources.

If a resident has the facility to control their home appliances in a convenient way, then they can improve the energy saving by avoiding unwanted energy usages and minimize the expenses for procurements [4]. An example, if a person is away from their residence there is no need for the HVAC systems to operate. The same scenario applies to lighting and other home appliances. The smart home automation control systems automatically stop the operation of these appliances until they are needed again [5].

The modern home automation systems have been developing in several areas. Thermal comfort control, lighting control, entertainment and security are the main focused areas which were based on home automation.

2.1.1 Thermal comfort

- Automatically controls of HVAC systems in residential buildings
- Instead of a pre-programmable thermostat based control system, focused on improved user comfort and energy efficiency by maintaining a pre schedule consistent with an automatic detection of occupants' presence in the living premises.
- Comfort can be improved when the automation system can detect occupants' motions and change the temperature setpoints of HVAC systems based on the real-time climatic conditions and time of day.
- Or automatically detect open windows or open doors and switch off the HVAC system until they are closed.

2.1.2 Lighting

- Automatic lighting controls also deliver the convenience, visual comfort, and energy efficiency by controlling lighting devices in interior and exterior of the building.

- Visual comfort devices or Lighting controllers are used to switch on and off and control brightness level settings for multiple lights in a home to achieve the desired environment for a given situation or occasion.
- Once a lighting condition is defined, it can be activated by the time of day, motion or contact sensing, or the push of a single button at a convenient place in the home.

2.1.3 Entertainment

- Convenient entertainment experience can be deliver by developing automated controls on entertainment systems.
- The universal remote functionality replaces many of the individual device remotes and provides the ability to control the entertainment activity by emitting multiple commands with the press of a single button.
- A consistent operational interface is provided when the same universal remote is deployed in multiple entertainment devices.

2.1.4 Security

- Most of the safety and security issues in a residence is addressed by the security alarm and surveillance system
- Automatic motion detection lighting systems can avoid chance of an accident at night.

2.2 The History of Home Automation Systems

The home automation system has been develop and use for nearly 35 years in different functionality levels. Table 2.1 shown the summary of developments on HAS.

Table 2.1 History of home automation system

Year	Contribution
1975	Power line based communication system was invented and patented as X10 by Pico Electronics.
1978	X10 technology based products initially introduced to the public commercials by Pico Electronics.

1983	The standardized protocol called HBS was proposed by Masashi Murata etal.
1983	Standardized protocol called CEBUS was proposed by Christos Douligeris et.al.
1984	Smart house concept was introduced by David MacFadyen
1985	The initial systems were developed based on HBS technology by Masahiro Inoue et al.
1988	The CEBus working draft standard was published by Christos Douligeris et al.
1992	Completion and release of CEBus by Christos Douligeris et al.
1993	Marketing of the Smart house by Smart House Inc.
1996	CEBus access demonstrated via WWW by Peter M. Corcoran et al.
2000	An internet application was proposed for smart home controlling by Renato J. C. Nunes et al.
2002	Bluetooth based home automation system was proposed by N. Sriskanthan et al.
2005	Insteon was released by SmartLabs.
2005	ZigBee wireless communication protocol was developed and released by ZigBee Alliance
2005	Z-Wave developed and released by ZenSys
2006	An open source development platform called Arduino was developed and commercialized by Arduino.inc
2011	Introduction of Android@home by google

2.2.1 Insteon

Smart Labs introduced a home automation technology called Insteon. Special feature of Insteon is that it can be operated by both radio frequency (RF) and power line communication (PLC) and operates as dual-mesh network. Insteon can be operated on the RF or PLC modes or it can be operates on both modes at same time. 904 MHz frequency is RF band of Insteon and it has 13,165 bits/sec of instantaneous data communicating rate and 2,880 bits/sec of sustained data rate. These devices are comparatively easy to install and configuration. It can be automatically connected to an Insteon network as soon as they are powered up. As it has own protocols, a single device can be connect up to 1024 of other devices operate in a single network. Insteon was design to have the capability to transmitting X10 messages over the power line. Figure 2.2 shows an image of the Insteon automation devices.

Figure 2.2: Insteon automation devices

2.2.2 X10

In late 1970s X10 power line carrier was designed and proposed as wired communication system suitable for home automation. Initially X10 was designed to use existing power distribution lines in a building and in 1990s, X10 was developed to use RF as well. X10 RF frequency band is 310MHz or 433MHz and the range is around 30 meters depending on the environment. The data rates of X10 is approximately 20 bit/sec. Figure 2.3 shows the image of the X10 based home automation system.

Figure 2.3: X10 automation devices

2.2.3 Z-Wave

A company named Zensys developed Z-Wave technology as a wireless communication protocol. The operating frequency bands of Z-Wave 868 MHz, 908 MHz or 2400 MHz and it can communicate up to 30 to 100 meters with 20kbit/s of data rate. According to the Z-Wave architecture it has two types of devices as control devices and slave nodes.

Controlling devices or master devices initiate the communication by sending commands to other communication nodes. Master devices can be communicated with all other devices in the network as in a routing and slave nodes can directly send the messages to the other nodes as ordered by master node or controlling node. During the operation, slave nodes receive the command and according to the command, slave device executes it and after it sends a reply to the master node notifying about the results of command execution as an acknowledgement. If the master device does not receive the acknowledgement message, master node resend the command frame with a random interval to avoid a potential of data collision. Figure 2.4 shows the image of Z-wave based home automation devices.

Figure 2.4: Z-Wave automation devices

2.2.4 ZigBee

ZigBee Alliance introduces ZigBee as a wireless communication technology suitable for home automation and IoT based development. 868MHz, 915MHz and 2400MHz are the operating frequency band of ZigBee and it can operates in a range up to 10 to 100 meters with 250kbit/s of data rate. In a ZigBee network there are two types of devices such as full function devices and reduce function devices. To establish a ZigBee network it has to be at least one full functional device as network coordinator operate as center node. All other devices were contacted by network coordinator as required. ZigBee used hand-shacked protocol in data communication. ZigBee is capable of connecting more than 64000 nodes in a network. Figure 2.6 shows the image of ZigBee based automation devices.

Figure 2.5: ZigBee home automation devices

2.3 Commercially Availabe Home Automation Systems

As the results of research and development of HAS, some of the commercial home automation devices has been launched into the market as shown in Figure 2.6. These systems facilitate to automate the home environment using different control techniques and device configurations.

Figure 2.6: Commercially available home automation systems

As a summary, these control system solutions are mainly focused on energy management, comfort management and safety management in a residential building. These systems have smart functionalities such as remote accesses, randomized programs, GUIs controls, voice controls to use them easily. Most of the commercial home automation systems are using standard home automation technologies such as Wi-Fi, Z-Wave, ZigBee, Bluetooth, Insteon, KNX, UPB, X10 etc. to make their system flexible, these systems are developed to control via a mobile and computer-based applications such as iOS, Android, Windows, Mac OS.

2.4 The Need for Energy Enhancement

According to the Ceylon Electricity Board (CEB) statistical digest issued in 2015, 33.5% of the electricity is being used for domestic purposes as shown in Figure 2.7. Also, electricity generated with thermal energy, represents 40% of the total production. Out of this 40% of thermal energy, 28% covered from thermal-oil and balance 12% from thermal-coal [5].

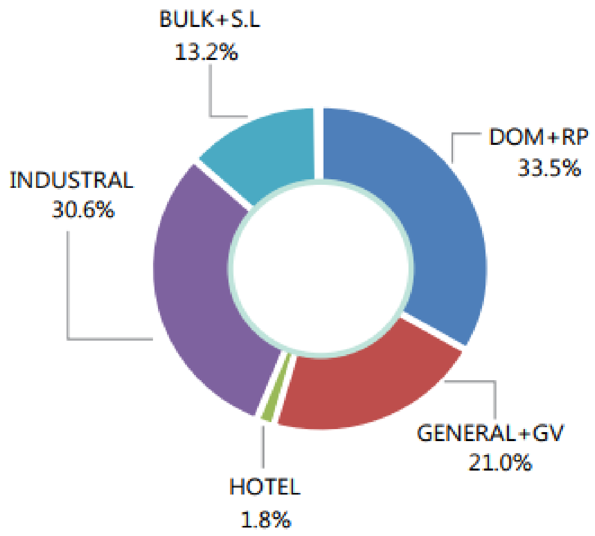


Figure 2.7: Electricity energy demand in year 2015

Reference - Ceylon Electricity Board (CEB) statistical digest issued in 2015

Since domestic component requirement contains a larger share of energy demand, any saving from that demand will result in a reduction in CO2 emission, cost of procuring thermal fuel and cost to the consumers.

2.5 Conclusion

However, by comparing these systems with existing residential applications some of the factors were identified as the drawbacks as follows,

- Absences of Artificial Intelligent control techniques (FIS (Fuzzy Inference System), ANFIS (Adaptive Nero Fuzzy Inference System))
- The absence of individual user Identifications and user preference based adaptive automation services
- Advanced home control technologies are not available in most home appliances (e.g. Wi-Fi, Z-Wave, ZigBee, Bluetooth, Insteon, KNX, UPB, X10)
- Additional network devices expensive and complex.
- The requirement for infrastructure modifications and professional skills on installation make it difficult to expand on your own.
- Low performance on energy utilization

- Still, the cost of available HAS systems are not affordable considering the people in developing countries

The HAS can be divided into two categories based on the building infrastructures and installing facilities. At present, most of the HAS are typically installed in modern residential buildings at the developing stage and rarely adopted in existing residential buildings such as domestic buildings due to flexibility issues, complexities, high cost and barriers to infrastructure modifications in installation. The modern home automation concepts such as IoT, are rapidly developed after the year of 2000. By comparing the age of an existing residential building two-decade is not much considerable age for most of the building. It may expect up to four or five decades. Comparing the usable lifetime of existing buildings, there is a need to develop HAS to existing building without doing major infrastructure modifications to the buildings. And also considering the energy crisis, since existing buildings contain a larger share of energy demand and need of low carbon footprint, it is another requirement to introduce efficient and convenient HAS to existing buildings.

Platforms were implemented to make the common control interface with the building appliances as device control interfaces. The main objective of this implementation was to improve the system flexibility by avoiding the automation barriers occurred in existing buildings and appliances. With this developed device interface, an experiment was carried out to verify the feasibility to use this system for the home automation applications.

As the final stage of this research a hardware platform for the IHAS was designed and fabricated based on a 32-bit single board computer and 8-bits and 16-bits microcontroller devices including the RF-based wireless communication system. By using the implemented control platform, sensory system and device interfaces, the different types of control algorithms were implemented to automate the home in order to achieve the improved comfort in living premises while maintaining the energy consumption at an the optimum level. Using the implemented entire system several experiments were conducted in different home residential applications and results were discussed illustrating the improved energy performance in the building.

3 THE PROPOSED SYSTEM AND WORKING PRINCIPLE OF INTELLIGENT HOME AUTOMATION SYSTEM (IHAS)

3.1 Introduction

Automation is the technology by which a process or procedure is performed without human assistance to improve the system performance. Even the using of basic automation controller to switch on and off a light bulb according to the presence of human also has some amount of energy saving and comfort improvement.

According to the conclusion of the literature review related to this research, it was identified that nowadays most of the Home Automation Systems (HAS) are design for fresh and large-scale residential buildings. And it has rarely adapted in existing and minor scale domestic buildings due to compatibility, flexibility and complexity issues and high cost. Considering the above facts, there is a need in the domestic environment to develop home automation systems with required flexibility and adaptability at an affordable cost to save energy with necessary predetermined comfort levels [6].

Hence, the main objective of this research is to design and develop an intelligent home automation system as an external controller to enhance the energy performance in the building while maintaining the desired comfort level at the living premises. As per this specified objectives and characteristics of the application, a flexible automation system was designed as Intelligent Home Automation System (IHAS) to incorporate with existing buildings.

In the research, there are four main aspects to be implemented during the development as shown in Figure 3.1. As a design of a typical automated system, the proposed system also consisting of an input system, controller and output system. These elementary systems are enhanced on different areas by doing literature reviews, experiments and hardware implementations to adapt for the proposed intelligent automated system [7].

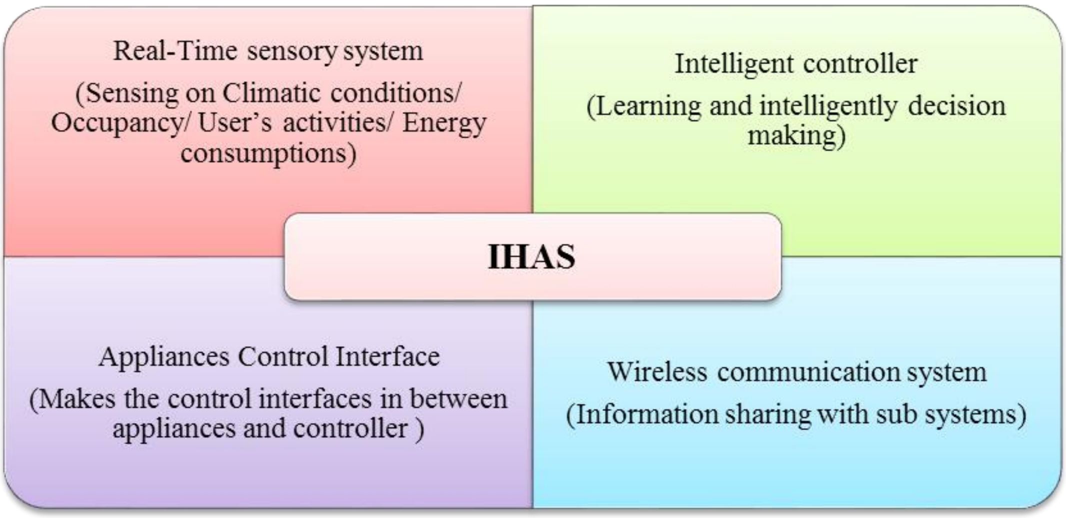


Figure 3.1: The main focused areas of Intelligent Home Automation System (IHAS)

3.1.1 Real-time Sensory System

A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. At present, many types of sensor systems have been developing for home automation systems. By using the enhanced sensory system it's possible to identify the changes which are occurred in living premises [8]. This information can be used to take the real-time estimations on the environment and if there are any factors which affect to decrease the comfort level or energy efficiency, it can be possible to make corrections by the controller. By enhancing the scale and performance of the sensory system, the control capabilities and accuracy of the controlled decisions can be increased. The real-time sensory system is the input system of the IHAS. This is used to identify the real-time information on indoor/outdoor climatic conditions, Occupancy, User's activity and energy consumptions. The sensory system has two stages as primary and secondary stages. In the primary stage, the raw information are collected by the different types of sensors which are incorporated with the different application areas. In the secondary stage, the collected raw information are analysed and generates additional information related to the sensing application. As an example, current transformers and potential transformers are the sensors of the energy consumption measuring system. At the primary stage, it will provide the voltages, currents and power. Based on these information, system will identify the predetermined load devices (Appliances) which operate in the measuring area. This is done by the secondary stage of the sensory system.

3.1.2 Intelligent Controller

An intelligent controller is also one important aspect considering the IHAS, as it computes sensory information and user's preferences in order to predict the optimum parameters to the living premises [9] [10] [11]. The intelligent controller of IHAS was developed as a Centralized Control System (CCS). In this design, it has two types of control systems as a central control system and sub-control systems. The central controller is a supervisory control system. The main function of the central controller makes the top level control decisions for the IHAS while controlling and monitoring the sub-control systems such as sensory systems and output control systems. The central controller is implemented on a single board computer and control algorithms are based on fuzzy inference systems.

3.1.3 Appliances Control Interface

In the large-scale building automation system installations, they used appliances which are directly compatible with BMS protocols such as BACnet, KNX bus etc. but in general, they do not have such interfaces with the appliance commonly used in the houses. As the main objective of this research, the IHAS was implemented as an external controller compatible with existing residential buildings as well as developing buildings without doing major infrastructure modifications to the building. Therefore, the design of proper appliances interface is important. The appliances control interface is a communication system which is implemented to make control interfaces in between central controller and general home appliances which are installed in living premises.

3.1.4 Wireless Communication System

Development of a proper communication system for the IHAS is the next important aspect. Basically, communication systems are used to sharing the information in between two nodes or multiple nodes at the different layers [12] [13]. IHAS consists of several subsystems which operate in different locations. Some systems may locate inside the controller and some systems are located outside. Development of a communication system is critical as there is a requirement of information sharing of the entire system to achieve uninterrupted automation service to the buildings [14]. Since all of these categories directly affect the performance of the automated system, these areas going to be specially addressed in this research to develop an intelligent home automation system for enhanced energy performance.

3.2 The Proposed Control Architecture of the IHAS

The proposed control design of the IHAS is shown in Figure 3.2. According to the proposed design, it has a multi-input and multi-output fuzzy interference system as the main controller [15]. Inside the main controller, there are two subsystems named as energy optimization and comfort optimization which are used to optimize the primarily obtained controlled decisions focused on energy utilization and user comfort improvements [16].

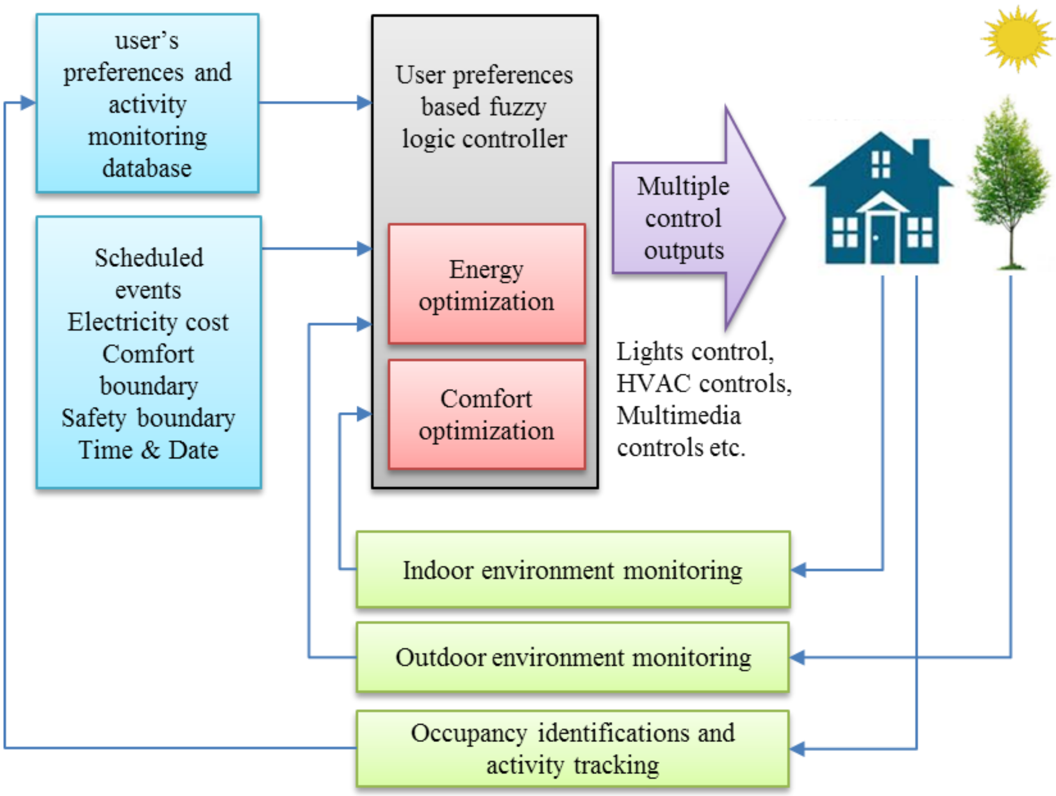


Figure 3.2: The proposed control architecture of the IHAS

The proposed system has three types of sensory systems which are allocated to indoor climatic monitoring, outdoor climate monitoring and user identifications with activity tracking. These three sensory systems provide the necessary information on the real-time environment to the main controller. Apart from the real-time sensory feedback systems, the controller model has additional information system operates as a database. This system provides the information on the predefined system parameters and self-identified information to the system when it needed. As an example, the occupancy identification system identifies the individual users living in the building and activity tracking system monitors on their activities associated with the building appliances such as HVAC systems, lights, timely events etc. [17]. Automatically obtained information save in a database to use in next instances. Finally, the multiple control outputs or decisions are delivered to the particular appliances to change the living environment automatically [18].

3.2.1 User Preference based Automation Controller

User preferences are the constraints provided by users individually. In related to the home automation applications, thermal comfort levels, visual comfort levels, hearing levels, multimedia favourites are the general user preferences which are change by the users at the different times and scenarios. As an example, a 20-year old person needs one-third less light than someone who is 60-years old for the same task as shown in Figure 3.3. And also for the same user, there may be different preferences for the same parameter at different times [19] [20]. As an example, in a living room for the particular person, the 400 lux of illuminance level may be more comfortable during the study time and the same illuminance level make an uncomfortable for the same person when he is watching a movie.

However, in most of the times, people are not going to change the HVAC set-points, lighting levels or multimedia parameters according to the presence and absence of the users or types of the event they involved. As the result, the appliances are set to archive mean value or most required value during the entire operation time. But it will cause to decrease the comfort levels and also increase the energy wastage by maintaining unwanted comfort level at the premises. According to the literature related to the HVAC system operations, the decreasing of 1 degree Celsius of the HVAC set point will cause an increase of 10% to 50% of energy consumption in order to the reach and maintain the desired input.

The proposed automation system (IHAS) is designed to operate as a user preference based controller to improve the user comfort by changing the environment according to the presence of different occupants automatically. And also by monitoring the user preferences and activities referred to the different events, it has the ability to maintain more comfort and energy efficient environment in the living premises.

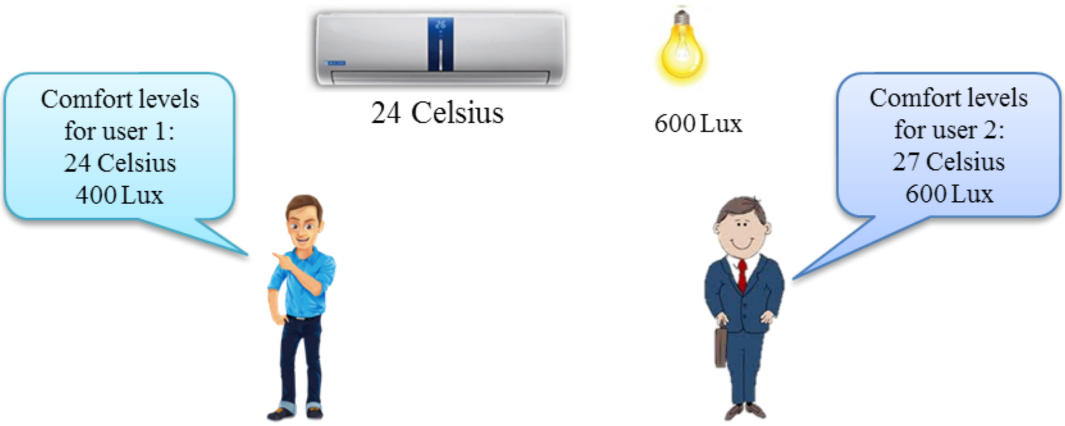


Figure 3.3: The deviations of the comfort preference of different occupants

3.2.2 Closed Loop (Feedback) Controller

The quantity of the output being measured is called the "feedback signal", and the type of control system which uses feedback signals to both control and adjust itself is called a closed-loop system. Closed-loop systems are designed to automatically achieve and maintain the desired output condition by comparing it with the actual condition. It does this by generating an error signal which is the difference between the output and the reference input.

According to the proposed design of IHAS, it has systems to operate in defined set-points such as lighting systems, HVAC systems etc. by changing the environment parameters to achieve comfort level. As an example, in a basic lighting system, the output light intensity or power rating of the light bulb was selected according to the application and it was switched on when it is needed and switched off when it is not needed. In advance, apart from the on and off control, the light dimmer controllers were used to control the light intensity level of the lights according to the required light intensity level. This would result in a comfort improvement and an energy saving by avoiding excess energy used to maintain the unnecessary lighting. But when it set to a certain level, some of the environmental factors will affect to the system such as natural light, when it is available at the location and the states of other artificial light sources closer to the system etc. as shown in Figure 3.4. Practically this types of adjustments cannot be done manually and there may be an opportunity to save energy while maintaining the desired comfort level. Therefore, closed loop controllers are used for the automation process of the IHAS to achieve the enhanced comfort and energy performance from the system [21] [22].

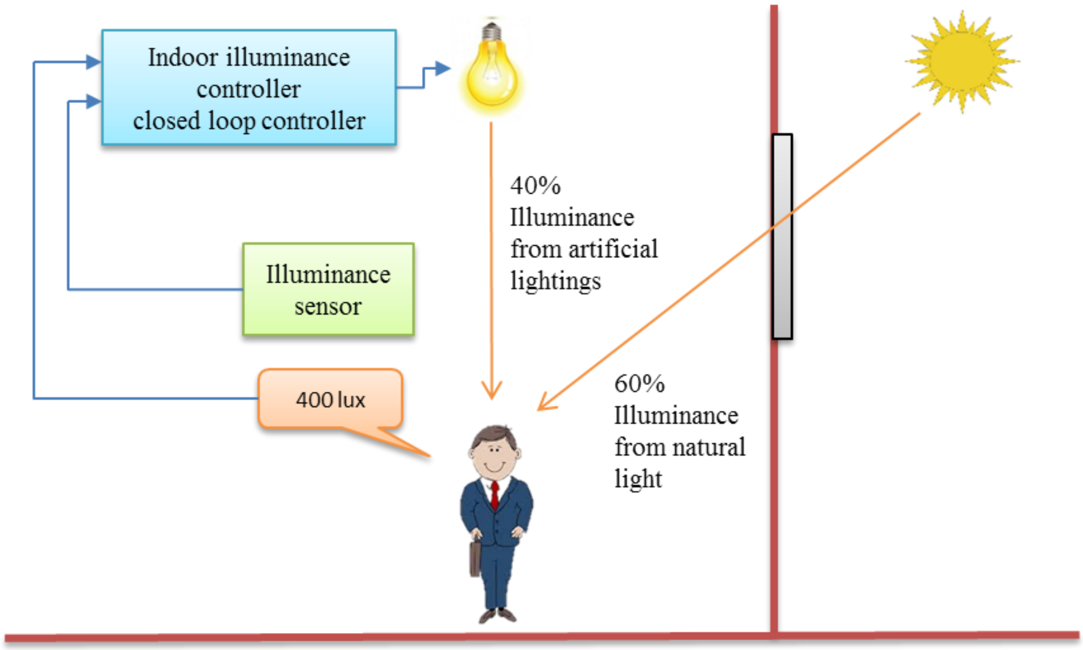


Figure 3.4: The lighting application based on the closed loop controller

3.2.3 Intelligent Control

Development of intelligent control systems are mainly based on the emulation of human biological intelligence to use in automation. It can be used to replace involvement of human in control task (e.g. manufacturing process plant operator) or it can be used to analyse decisions or ideas from how human biological systems solve day to day problems and applies them to make accurate decisions in control problems. [23].

According to the control architecture of IHAS, it has a wider sensory information system focused on the necessary parameters of the environment which needs to obtained accurate control decisions on the appliances of the building. To achieve this, IHAS should have the capability to perform the decision making accurately based on the input information. Therefore the intelligent control techniques were used to implement the control algorithms of the IHAS.

3.3 System Functionality of Proposed Intelligent Home Automation System (IHAS)

According to the objective of this research, the layout for the proposed system was discussed by focusing on the main structures. Based on this control structures the system functionalities were identified to implement the system. The functionality of the proposed automation system can be categorized into four sections as shown in Figure 3.5.

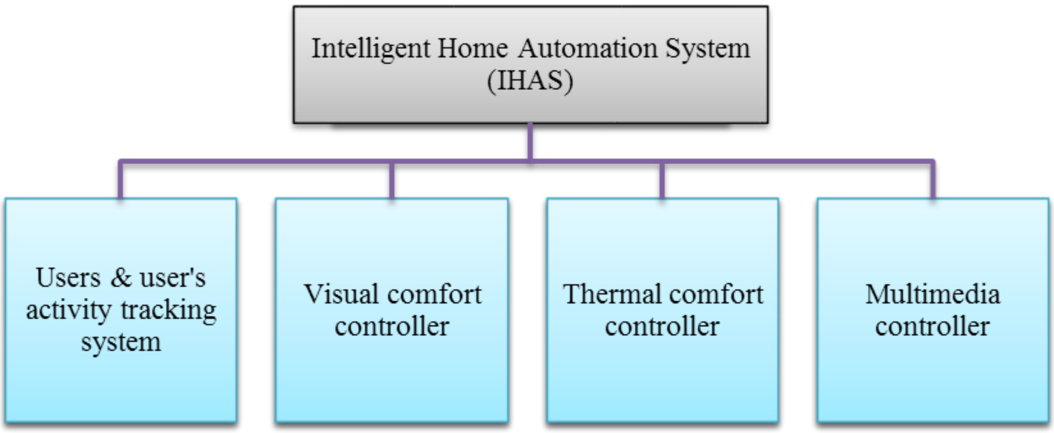


Figure 3.5: The block diagram of main functionality of the Intelligent Home Automation System (IHAS)

3.3.1 Users and User Activity Tracking System

Users and user activity tracking system is a primary sensor system which is developed to detect the presence of individual occupants in the living premises through interactive and non-interactive sensory systems. This system has the capability to detect the occupants together with their locations in real-time.

Apart from that, the system has the ability to identify the individual user preferences based on the comfort levels and usage of multimedia, by monitoring and analysing their activities performed by individual users to the related appliances.

3.3.2 Visual Comfort Controller

According to the presence of individual occupants, their present locations and recognised user preferences, the visual comfort controller accurately defines the desired parameters for the lighting system to maintain the energy efficient visual comfort environment by using available luminaires in the building [24] [25] [26] [27]. These parameters can be used for the artificial light controllers, natural lighting devices such as electric curtains to deliver the right amount of light to the desired location when it is needed.

3.3.3 Thermal Comfort Controller

According to the literature approximately 30% to 60% of total energy is consumed by the HVAC appliances [28]. And thermal comfort is an important factor to maintain the healthy living style. Since it is important to user comfort and as well as energy consumptions, the thermal comfort controller is developed to control the HVAC appliances through the IHAS [29]. The controller accurately calculates the Indoor temperature forecast according to the occupant and their preferences, climatic conditions and energy demand. This is done through maintaining an optimum user preferred living environment for users with maximum energy utilization by avoiding unnecessary comfort levels at occupied and non-occupied states.

3.3.4 Multimedia Controller

The multimedia systems such as television sets, audio setups, projectors, DVD systems etc. are the general appliances which might be used in a living premise for the official and personal purposes. Compared to the HVAC systems and lighting systems, the energy consumption of multimedia systems are not significant. But these appliances are helping to improve the user comfort through the mentality and peace of mind. The multimedia controller was implemented for the IHAS to control the multimedia devices automatically based on the presence of users by recognising their preference.

As a summary the proposed system of the IHAS consists of a real-time multi-sensory sensor system, artificial intelligence based centralized control system and appliance control interfaces. The central controller is monitoring the real-time environmental factors, users and their preferences to make the accurate decisions for the appliances for making the environment more comfortable and energy efficient. The obtained control decisions are delivered to the specific appliance using the developed appliance control interfaces to change the environment automatically. Figure 3.6 shows the practical application and system configuration of the proposed intelligent home automation system.

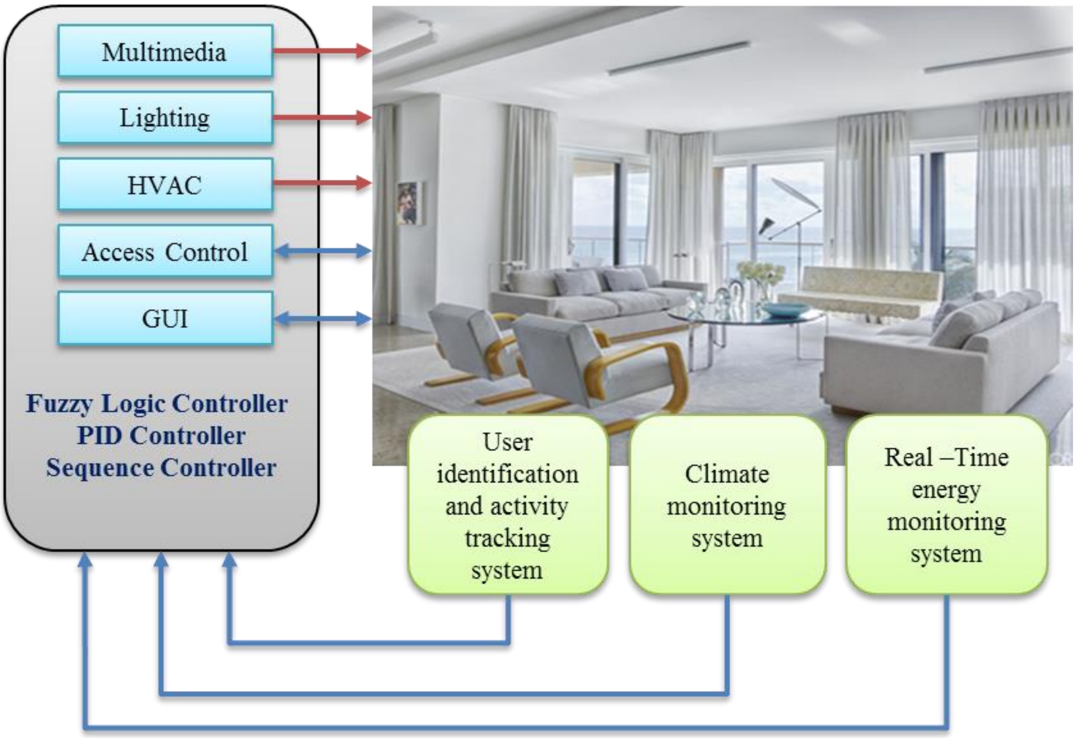


Figure 3.6: The system configuration of the proposed intelligent home automation system

4 DEVELOPMENT OF IHAS

4.1 Introduction

According to the conceptual design of IHAS, the next task is to develop the identified systems and validate them by integration. The entire development process of IHAS includes the case study on theoretical areas, primary experiments and finally hardware and software implementation for the specific developments.

In the development process of IHAS, first identified the requirements of sensory systems related to the building automation systems and studied on different sensing technologies, sensors, sensor interfaces and their applications to develop an enhanced sensory system. After implementation of the sensory system, identified general appliances or systems used in the residential buildings related to the user comfort, safety and energy consumption which need to control from the controller. Then studied on developing a flexible control interface with these equipment through the controller. Finally development of a hardware system for a suitable controller and development the control algorithms to combined input and output of the entire system of IHAS was carried out. In this chapter the development process of IHAS will describe under the main five categories as shown in Figure 4.1.

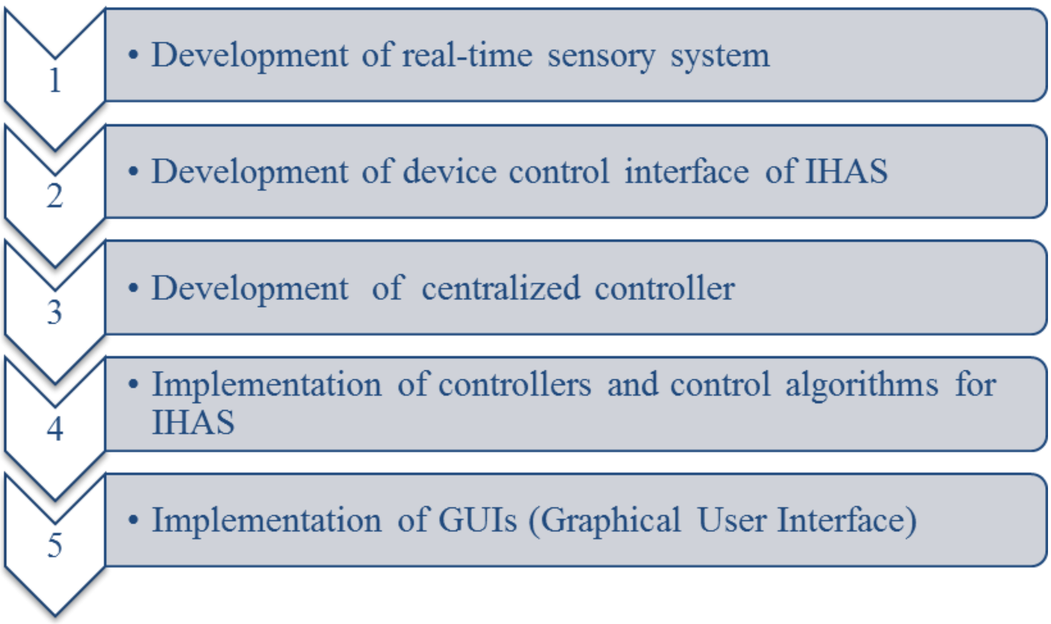


Figure 4.1: Main development areas of IHAS

4.2 Real-time Sensory System for IHAS

A sensor is a device that detects and responds to some type of input from the physical environment. These specific inputs could be light, heat, motion, moisture, pressure, or any combination of the mentioned environmental phenomena. At present, several types of sensor systems have been developing for the home automation systems. By using an enhanced sensory system, it is possible to identify the changes which are occurred in a living premises. This information can be used to take the real-time estimations on the environment and if there are any factors which affect to decrease the comfort level or energy efficiency, it is possible to make corrections by the controller. By enhancing the scale and performance of the sensory system, the control capabilities and accuracy of the controlled decisions can be increased.

The real-time sensory system of the IHAS has main four types of sub sensory systems as external environment monitoring system, Indoor climate monitoring system, Occupancy identification and localization system, Energy monitoring system with load device identification, which are located at indoor and outdoor for take the measurement on different parameters. These sensor systems have been developed as wireless sensor systems to compatible with existing building applications and newly build building applications with improved flexibility and minimized installation barriers. The Figure 4.2 shows the layout of developed sensor system for IHAS.

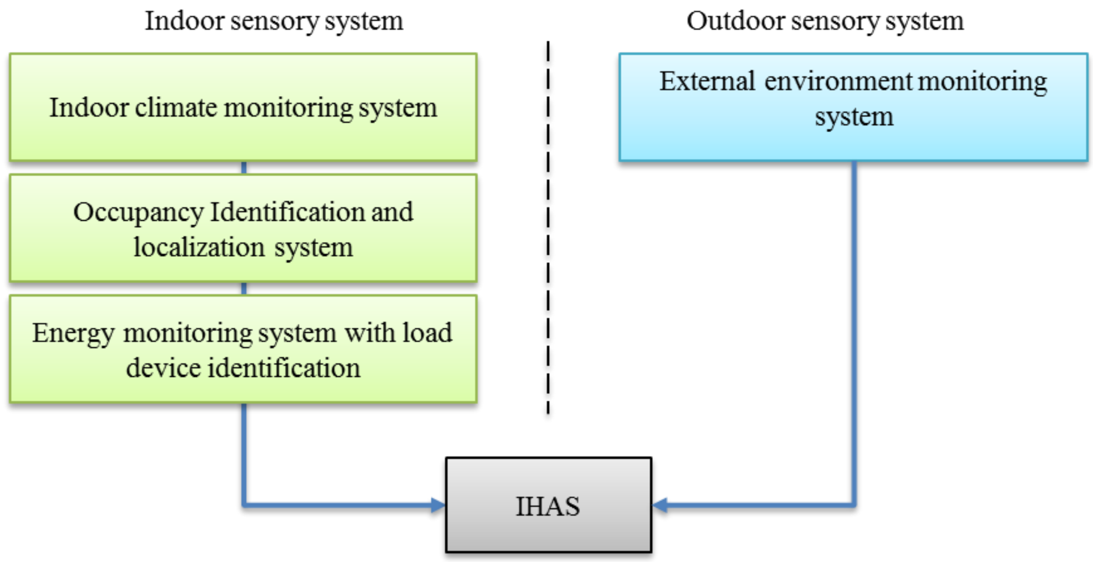


Figure 4.2: Layout of real-time sensor system of IHAS

4.2.1 External Environment Monitoring System

The condition of external climate is one of the major factors which effect for the indoor environment conditions of the building. Related to the indoor comfort of the building such as visual comfort and thermal comfort the ambient temperature, relative humidity, illuminance level and solar irradiance are the specific parameters which are need to get considered [30].

Generally in a building, thermal comfort and visual comfort systems such as HVACs and artificial lighting systems are designing by considering these climatic parameters as the function of geometrical and seasonal factors or as pre estimated values. However, climate parameters are very uncertain factors and difficult to predict accurately. But if it is possible to measure the real-time climatic parameters accurately then it can be integrate to control indoor climate conditions of the building effectively [31]. As an example the Figure 4.3 shows a natural light harvesting system, which is an energy efficient lighting system used to maintain the desired illuminance level at specific location utilizing the natural light if it is available [32] [33] [34].

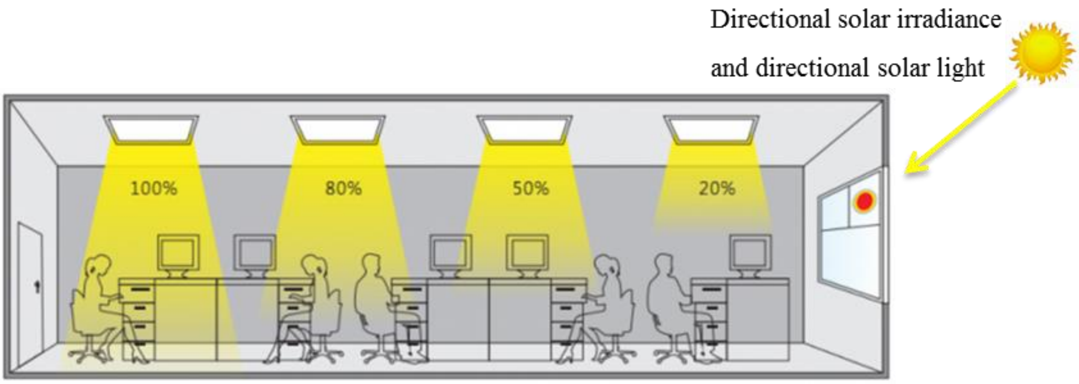


Figure 4.3: Adaptive lighting system with natural light harvesting

The external environment monitoring system is a sensory system which was design to measure real-time external climatic information which is related to the thermal comfort and visual comfort systems of the IHAS. This system was facilitates to take the real-time measurements on following parameters and these parameters will used as sensory information in different controllers discussed in next chapters.

Measuring parameters of the external environment monitoring system

- Directional solar irradiance
- Directional solar illuminance
- Ambient temperature
- Relative humidity

The complete module is having approximate dimensions of 28 cm X 28 cm X 21 cm. As shown in Figure 4.4, the suggested device has a 5W polycrystalline PV panel (cell) as the main sensor which is used to detect the average solar irradiance. It is mounted on two vertical columns where one end its supported by a stepper motor providing the capability of rotating around its transverse axis to track the sun. The opposite side is supported by a bearing. At one end of the PV panel, a sensor panel is attached. In that sensor panel the light intensity sensor, humidity sensor, ambient temperature sensor and accelerometer are mounted. In addition, a temperature sensor is attached to the back side of the PV panel to measure the panel temperature variation. All the sensors and actuators are wired to the control box underneath. The controller of the system is based on the Atmel ATMEGA 2560 8-bit microcontroller which is installed in the control box. The system is equipped with a Bluetooth communication module and long distance ISM band RF communication module. There is a Micro SD memory module combined with a Real-time clock module which are used to record all the data acquired for the future requirements. The base plate is mounted on four adjustable mountings allowing adjustments for effective tilting angle of the PV panel. External 24V DC power source is used for power requirements of the device, as shown in Figure 4.5. A graphical user interfaces have been developed, so that the user can visualize real-time acquired data. In addition, it provides the controls for solar panel operation, thus optimizing the data set acquired. According to design of the proposed system it has two application areas. The first application area is that the system can be used as an external environment monitoring sensor module for the automation controllers. Secondly it can be used as a measuring equipment for available solar potential at a given location.

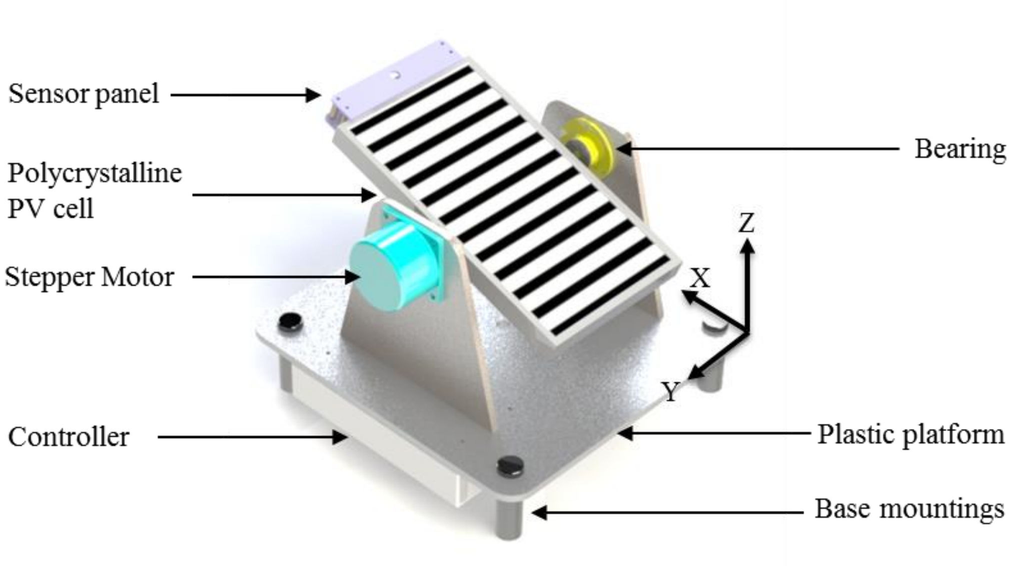


Figure 4.4: Proposed design of external environment monitoring system

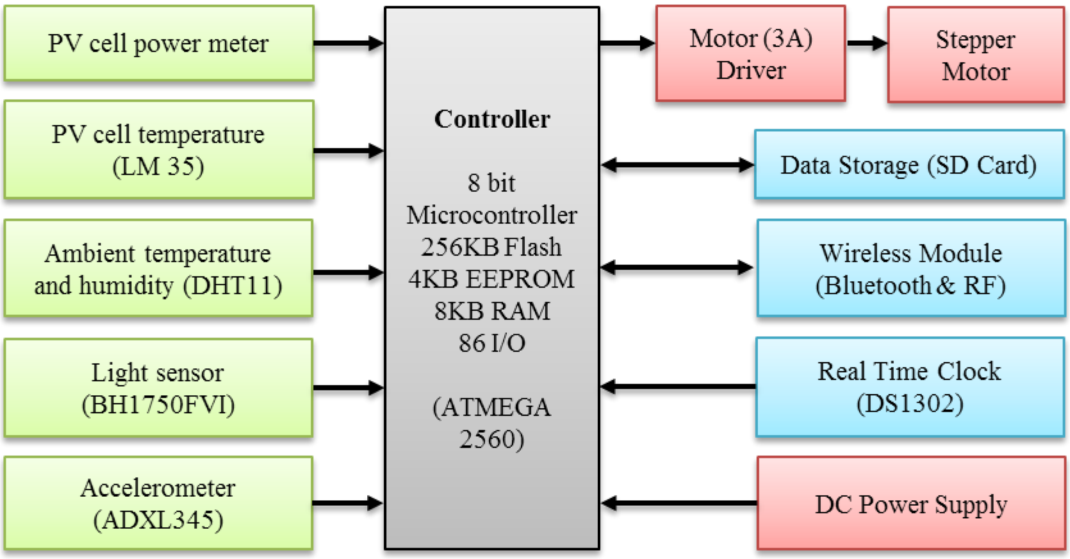


Figure 4.5: System layout of external environment monitoring system

4.2.1.1 Working Principle of the Proposed System as an External Environment Monitoring Sensor Module

In this application mode the proposed system can be used to measure the four environment climatic information such as ambient temperature, ambient humidity, directional Illuminance, directional solar irradiance. Based on these parameters and installed location of the sensor module reference to the building it can be possible to calculate the effect of such parameters to the building [35] [36]. Central controller of IHAS can connect as an external controller to the system via the 2.4 GHz (ISM) radio link. Then it can change the direction of the PV panel and Illuminance sensor in the operating range and read the real-time climatic parameters according to requirement of the controller. These external climatic information are used as input parameters in different control algorithms execute in IHAS central controller. The Figure 4.6 shows the system configuration and graphical user interface which are related to the application.

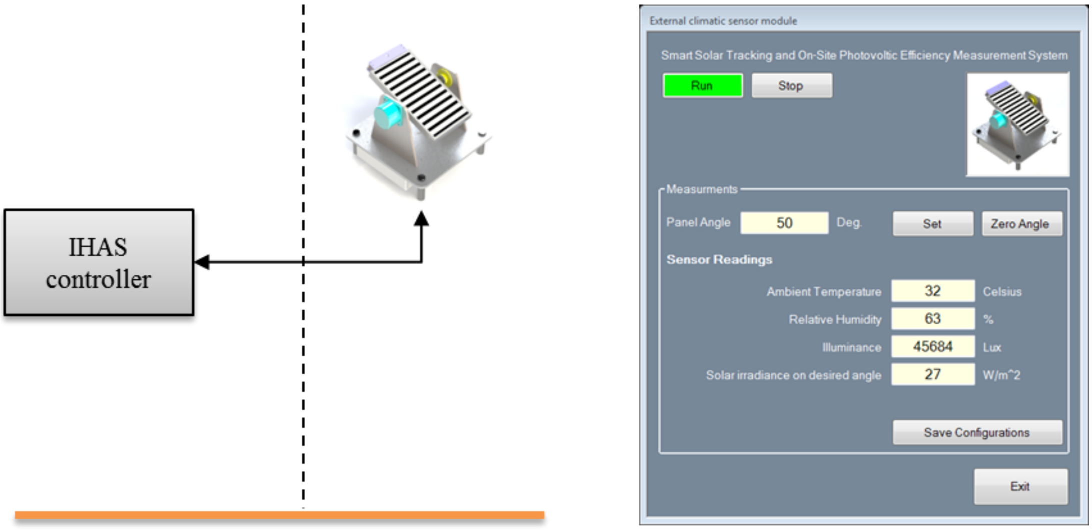


Figure 4.6: (a) System configuration of external environment monitoring system (b) Developed computer based graphical user interface for the sensory system

4.2.1.2 Photovoltaic Efficiency Measuring System

When a location is identified for evaluating the photovoltaic efficiency, this device can be placed there [37]. When placing the device, two factors should be considered for better results. First point is the orientation of the device. The device should be oriented such that, the longitudinal direction of the PV panel (X axis in Figure 4.4) lies parallel to the East-West direction of the earth. It allows the PV panel to follow the solar track effectively. Then the tilt angle should be set. Tilt angle for the panel is the angle of the transverse direction of the panel with the ground horizontal (Y axis in Figure 4.4). Controlling of tilt angle enables the maximum capturing of solar irradiation [13]. Tilt angle of this suggested device can be adjusted by adjusting the four mountings of the base plate. When these two parameters are being set, the device can start logging data. As shown in Figure 4.7, the stepper motor allows the rotation of the panel from -45 degrees to +75 degrees from its home position with maximum step resolution of 1 degree. At each step the angular position of the panel, the power output of the panel, panel temperature, light intensity, ambient temperature and ambient humidity is recorded together with the calendar date and the time of recording. Thus during a single operation cycle the device will be able to log a maximum of 120 data points to build up a photovoltaic efficiency data base. The user is allowed to control the starting angle, end point, step size and the time duration for each operation cycle via the developed user interface as shown in Figure 4.8. The duration of operating cycle determines the time resolution of data set and the size of the data set. The collected data is then stored in an internal memory and can be monitored remotely through a Bluetooth device paired with. The GUI provides the flexibility of choosing among 3 modes; instant measurement mode, raw data acquisition mode and maximum power tracking data acquisition mode. In the first mode, the user can set the position of the panel and measure data. The second mode allows the measurement of desired range of angles with desired step resolution. In the third mode, it measures the PV panel angel which captures the maximum power and records it with the time of the day [38] [39].

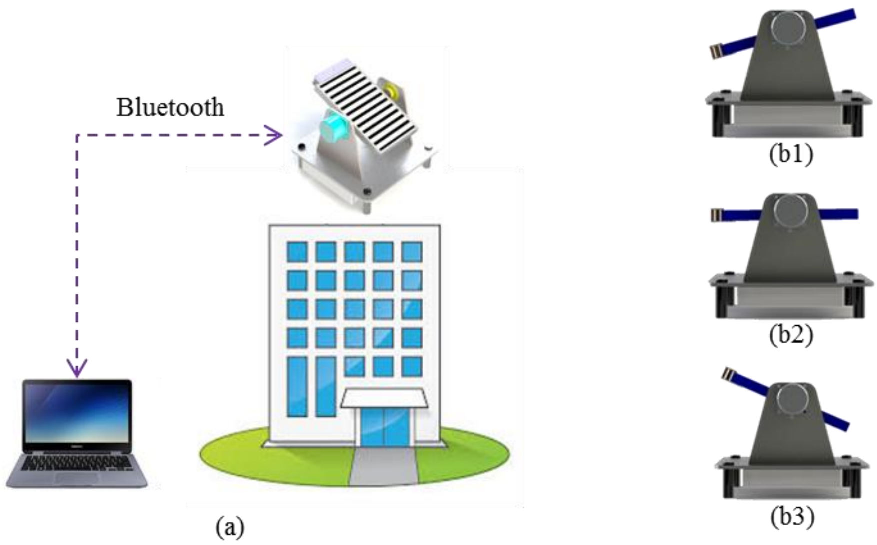


Figure 4.7: (a) System configuration of photovoltaic efficiency measuring system (b) Panel rotation angles; b1) Negative angle; b2) Home position; b3) Positive angle

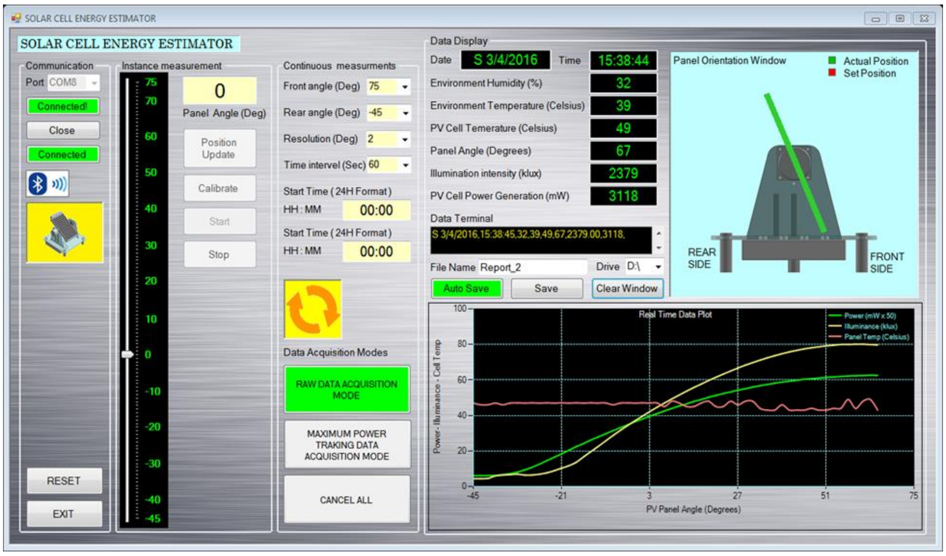


Figure 4.8: Developed graphical user interface for photovoltaic efficiency measuring

In the developed system, solar irradiance is a major parameter which needs to be measured. Solar irradiance is proportional to the photo voltaic energy which is generated by a particular PV cell [40]. Solar cell in the panel is the device that converts the sunlight into electricity using photovoltaic effect. Basically solar cells are manufactured using two types of silicon; monocrystalline silicone and polycrystalline silicone [41]. In the proposed system solar irradiance is measured by using polycrystalline PV cell as the photovoltaic energy in unit of watts per square meters (W/m^2) [42]. The selected PV panel, consist of 36 series polycrystalline silicon solar cells each with 10 mm X 50 mm of area and the important specifications are listed in the Table 4.1.

Table 4.1 Manufacture specifications of selected photovoltaic panel

Panel area	$0.018m^2$
Maximum power (P_{MPP})	5W
Open circuit voltage (U_{OC})	21.36V
Short circuit current (I_{SC})	1.42A
Optimum power voltage (U_{MPP})	17.8V
Optimum power current (I_{MPP})	0.29A
Test condition	25 Celsius at $1000W/m^2$

PV cell generates Direct Current (DC) electrical power. The DC power produced by PV cell is the product of terminal voltage and cell current. According to the manufacturer details it is mentioned that, the optimum power voltage (V_{OP}) is 17.8V and the optimum power current (I_{OP}) is 0.29A. Using these values the optimum load resistor (R_L) was calculated by the Equation 4.1. and fixed it to the output terminal of the PV cell. Based on producing voltage of the PV cell under the certain load (V_{RL}), the power was calculated by Equation 4.2. Figure 4.9 shows the equivalent circuit of the photovoltaic power measuring circuit.

$$R_L = \frac{V_{OP}}{I_{OP}} = \frac{17.8\,V}{0.29\,A} \approx 62\,\Omega \quad (4.1)$$

$$Power\ (W) = \frac{{V_{RL}}^2}{R_L} \quad (4.2)$$

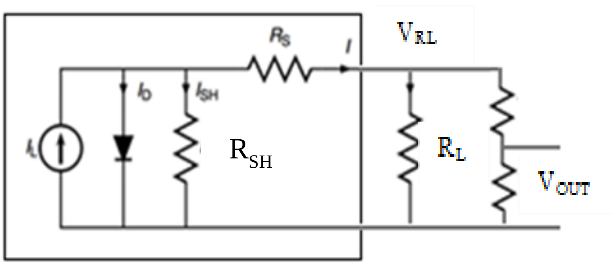


Figure 4.9: Equivalent circuit of the photovoltaic power measuring circuit

The next parameter is the light intensity level. There are different types of sensor systems available for the photometric applications. Considering the application, the sensor should be small and accurate to a certain level and cost effective. A Light Dependent Resistor (LDR) is a common sensor widely used for the light sensing applications due to the simplicity and low cost. They are strongly temperature dependent, so they are not suitable for stable repeatable precision light level measurement.

Compare to the LDR, photodiode is semiconductor based sensing device which generate electrical current flow according to the light level by absorbing photons.

BH1750FVI is a digital ambient light sensor (Figure 4.10) which is having 1 – 65535 lux of wide range and 16 bit resolution. The sensor values can be read through the I^2C

communication link. Further it has Spectral response which is approximately same with human eye response. This sensor was selected to implement the photometric system of the external environment monitoring system. Since the selected sensor has very narrow directional responses, it is modified with a shaded diffuser to increase the directional response. After the addition of a diffuser, the sensor is calibrated with a standard photometric lux meter. The comparison results are shown in Figure 4.11.

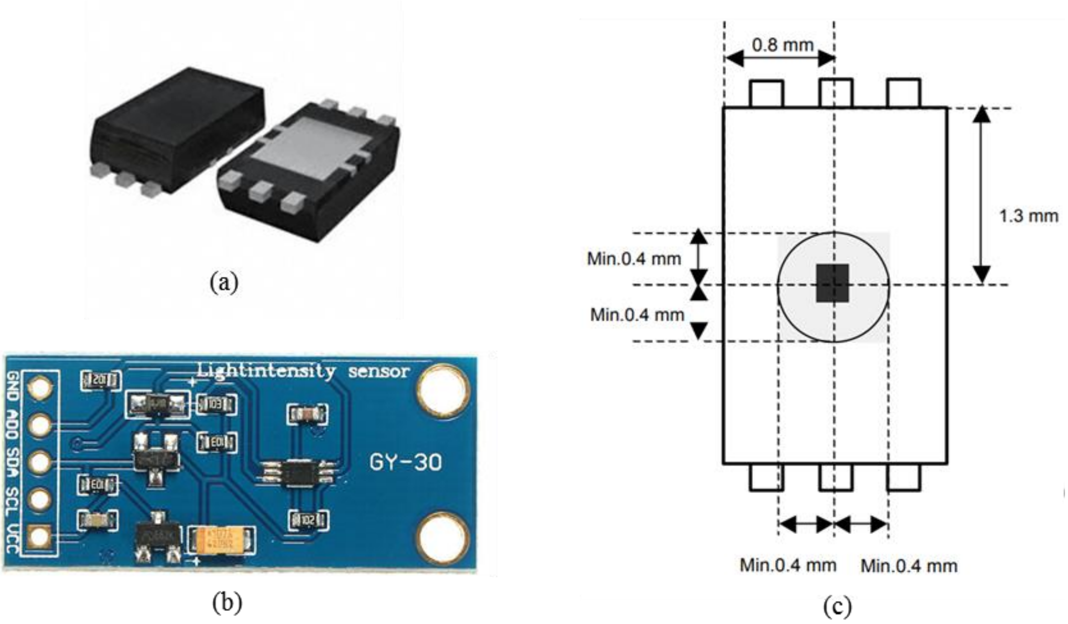
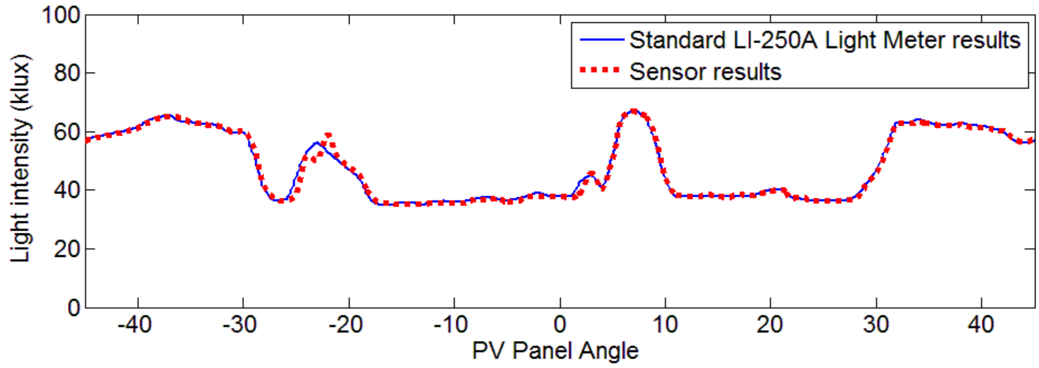


Figure 4.10: Details of BH1750FVI ambient light sensor (a) BH1750FVI Sensor Chip (b) Commercially available BH1750FVI based sensor module (c) Dimensions of the sensor chip

(a)



(b)

Figure 4.11: Calibration of ambient light measuring system (a) Calibration setup with LI-250A Light Meter (b) Calibration results with shaded sensor

Atmospheric temperature and humidity are the most important parameters related to the thermal comfort [43] [44]. When measuring the ambient temperature, there are several options available. In this suggested device, a Negative Temperature Coefficient (NTC) component based temperature and humidity sensor (DHT11) which is mounted in the sensor panel is used. It is capable of measuring ambient temperature in a range of 0-50 C with ±2 °C accuracy and relative humidity (RH) in range of 20 – 90 % with ±5% accuracy. The sensor has a fast response time and its calibrated digital signal output can be directly connected to the controller. In addition to the ambient temperature, PV cell temperature determines the efficiency of the PV cell output. Many measures have been taken to minimize the PV cell temperature [18]. Since the target is to prepare an effective database of available solar power, the PV cell temperature also measured using precision integrated circuit temperature device (LM 35) pasted to the backside of the panel. It has very wide operation range (-55 °C to 150 °C) with 0.5 °C accuracy and provide a linear voltage output.

In order to locate the rotating PV panel, an ultralow power 3-axis accelerometer (ADXL345) is mounted in the sensor panel. The sensor has a range of ±16g in all directions and has high measuring resolution (13 bit) allowing the detection of an inclination change of 1°.

Position of PV panel is determined based on the orientation angle, tilt angle and rotation angle of the panel. Orientation angle simply means the direction of longitudinal axis (X axis of the Figure. 1) PV panel is facing, and the tilt angle is the angle between the transverse axis (Y axis) of the PV panel and the ground. Angle of rotation of the PV panel (around Y axis) is achieved by a motorized system in range of -45 degrees to 75 degrees reference to its home position. It has the capability to the maximum of 1 Degree of position resolution.

The initial position of the PV panel is calibrated with reference to the direction of gravitational acceleration using an accelerometer. Controlling or reading of rotating angles is always with reference to the geometrical references. With the initial calibration process, the position controller updates the internal position registers to a reset. Further in each step, controller updates this registers with position data of the current step. So during operation, the value of this position register represents the actual position of PV panel. Figure 4.12 shows the block diagram of position control system of the PV panel.

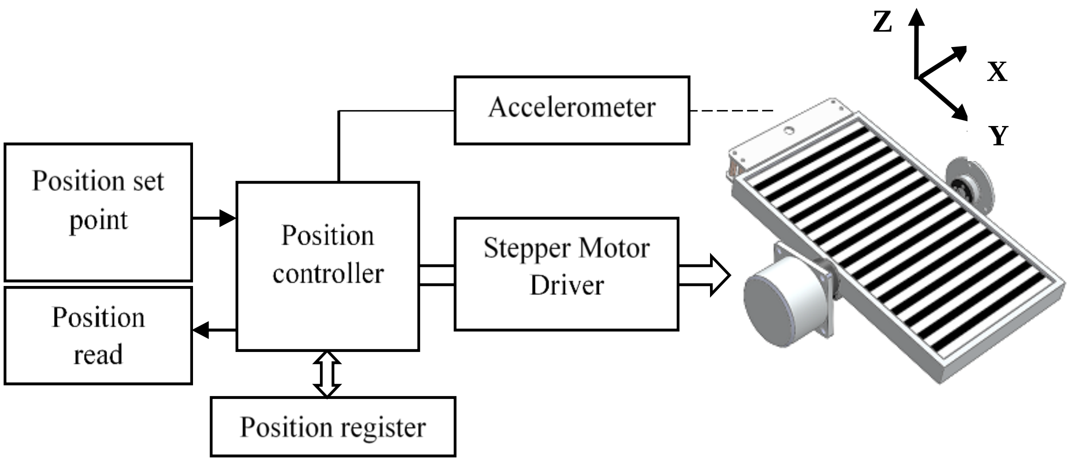


Figure 4.12: Position controlling system of PV panel

The suggested device was fabricated in-house with discussed sensors and actuators as shown in Figure 4.13. After few test operation cycles for validating the operation, it was kept outdoor for measuring solar potential and related parameters to validate the system. Figure 4.14 shows the graphical representation of the obtained results related to the available solar potential at particular location.

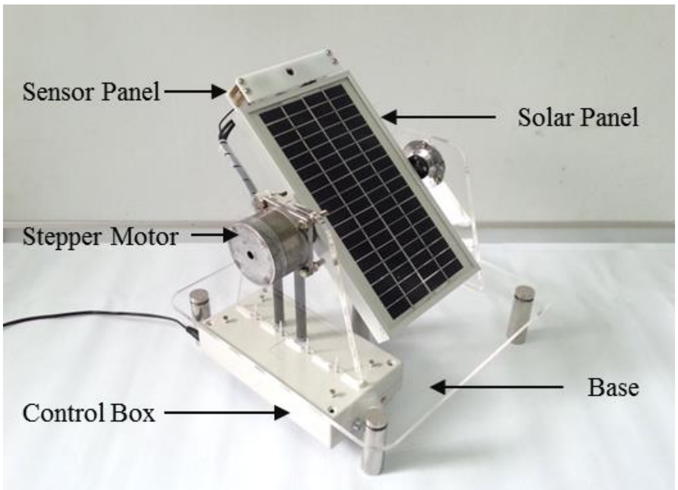
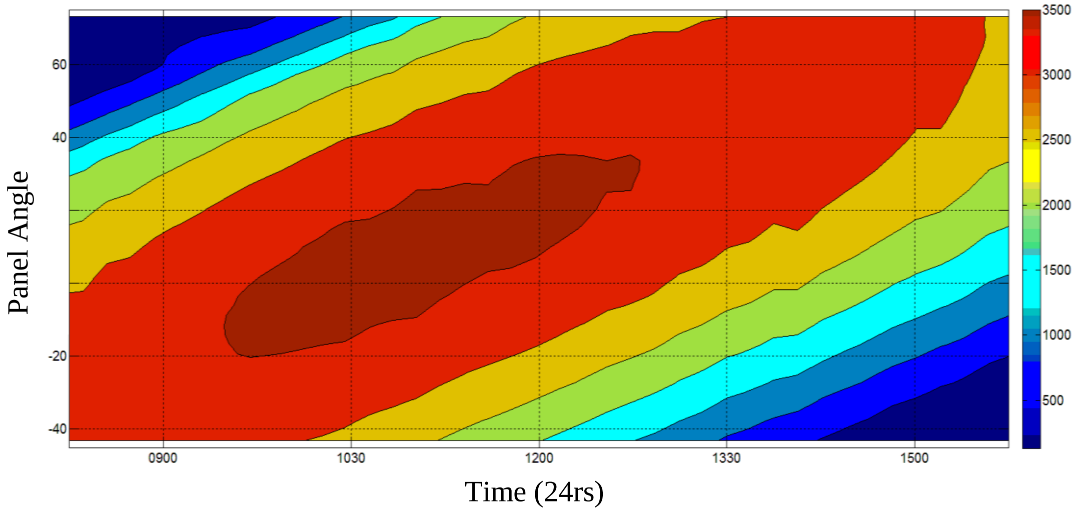


Figure 4.13: Developed prototype of external environment monitoring system



Place : Hendala, Wattala. (6.99737 N, 79.87424 E)

Date : 03/04/2016 from 8.30 AM to 3.30 PM

Figure 4.14: Available solar potential at specific location with time of the day and panel

4.2.2 Indoor Climate Monitoring System

4.2.2.1 Introduction

Indoor climate monitoring system is an indoor environment sensing system which is used to take the measurements on environmental parameters which is related to the building comfort aspects. Since the real-time indoor user comfort parameters directly measure from this system, the indoor climate monitoring system is important and capable to take the necessary real-time measurements accurately.

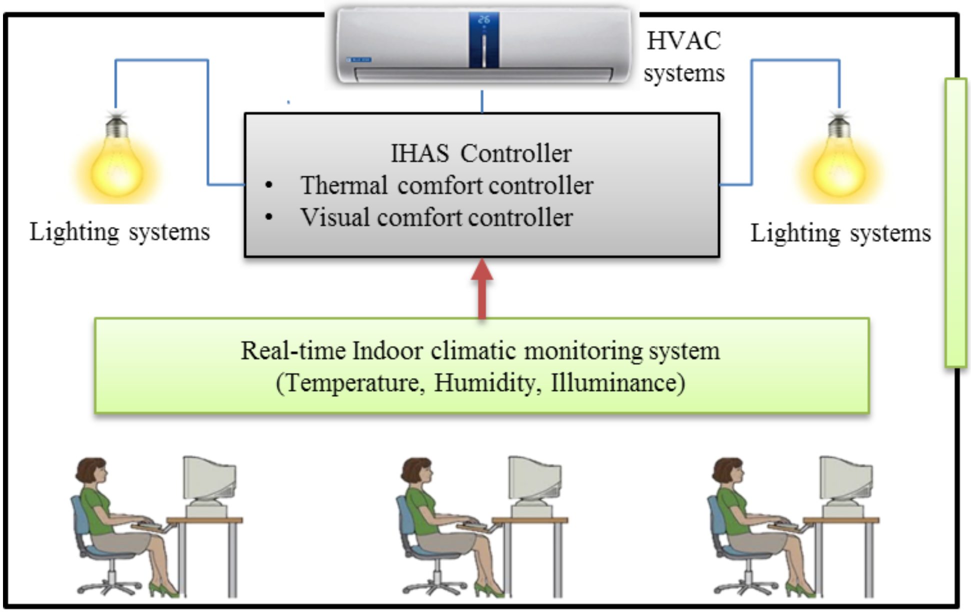


Figure 4.15: Configuration of indoor climate sensor system

For this system three types of different parameters were identified to measure which are necessary to control indoor comfort level as well as improve the energy unitizing performance. These parameters are indoor room temperature, relative humidity and ambient illuminance as shown in Figure 4.15. The measurements on indoor temperature and relative humidity are the main feedbacks of the indoor thermal comfort controller. The ambient illuminance sensor is the main feedback of the visual comfort controller.

4.2.2.2 Sensor Configuration of Indoor Climatic Monitoring System

According to the application of indoor climatic monitoring system, it was designed to install inside the central controller. There are two types of sensor modules were used. DHT11 was used to measure the temperature and relative humidity and BH1750FVI sensor was used to measure the ambient light condition as explain in previous section. These digital sensors are connected with an interface controller through the different digital communication protocols as shown in Figure 4.16. The interface controller is a part of main control system and it is explained in a next section.

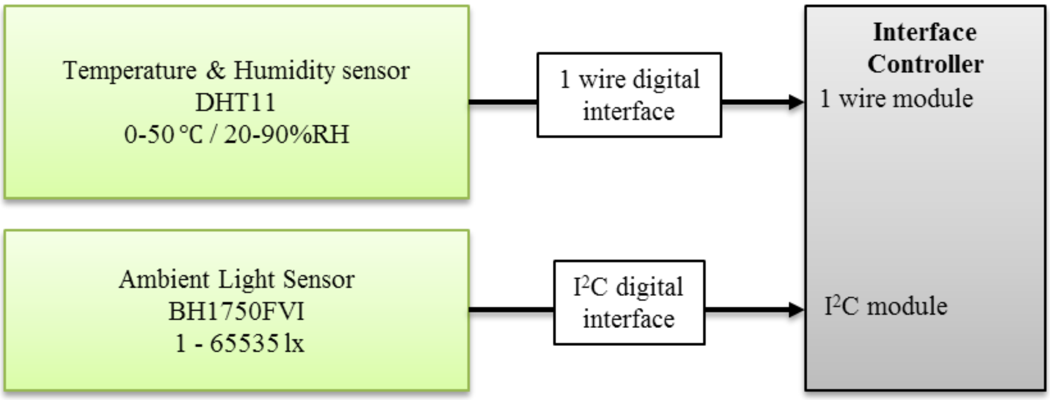


Figure 4.16: The configuration of climatic sensors of indoor climatic monitoring system

4.2.3 Occupancy Identification and Localization System

4.2.3.1 Introduction

Since the user preference based automatic controlling is the main objective of the IHAS, it is required to identify the presence of individual users in particular location to control home appliances according to their individual preferences in order to avoid the uncomfortability and unwanted energy consumptions due to maintaining an unwanted comfort level at living premises. The occupancy identification and localization system is a sensory system which was developed to identify the presence of individual persons at the specific location [45].

In the literature it is shown that many researches has been conducted to develop user identification systems for abuilding automation applications using different sensor technologies. The user identification systems mainly categorized into two sections as interactive user identification systems and non-interactive identification systems. In interactive identification systems, users are needed to do some specific procedures for the identification process and in non-interactive identification systems users are automatically detected by entering or passing through a specific location.

Interactive identification systems are very accurate and most of the systems can identify the individual users exactly. These systems include finger print scanners, optical image scanners (Eye detectors, face detectors), RFID scanners etc. But interactive identification process is making the users uncomfortable. However based on the application these types of sensor systems have been used where the access control is precisely need.

Non-interactive identification systems are non-contact detection systems which are used to detect users without ant interaction. These systems are more convenient and widely used in BAS. IR thermal sensors (PIR, IR image sensors), ultrasonic detector, foot pressure sensors, radar sensors are example to the non-interactive identification systems. But in most of the cases, this kind of systems are not capable to detect individual users accurately compared with interactive identification systems.

As a summary the Table 4.2 shows the different human identification technologies and their characteristics.

Table 4.2: A summary of different human identification technologies and their characteristics

Human detection technologies	Type of detection method	Identification factors
Finger print	Interactive	Individual users & user presence location at interactive time
RFID	Interactive	Individual users & user presence location at interactive time
Typing an identification key via a HMI	interactive	Individual users & user presence location at interactive time

Image recognitions (Eye scanners / Face detection)	Interactive or None interactive	Individual users & user presence location at detection time
Detection of the mobile phone (Bluetooth, Wi-Fi)	None interactive	Individual users & approximate presence area
IR scanners (PIR sensor / Thermal images)	None interactive	User presence or not & presence location
Radar	None interactive	User presence or not & presence location
Ultrasonic	None interactive	User presence or not & presence location
Pressure-sensitive floor tiles	None interactive	User presence or not & presence location
Acoustic sensors	None interactive	User presence or not & approximate presence area

According to the application of IHAS, following parameters were considers to select proper user detection technologies for occupancy identification and localization system.

- Convenience

Since the comfort improvement is an objective of the IHAS, the user identification procedures of IHAS should be more convenient for users.

- Identification accuracy

In the IHAS, the user identification is used to change the comfort parameters such as thermal comfort, visual comfort and multimedia actions of the environment to the best configuration according to the individual preference of present occupant. Therefore identification is not required as a level of access control.

- System configuration and cost

As an objective, IHAS should be a simple, flexible and cost effective system to compatible with existing and newly developed buildings. And it should be capable for rapid installations.

By considering these parameters, the occupancy identification and localization system was designed as a multisensory systems which are including different sensor systems as summarized in Table 4.3 and Figure 4.17

Table 4.3: A summary of identified sensor systems of occupancy identification and localization system

Human detection technologies	Type of detection method	Identification factors
RFID scanner inbuilt in controller	Interactive or non-interactive	Individual users & user presence location at interactive time
HMI inbuilt in controller	interactive	Individual users & user presence location at interactive time
Bluetooth based mobile device detection system	None interactive	Individual users & approximate presence area
IR thermal image scanner	None interactive	User presence or not & presence location

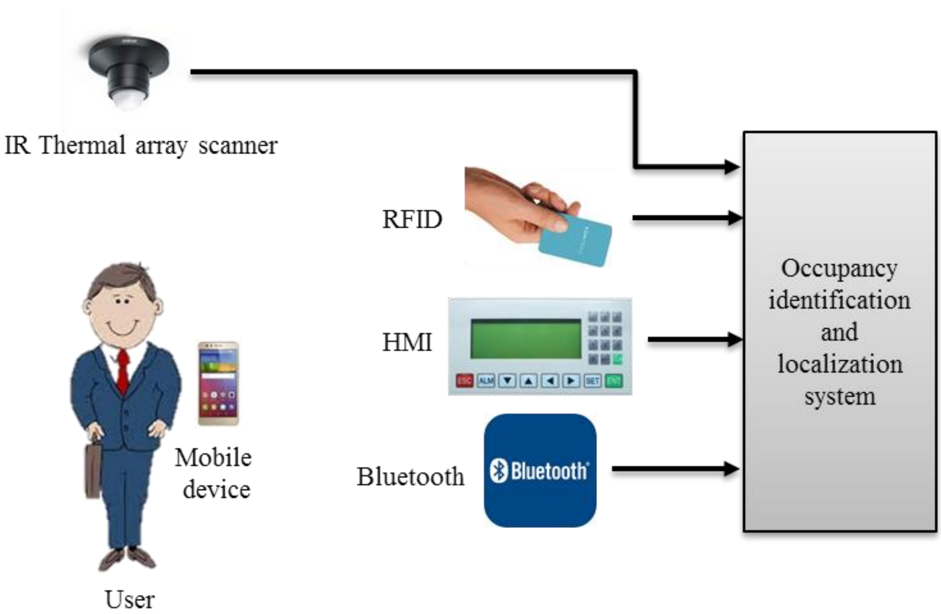


Figure 4.17: The layout of occupancy identification and localization system of IHAS

4.2.3.2 RFID (Radio-Frequency Identification) based Occupancy Identification System

RIFD is a small electronic tag which can be used as a remote electronic key. RFID tags come with different shapes and packages. Therefore it can be easily keep with personal accessories without extra care. As an example the RFID tag can easily be kept attached to the door key tag. Assigning specific tag for the specific person and using the RFID scanner system installed in the entrance or exit and when someone entering or leaving from house or room the tag can be scanned and trough the tag ID the person can be identified. This system can be semi interactive or non-interactive depending on the performance of scanner and tag. By using a high sensitivity long range RFID scanner system, it is possible to detect occupants without any interaction. If scanner system is not sensitive enough to detect from afar, the occupants' need to come closer to the scanner for identification.

Radio Frequency Identification (RFID) system uses a small tag which is used to read and write the information attached to the object through the radio waves. These tags can be read and write within a distance from several centimeters to several meters according to the type of RFID tag. A RFID system has main two components as tag and reader.

Each RFID tag includes a pre assigned specific character code called UID or Unique ID which is used to identify a specific RFID card or object through the RFID reader.

There are main three types of RFID tags are passive tags, active tags and battery assisted passive tags. Active RFID cards include on-board battery inside the tag and it transmits periodically its ID signal. Battery –assisted passive tags also contain small battery attached to the tag itself, but when a tag is near to the reader, then it transmits its information to the reader using the battery power. A Passive tag not utillizes a battery itself, therefore passive tags are very small and cheap. Passive tags use radio energy transmitted by the reader to activate its communication and internal operations process.

There are six major frequency ranges that RFID systems operate at as shown in Table 4.4 and Figure 4.18. Most of the low frequency RFID systems are comparatively cheap and operates in short distance approximately up to few millimeters with slow data communication rate. When it is needed to higher distance identification and higher data rate, higher-frequency RFID systems are involved (e.g. automated vehicle tracking systems etc.).

Table 4.4: The RFID standard

Frequency		Range	Tag cost
125 - 148 KHz	Low-frequency	up to 3 inches	$+
13.56 MHz	High-frequency	up to 3 feet	$0.50 - $5
433 MHz	Ultra-high frequency	up to 300 feet	$5
865 - 928 MHz	Ultra-high frequency	up to 36 feet	$0.15
2.45 - 5.8 GHz	Microwave	up to 6 feet	$25 (active)
3.1 - 10 GHz	Microwave	up to 600 feet	$5

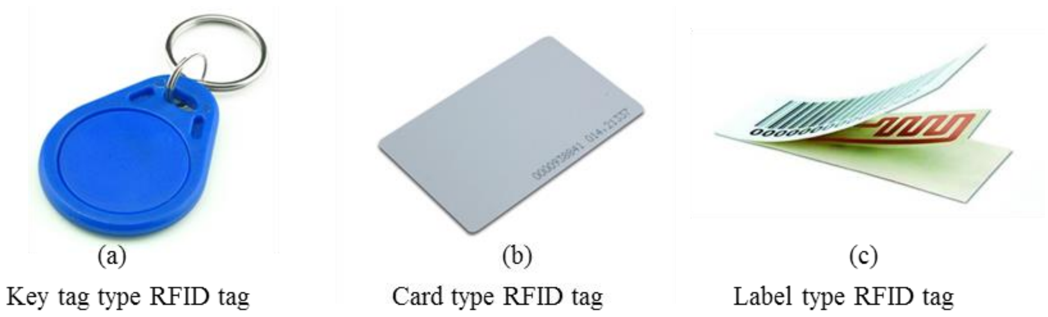


Figure 4.18: (a) (b) 13.56 MHz HF re-writable passive RFID tags. (c) 433MHz UHF write-once passive RFID tag

Configuration of RFID Scanner

The HF (High-frequency) 13.56 MHz RFID (ISO 14443A) tags standard is widely used and cost effective and captures up to 3 feet of operation range. These type of tags have 32 bit length unique ID (UID) and 1KB of rewritable memory space to store additional information as required. Considering these facts 13.56 MHz High-frequency RFID system was selected to integrate with IHAS prototype.

The Figure 4.19 shows the layout of the RFID system of IHAS. The scanner was installed in the front panel of the central controller and it was used to read specific RFID tags for occupant identification and configure the RFID tags to the systems. This system is based on the MRFC522 module which is a highly integrated reader/writer IC for contactless communication at 13.56 MHz as shown in Figure 4.20. This module was connected to the interface controller through a SPI bus and the processing and control algorithm associated to the RFID system run on the interface controller itself. The main function of this system is as follows.

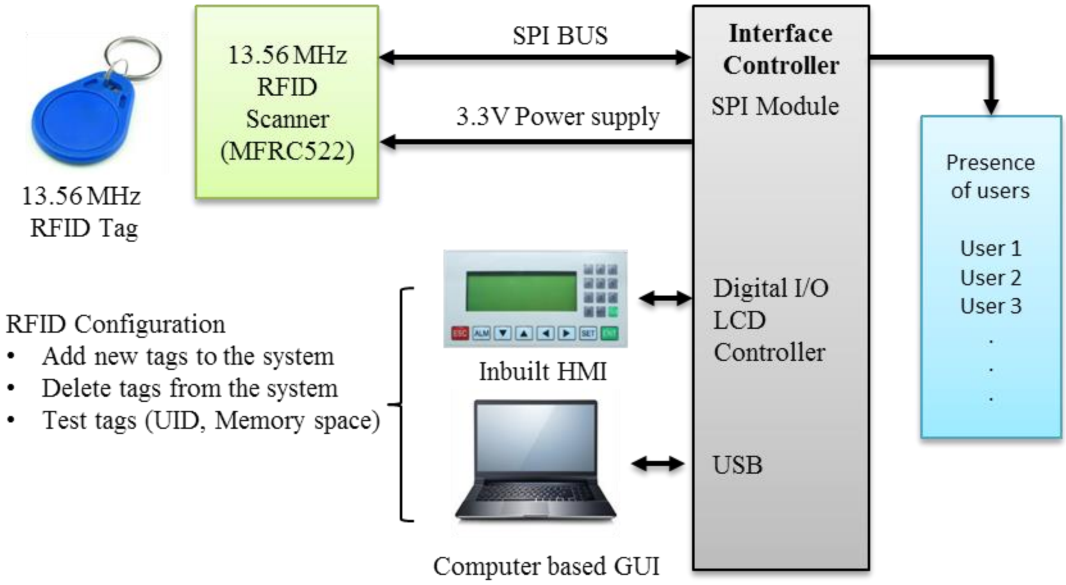


Figure 4.19: System layout of RFID based user identification system

1. User need to put their tag in front of the scanner (located at the front panel of the central controller)
2. Scanner read the tag and detects the tag UID.
3. RFID controller compares the detected UID with pre-installed UIDs in the system
4. If the detected UID matches with a pre- installed UID, then identify the specific user assigned with the UID.
5. Toggle the user states as Entered or Leave and display the result trough the inbuilt HMI display. If the obtained result is wrong, then user can scan the tag again to toggle the result.

6. Finally updates the RFID user identification results registers (this registers can be read from different control algorithms as discussed in the next sections)

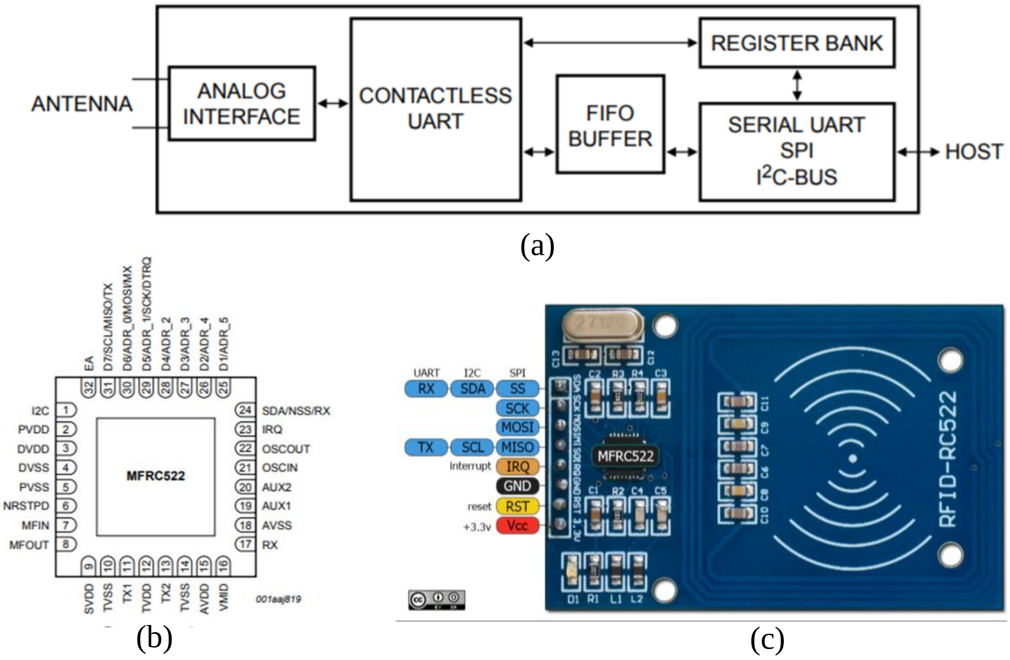


Figure 4.20: (a) Simplified block diagram of the MFRC522 (b) Pinning configuration HVQFN32 package of MFRC522 (c) MFRC522 based RFID scanner module with PCB

Addition to the basic operation, this system includes configuration setup for tag initialization. For this task a computer based GUI and an inbuilt HMI application was developed. Using these interfaces the RFID tags can be initialized and assigned for the specific users and manage RFID database as required as shown in Figure 4.21.

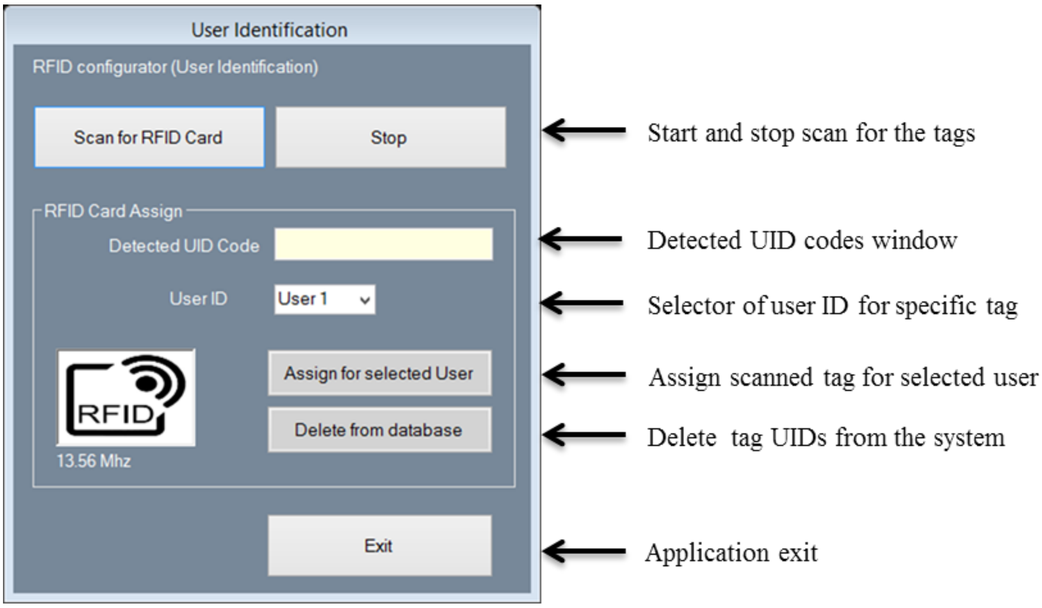


Figure 4.21: Developed computer based GUI for RFID system configurations

4.2.3.3 Human Machine Interface based Occupancy Identification

Human Machine Interface HMI is a user control interface which operates as a dashboard to connect users to a machine system or a device in automation systems. Typical HMI system contains numeric or character displays or advanced graphical monitors to show the system information to the user and function buttons, numeric or character keys or touch panels to feed user command to the system.

According to the proposed deign of IHAS, the central controller can be setup to control the entire home appliances directly through the controller. Therefore a HMI was develop for IHAS controller. The developed HMI has a LCD numeric display and 16-key key pad which directly connects with interface controller as shown in Figure 4.22. The LCD and keypad was mounted on front panel of the IHAS central controller. This interface can be used for control the home appliance which are connected to the central controller and monitor the system parameters such as sensors values and states. Figure 4.23 shows developed inbuilt HMI mounted on front of the central controller.

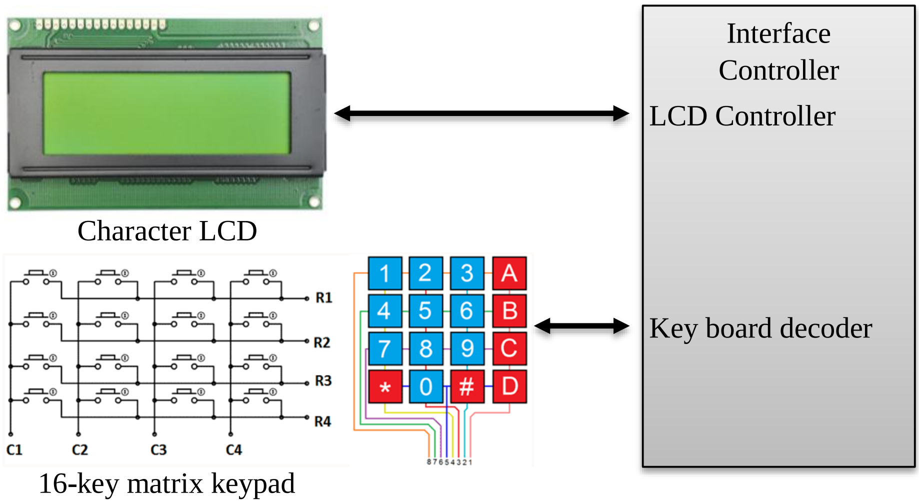


Figure 4.22: Configuration layout of inbuilt HMI of the IHAS central controller

Figure 4.23: Developed inbuilt HMI on front of the IHAS central controller

4.2.3.4 Non-contact Infra-red Temperature Measurement based Occupancy Identification and Localization System

The non-contact occupancy identification and localization system is a non-interactive occupant identification system which is used to identify the presence of occupants in a specific location. Compared with other discussed occupant identification and localizing sensor systems, this system has the capability to accurately identify the presence and present location of the single or multiple users as a live body in real-time.

Infrared energy band is a unique and identifiable region in the electromagnetic spectrum, which also comprises with radiation types such as radio waves, micro waves, tetra hertz waves, a narrow region of visible light, ultraviolet, x-rays, gamma rays. All these different types of radiations are distinguished by their wavelengths (or frequencies). Typically every object emits a noticeable amount of black body radiation depending on their temperature. When Objects have significantly high temperatures, they emit infrared radiation as blackbody radiation.

PIR Sensor

The first task is to select a suitable sensor system to measure the IR radiations. A passive infrared sensor (PIR sensor) is an electronic sensor that detect infrared (IR) radiation from objects in its field of view. These sensors most often used in PIR motion detection systems due to its operation and simplicity.

A PIR-based motion detector is used to sense movement of people, animals, or other objects. They are commonly used in burglar alarms and automatically-activated lighting systems as shown in Figure 4.24. But this sensor has significant drawbacks in couple of behaviours. Since having approximately 150 degrees of field of view this sensor cannot be used to identify the exact location of the occupant presence. And the second drawback is in motion detection, as this sensor can only identify moving heat objects. It cannot be used to identify a stationary thermal source or a stationary person.

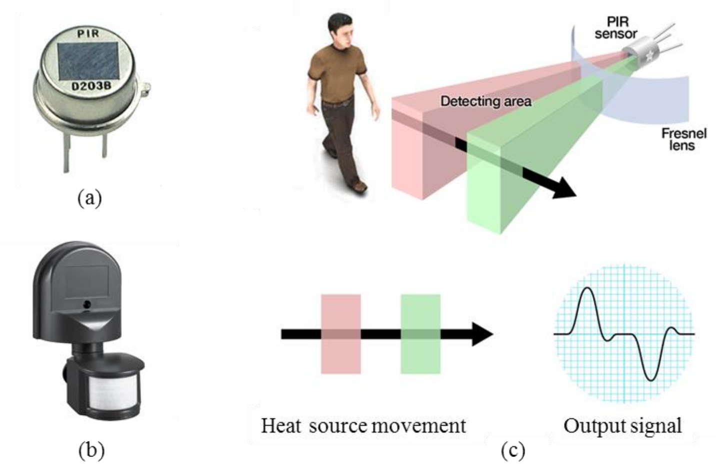


Figure 4.24: PIR motion detector system (a) PIR sensor element (b) Commercially available PIR based motion detection system (c) working principle of PIR sensor

IR Thermopile Sensor

When a closed circuit composed of two dissimilar materials and their joining ends are maintained at different temperatures, the generated currents can be described by the Seebeck effect. This effect is more often describes the operation of wire type thermocouples in temperature measurements. The thermopiles or thermocolumn are composed of an array of thermoelements, each element is a thin wire made out of two materials having different thermal behaviors. In a situation where a temperature difference arises between the two ends of a wire, an electrical tension also known as thermotension develops. The hot junctions are placed on a thin common absorbing area, while the cold junctions are placed on a surrounding heat sink having high thermal mass. Thermopiles are designed to measure temperature from a distance by detecting an object's infrared (IR) energy. The higher the temperature, the more IR energy is emitted. The thermopile sensing element, composed of small thermocouples on a silicon chip, absorb the energy and produce an output signal which related to the temperature of the detected object. Figure 4.25 shows the image of commercially available thermopile sensors.

(a) (b)

Figure 4.25: IR Thermopile sensor (a) Thermopile sensor element (b) PCB mounted thermopile sensor module

Compared to the PIR sensors thermopile sensor has advantages to take the accurate temperature measurements on detected objects and it can be used to detect the stationary and moving heat body based on the temperature changes on the field of view. However, when localization is important, then it needs to arrange multiple thermopile sensors in an array in order to identify the location of the heating body in a certain space.

MEMS-based IR Thermal Array Sensors

The IR thermal array sensors are multiple thermopile sensor arrays as pixels developed on compact SMD package including all the electronics and digital interface circuitry using MEMS technology. Nowadays, the commercially available MEMS IR thermal sensors have 8 to 2048 thermopile elements in a 4×4, 8×1, 8×8, 24×32 grid formats that detect absolute surface temperature without any contact. Figure 4.26 and Figure 4.27 show the MEMS design of two different commercial sensors.

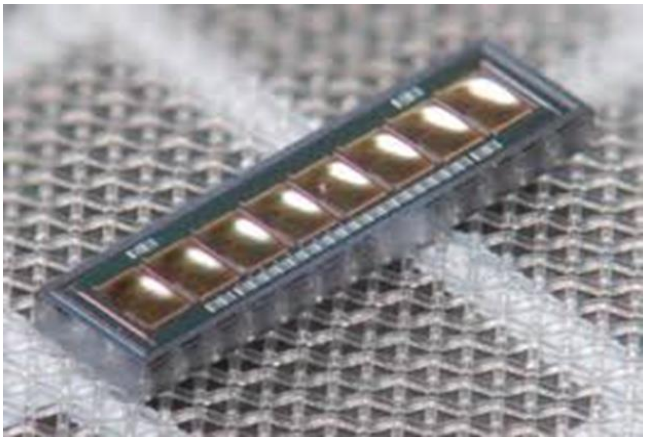


Figure 4.26: MEMS design of 8x1 thermopile sensor array of Omron D6T thermal array sensor

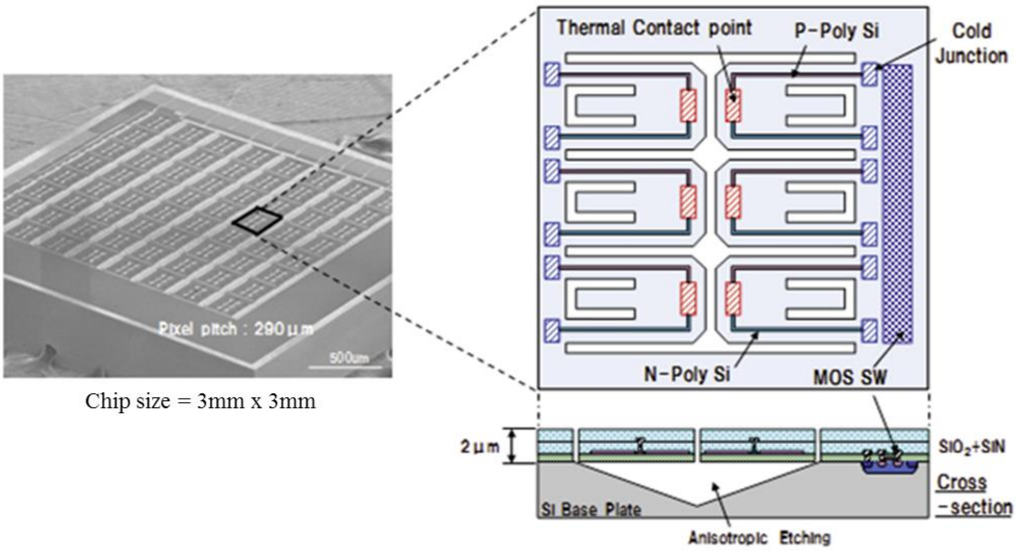
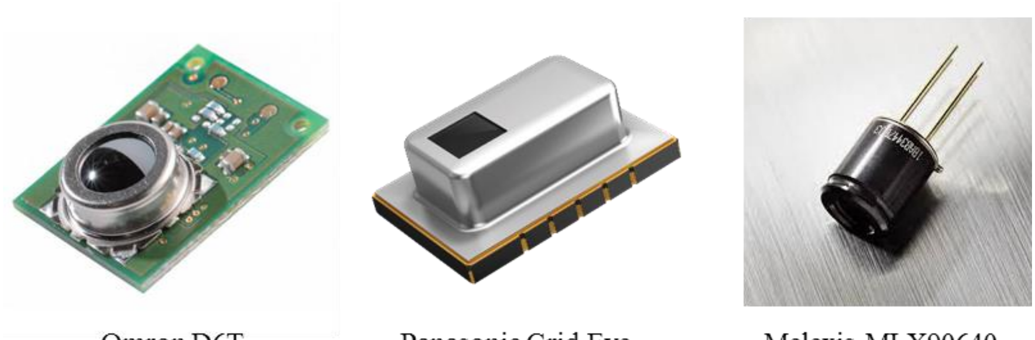


Figure 4.27: MEMS design of 8x8 thermopile sensor array of Panasonic Grid Eye thermal array sensor.



Omron D6T
8x1/ 4x4

Panasonic Grid Eye
8x8

Melexis MLX90640
32x24

Figure 4.28: Commercially available IR thermal array sensors

Figure 4.28 shows the different types of thermal array sensor available in the market. Compared to the drawbacks of previous sensors related to the occupancy identification and localization the IR thermal array sensor was selected for the implementation of the occupancy identification and localization system of the IHAS.

Development of MEMS IR Thermal Array Sensor based Occupancy Identification and Localization System

The next task is to develop the prototype for the proposed occupancy identification and localization system using a MEMS IR thermal sensor.

According to the previous discussion, it showed the availability of different types of MEMS-based thermal array sensors in the commercial market. But due to the import-export regulations operate at the developing time some sensors are restricted to import to Sri Lanka due to the 9 Hz of maximum frame rate limit.

Omron D6T is a MEMS IR thermal array sensor which has (4 x 4) and (8 x 1) array configuration with 44.2^0- 45.7^0 and 54.5^0 5.5^0 of field of views respectively. This sensor has 0 to 50 Celsius measuring range with ±1.5 Celsius of accuracy. It has 4Hz of maximum sample rate and 100 kHz I^2C digital communication interface to communicate with host microcontroller. By considering the field of view and pixel configuration (8 x 1) linear array sensor was selected to implement this prototype. Figure 4.29 shows details of the field of view of the selected sensor module.

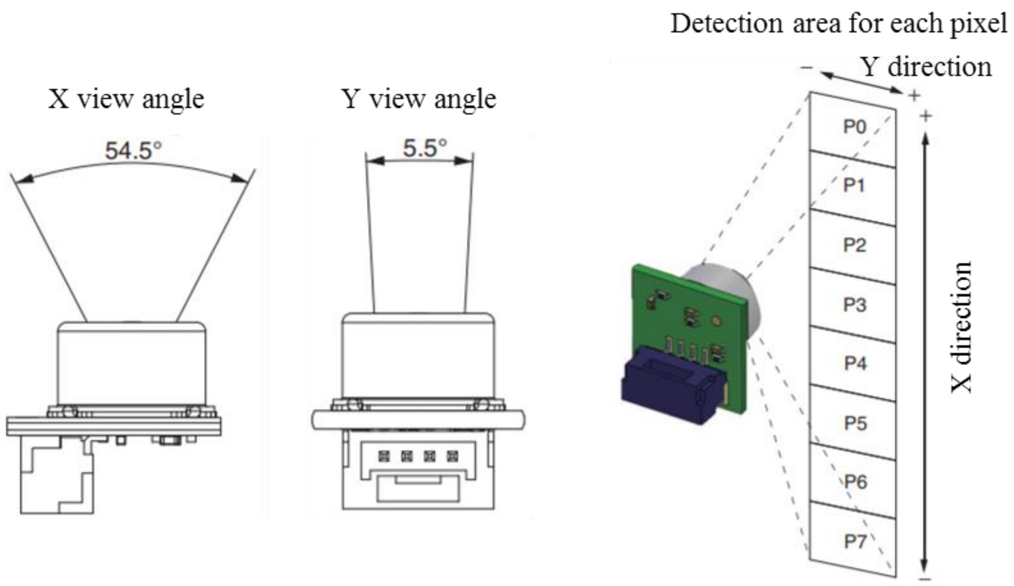


Figure 4.29: Operating field of view of Omron D6T-8L-09 IR thermal sensor

This sensor module is one of the external sensor modules which has to locate in a specific location to identify the occupants properly. As an example, if the IR sensor has a larger number of pixel counts as 8 x 8 grid, then this sensor can locate in the middle of the ceiling to detect the occupants in the square shape room as shown in Figure 4.30. Therefore this sensor system was designed as a wireless sensor module to increase the flexibility in the system integration.

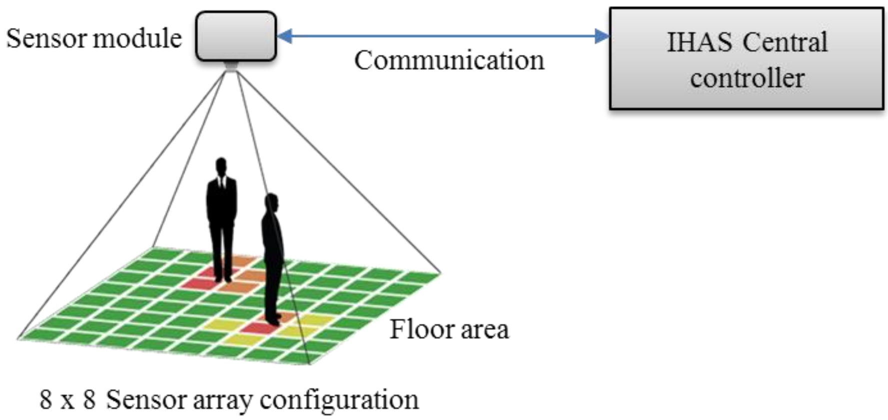


Figure 4.30: 8 x 8 sensor configuration for identify the occupants in typical living premises.

As the hardware specification of the Omron sensor module, I2C compatible 8 Bit microcontroller was used to implement the hardware platform and firmware of the occupant identification algorithm. A radio communication module was used to make communication link with central controller as shown in the block diagram in Figure 4.31. Finally assembled all the circuitry components in a plastic enclosure as shown in Figure 4.32 and 4.33 to protect the vulnerable components from physical hazards. Figure 4.34 shows the detection range and the pixel map of the developed prototype.

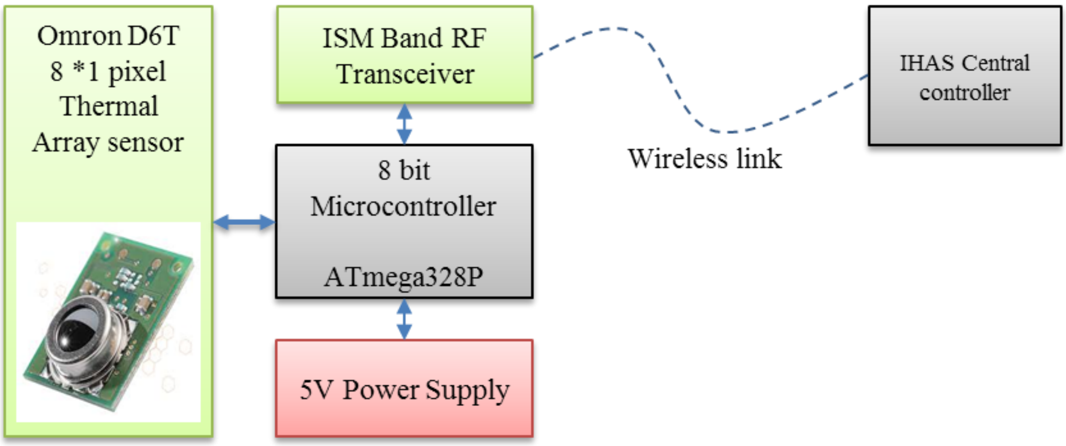


Figure 4.31: Block diagram of MEMS IR thermal array sensor based occupancy identification and localization system

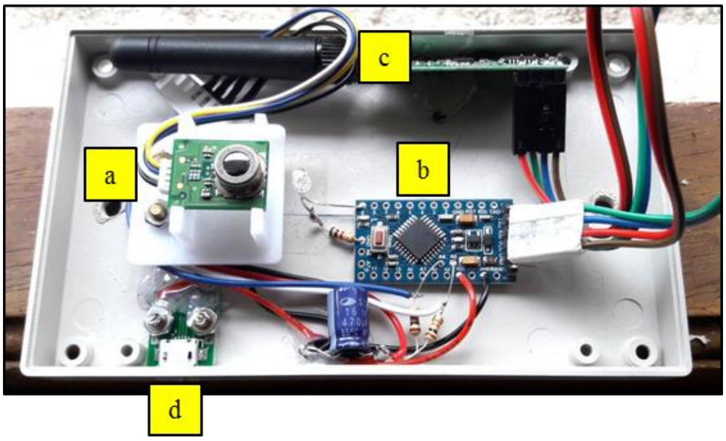


Figure 4.32: Image of circuit assembly of the occupancy identification and localization system (a) Omron D6T sensor (b) Microcontroller (c) RF radio transceiver (d) 5V power supply connector

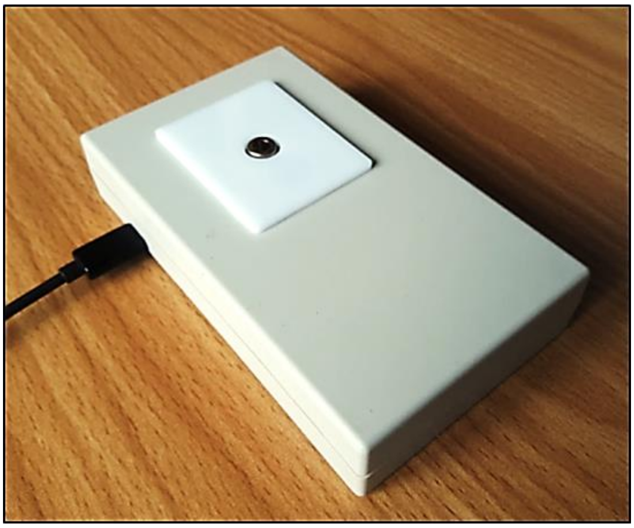


Figure 4.33: Image of the developed prototype of occupancy identification and localization system

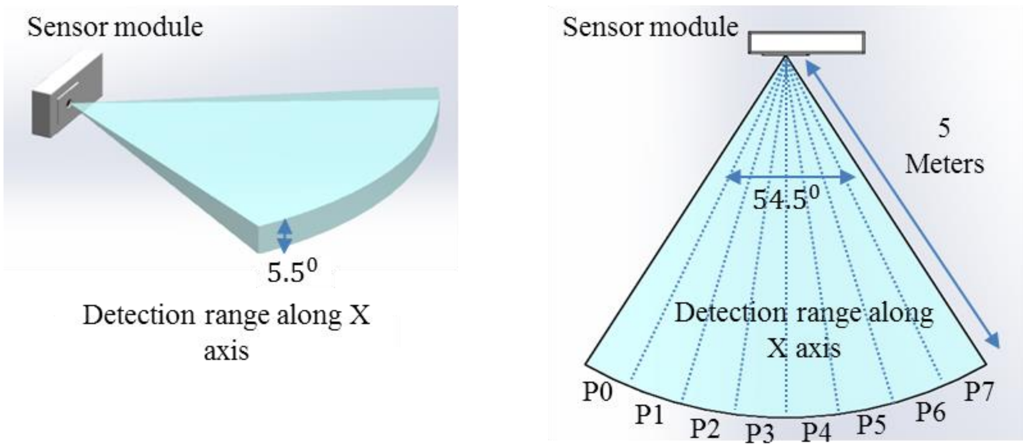


Figure 4.34: Detection range and pixel map of the developed prototype of occupancy identification and localization system

The next task is to implement a firmware on the microcontroller to read the sensor module. As an initial task, a program was developed to read the sensor values through the I^2C communication bus and tested the developed program by placing heat objects in front of the sensor away from a one-meter distance. The sensor measured the eight temperature values related to the P0 to P7 pixels and one additional measurement reference to the sensor body temperature as described in the datasheet in appendix. Figure 4.35 shows the compression of measured temperature reading of D6T sensor compared to the standard handheld thermocouple measuring system.

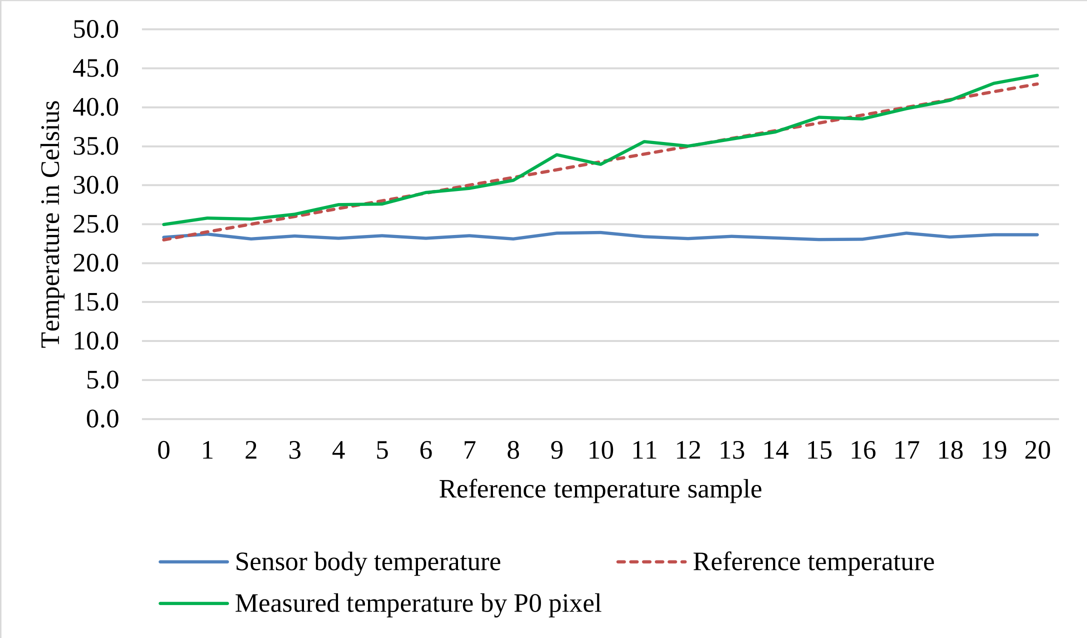


Figure 4.35: Compression of measured temperature reading of D6T sensor compared to the standard thermocouple measuring system.

Implementation of Occupancy Identification Algorithm

The occupancy identification algorithm is based on the numeric comparator. At the normal condition, the human body temperature considered as 37 degree Celsius. Often, this temperature level is above the normal room temperature. Based on that, by identifying the surface temperature values (a pixel value) in a specific location and comparing this value with s threshold value related to the average room temperature, it is possible to detect the presence of heat object or a live body at the particular location. By doing the same procedure for the entire pixel grid of the sensor, the occupancy identification system was implemented which can be used to detect human presence and localize details related to the sensor mounting location. Figure 4.36 shows the block diagram of the implemented occupancy identification algorithm in the microcontroller. According to the block diagram, initially the microcontroller read the temperature of a pixel and then compare with a predefined temperature value which is obtained by the initialization to determine whether the read temperature is above the threshold temperature or not. Which indicates the temperature changes in a particular location and it will identify as the presence of a person by the system. The initialization is very important and according to the installed location of the sensor, the default environment temperature values of each pixel recorded as default temperatures. Then this value is modified by adding some offset value in order to obtain the individual thresholds for each pixel. The threshold values define the sensitivity of the system.

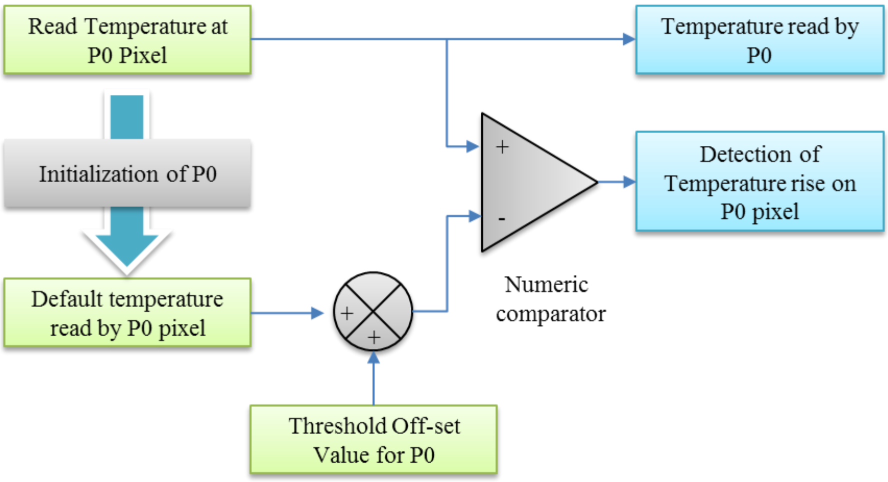


Figure 4.36: The graphical representation of occupancy detecting algorithm of a single pixel of the thermal sensor array

Finally, a computer-based GUI was implemented to control all the system parameters and visualize the system operation as shown in Figure 4.37. The application can visualize all the measuring parameters such as pixel temperature values sensor body temperature on the numeric displays and 2D thermal distribution displays. Figure 4.38 shows the testing results of the system in a real application.

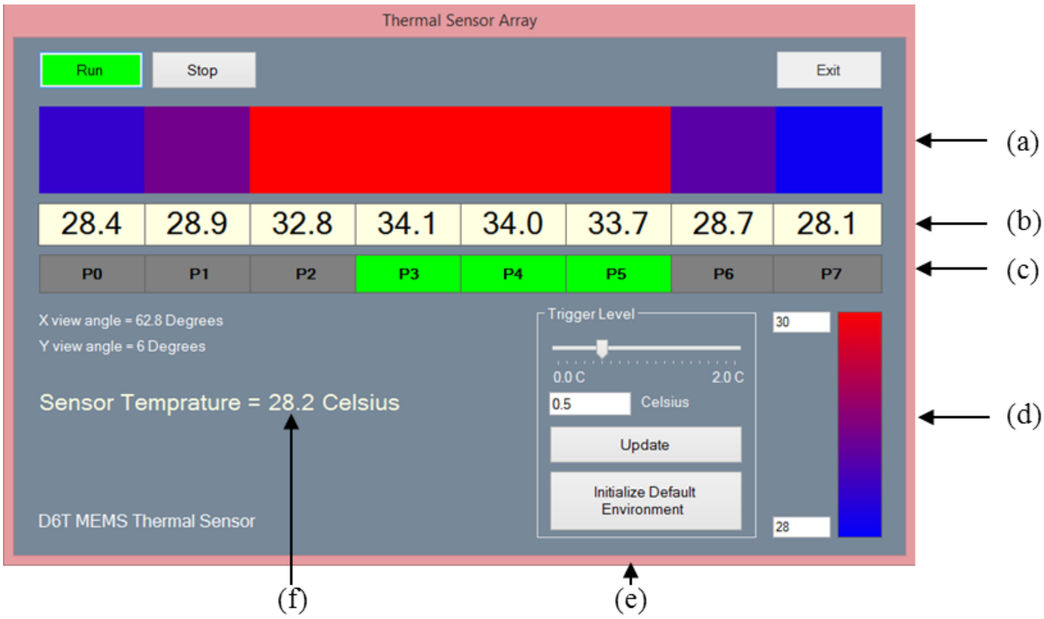


Figure 4.37: The developed GUI of occupancy identification and localization system

(a) 2D thermal distribution displays (b) numeric displays of the pixel temperatures

(c) Detection outputs (Green: detect, Gray: Not detect)

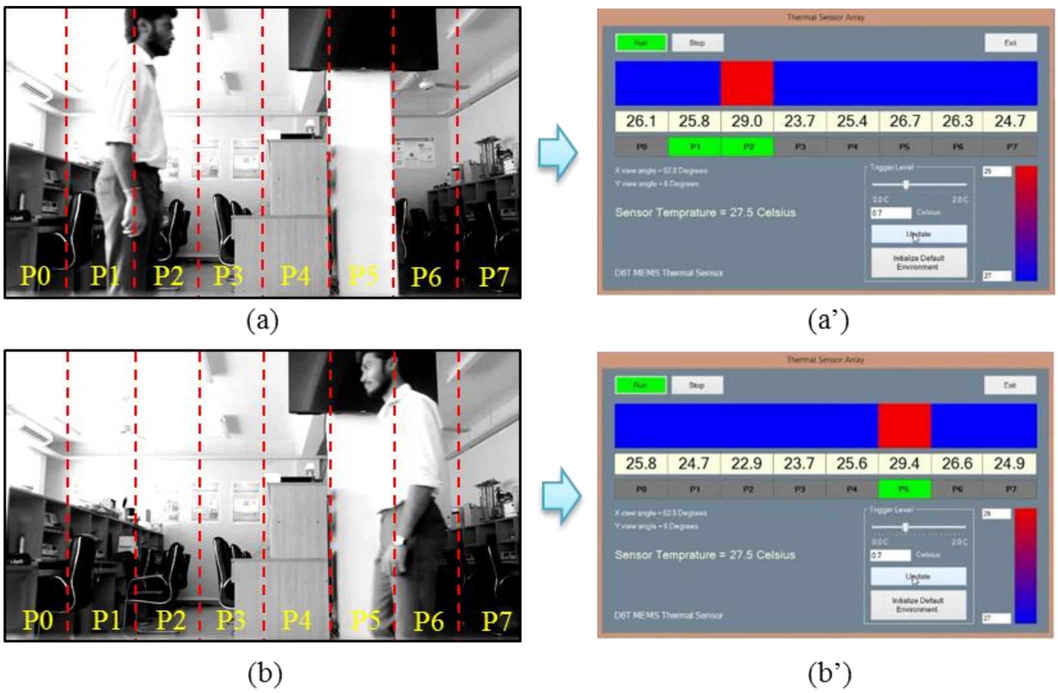


Figure 4.38: Testing results of the developed occupancy identification and localization system

(a) and (b) are the actual images reference to the thermal sensor field of view

4.2.4 Smart Energy Monitoring System

4.2.4.1 Introduction

Electrical energy is the most convenient and controllable form of energy which use in residential buildings to operate building appliances. Electricity is the secondary energy source which generates by primary energy sources such as renewable energy sources (wind power, hydro power, solar power, geothermal), fossil fuel (coal, natural gas and oil) and nuclear power.

Energy monitoring system is a measuring system which has hardware and software systems that indicates the energy usage or consumption in a particular location. In the buildings which are powered by the external electricity source have energy meters. These measuring systems are used for the tariff purpose and measure the overall building energy consumption for a given period or consumption at different time slots during a given period.

Nowadays unit costs of the energy are going to go up and clean energy is too expensive and unreliable for the supply side. Since energy is a critical and important factor of the operating expenses as well as the climatic impact, there are many ongoing research conducting to develop smart and intelligent energy measurement systems for the buildings. And some of the energy monitoring systems are already available in the market as IOT enabled smart energy measuring systems. These systems facilitate to monitor the energy consumption through the appliances and present all details via the mobile phone or tablet application through the internet. Using this kind of systems, the users will be able to know all the information regarding the energy usage in their own building time to time. It helps to make a self-motivation for the users to improve the energy utilization.

IHAS is a home automation system developed to improve the user comfort while enhancing the energy performance. In this research, it has some control applications and control algorithms which are focused on improving the energy utilization. Therefore this research needs an energy monitoring system for system validation of the implemented systems on energy performance including some improved features related to the research applications.

Apart from the energy monitoring facilities, the load device identification is a main focused and identified area to implement in the energy monitoring system. The objective of this system is to identify the active load devices in a particular location and central controller is allowed to know about those loads. Using this information the central controller can make usage report for individual appliances and give attention when these appliances are active. As an example, if the steam iron was switched on the central controller detect this event and switching on a temporary timer. If this appliance is active for an unusual time, then the central controller makes an alarm for users for this event to avoid the unnecessary energy drainage and make the environment safe as shown in Figure 4.39.

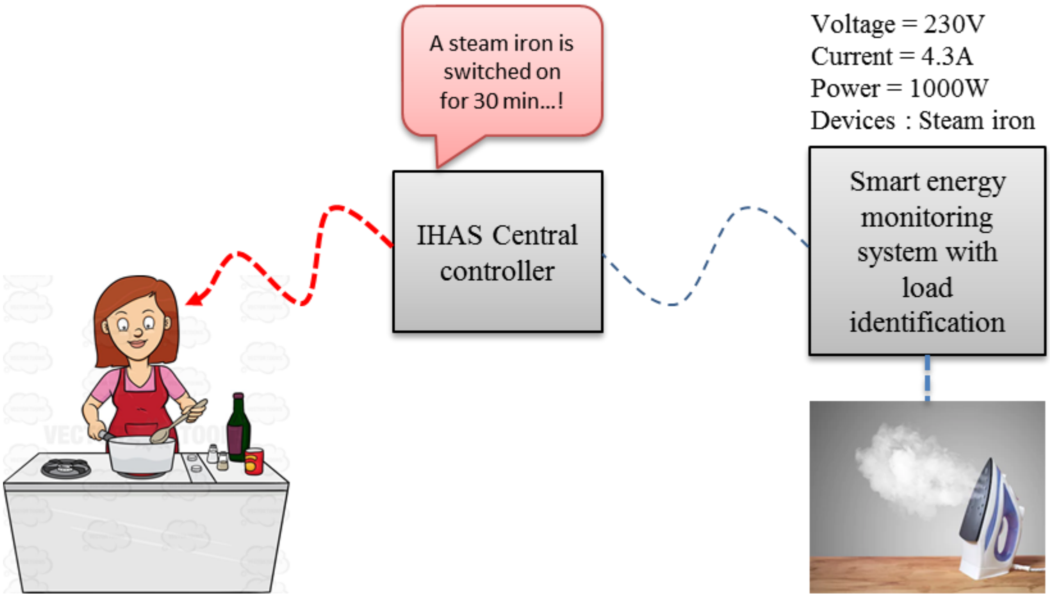


Figure 4.39: System configuration and application of smart energy monitoring system with load identification

Considering these factors, a smart energy monitoring system with load identification was designed for IHAS to use as a part of the sensory system.

4.2.4.2 Development of Smart Energy Monitoring System with Load Identification

Next task is to develop a prototype for smart energy meter. Before going to the prototype design it is essential to identify the key factors which are needed to be addressed in this implementation based on the application of the IHAS [46] [47] [48].

According to the structure of the electrical distribution system of an existing residential building, the main electrical supply is divided to several low current loops (approximately 5A and 13A) from the distribution board. Generally, these loops are allocated to particular areas in the building. Therefore the energy measuring system has the capacity to take measurements on multiple power channels to takes the accurate measurement on the distribution of the building [49].

When measuring an alternative signal, it is important to convert measuring signal into the form of direct current signal of which is equivalent or called as Root Mean Square (RMS) value. Most of the basic alternative signal measuring systems used mathematical correction to obtain RMS value of the measuring signal by considering measuring signal as pure sinusoidal. But according to the shape of signal due to the distortion or offsets the measurements will be inaccurate.

Apart from the basic resistive and inductive loads such as electric heating appliances, induction motors etc., most of the loads used in the residential buildings are nonlinear loads, which are producing the distorted non sinusoidal waves at current input. As a solution for this, the true RMS conversion method can be used in the measuring system to obtain an accurate measurements on both sinusoidal and non-sinusoidal inputs to the system. When developing the digital true RMS measuring system, the measuring accuracy is influenced by some factors such as the performance of the voltage and current sensors, ADC (Analog to Digital Converter) resolution and sampling rate, properties of algorithms adapted to compute energy, type of arithmetic computation adapted and the performance of the analog electronics [50] [51]. Considering these aspects a hardware prototype was designed to implement the digital energy meter based on a DSC microcontroller which is having sufficient computational power and data acquisition features as shown in the Figure 4.40. This system was design as a four channel energy measuring system which includes four true RMS current measuring and single true RMS voltage measuring system to calculate the apparent power and energy consumption in four load channels which are operated in a single phase power distribution system.

Finally, a load identification system was implemented. Some research has been shown that the load devices identification can be done by analyzing the current waveform of the system under the load current magnitude, shape, pulse duration and mixed. In the current magnitude analyzing method, first, the system needs to identify the current rating of the specific devices. This is done by a teaching program. At the operation, the system matches these values with the electric current reading to identify the single or multiple appliances operates in the specific area [52] [53].

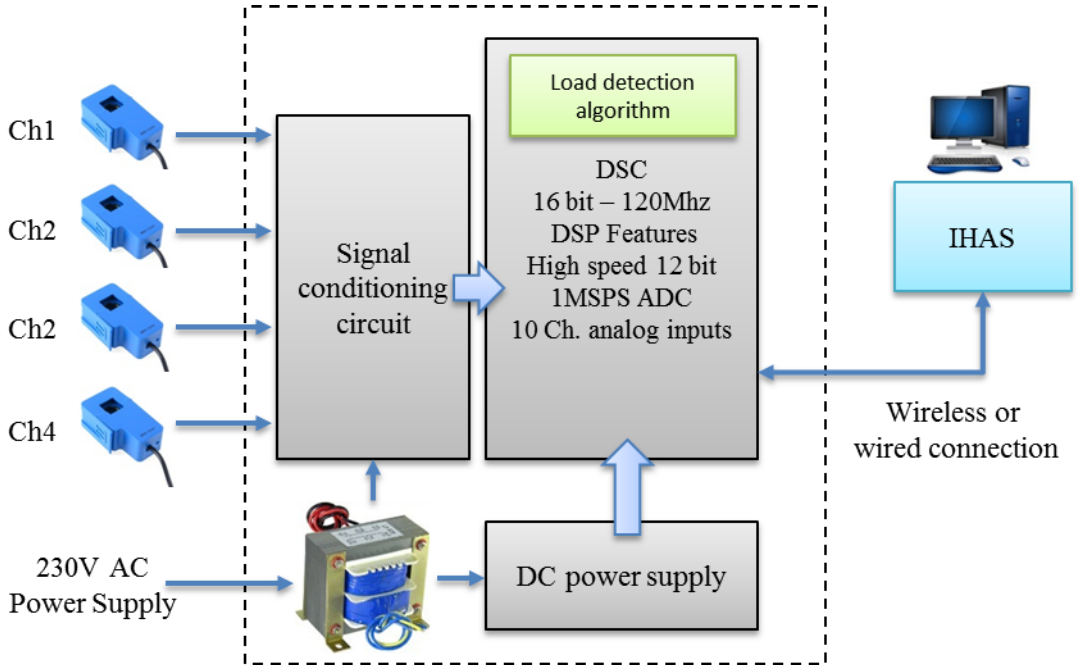


Figure 4.40: Block diagram of proposed design of energy monitoring system

The current magnitude analyzing method was selected to implement the system. This method is simple to implement and it can be accurately operated if the load devices have different current ratings in a wider range.

Apparent power can be calculated by taking the product of RMS value of voltage and RMS value of current. During electricity billing process the apparent power is taken into account. The proposed energy measuring system has two types of sensor systems which are used to measure the RMS voltage and RMS currents flowing through the different channels. Finally based on the RMS voltage and currents reading the apparent power and energy consumption will be calculated.

Current transformers or CTs are a type of isolated sensors which can be used to measure current on AC circuits. CTs measure the AC current in a conductor by a magnetically induced current within the CT which is proportional to the conductor AC current.

Current transformers can be categorized into the main two types as solid core CTs and split core CTs. Solid core CTs comparatively less expensive and accurate. But during the installation solid core CT need to disconnect the measuring conductor and get it through the CT core. Split core CTs have a fragmented core that allows the CTs to place around the measuring conductor without doing any interrupt to the wiring. Split core CTs are comparatively expensive but easy to use in measurements.

Based on the installation facilities, the split core current transformers were selected as current measuring elements of the proposed system. The selected current transformer has 30A maximum current measuring range with an inbuilt burden resistor which converters the induced current signal to the voltage signal itself. The manufacturer details of the selected sensor is shown in Figure 4.41.

After selecting a current measuring sensor, then an interface circuit was developed to connect the CTs to the ADC input of the microcontroller as shown in Figure 4.42. According to the developed circuit, R3 and R4 are the equal resistors which are used as a voltage divider to make 2.5V of fixed biased voltage for the CTs as shown in Figure 4.42.

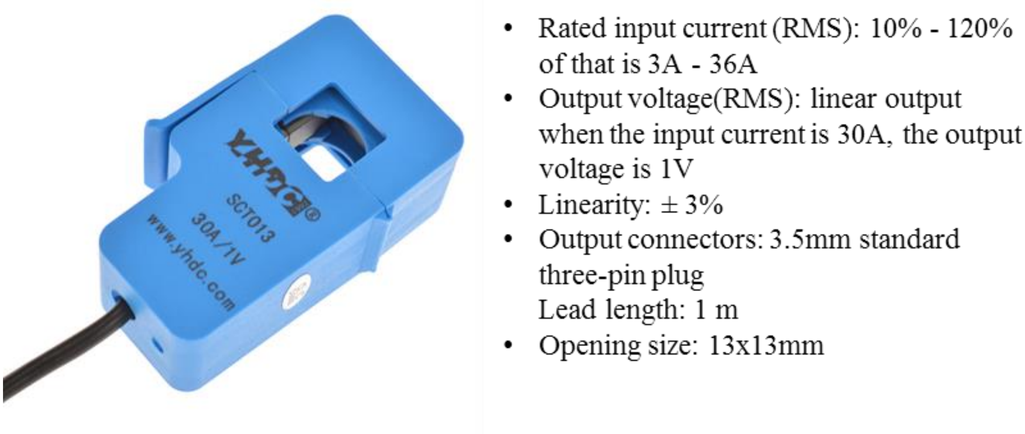


Figure 4.41: Selected split type current transformer with manufacture details

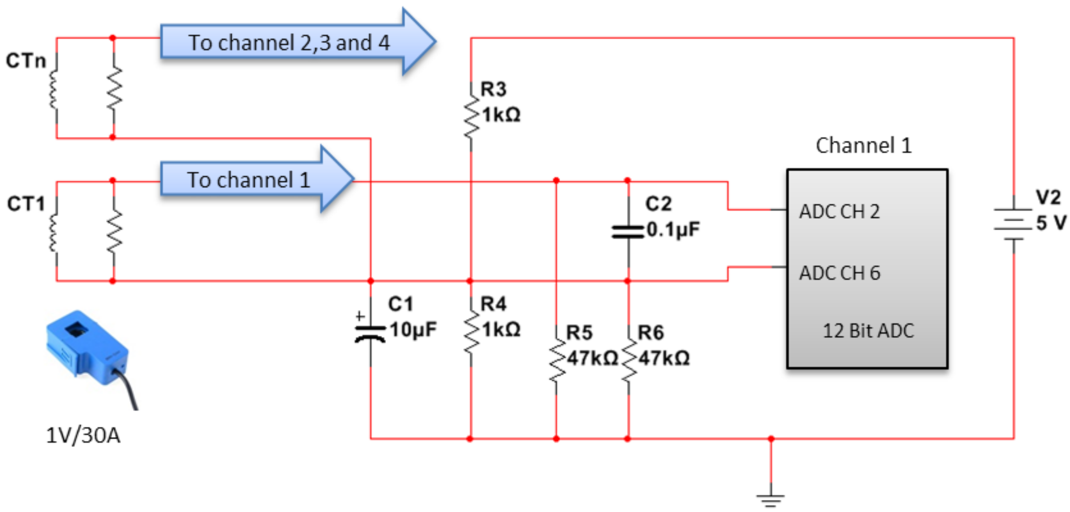


Figure 4.42: Schematic diagram of implemented current transformer interface circuit

The bias voltage converts the AC voltage coming from the CTs to the variable DC voltage level in the range of ADC can measure. As an example when CT measure the $30A_{(RMS)}$ of current from the load, then it will produce $1V_{(RMS)}$ AC voltage in between the sensor terminal. Which is equal to 2.8284 $V_{(PP)}$ of signal floating in a range of +1.4142V and -1.4142V. But according to the electrical specification of the microcontroller, the ADC module cannot be used to read the reverse voltages in below the 0V and the allowable reverse voltage is Vss - 0.3V. The use of a positive bias voltage is possible as it will avoid negative voltage levels of the measuring source by offsetting the zero voltage level. According to the developed circuit, the +1.4142V to -1.4142V of the input voltage is offset by the 2.5V of positive voltage. Then it results to converts sensor output voltages to the 3.9142V to 1.0858V voltage which are in the ADC measuring range. C1 is a smoothing capacitor for the voltage divider and C2 is a low pass filter capacitor. Each CTs connect to the ADC module trough four different ADC channels as CH2, CH3, CH4 and CH5 and the bias voltage is connected to the CH6. During the current calculating program, the microcontroller read the sensor voltages levels reference to the bias voltage and it will removes the bias voltages from the ADC readings.

The next measurement is for the supply voltage. The voltage measuring system is based on a step-down transformer which is having 230V to 12V voltage ratio. The interface circuit is the same as the current transformer interface discussed previously. But apart from the previous circuit, this circuit has additional voltage divider (R1 and R2) for scale down the transformer output voltage in 1/12 ratio as shown in Figure 4.43. This is due to the voltage limit of the ADC. The voltage measuring system has two electric signals to be measured as transformer output voltage and bias voltage. The CH1 is used to measure the DC bias voltage and CH 0 is used to measure the transformer voltage level reference to the bias voltage level.

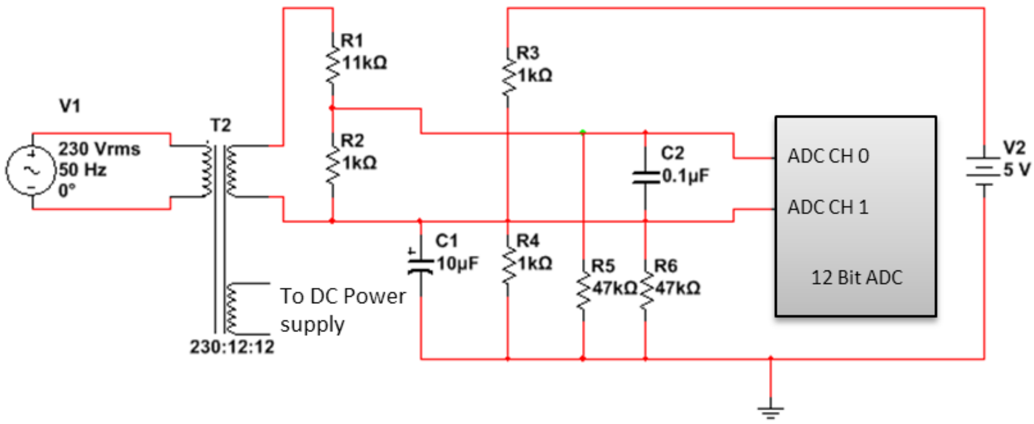


Figure 4.43: Schematic diagram of implemented potential transformer (voltage transformer) interface circuit

After completing the sensor interface circuitry for the current transformers and potential transformers the next task is to develop an algorithm to obtain the $V_{(RMS)}$ values of the sensor outputs by commuting the quantized voltage samples from the ADC module.

The selected DSC controller dsPIC30F4013 has 12bit SAR (Successive Approximation) Analog to digital converter which can be operated up to the 1 Mega samples per second (MSPS) of sampling speed at the rated conditions. The sampling rate or quantization speed and ADC resolution are the important factors which are directly related to the measuring accuracy. According to the literature, it has shown that 100 samples per cycle (5 kHz of sampling frequency for 50Hz of supply) with 12 bit of resolution is accepted for implement true RMS voltage measuring system with up to ±1% of accuracy.

The magnitude of an AC signal can be elaborated by its Root Mean Square (RMS) value. It can be defined as the equivalent Direct Current (DC) required to generate equal amount of heat dissipation across a load, as the AC signal applied to the same load.

The RMS value of a continuous signal V (t) is defined in Equation 4.3.

$$V_{(RMS)} = \sqrt{\frac{1}{T}\int_0^T V^2\ (t)dt} \quad (4.3)$$

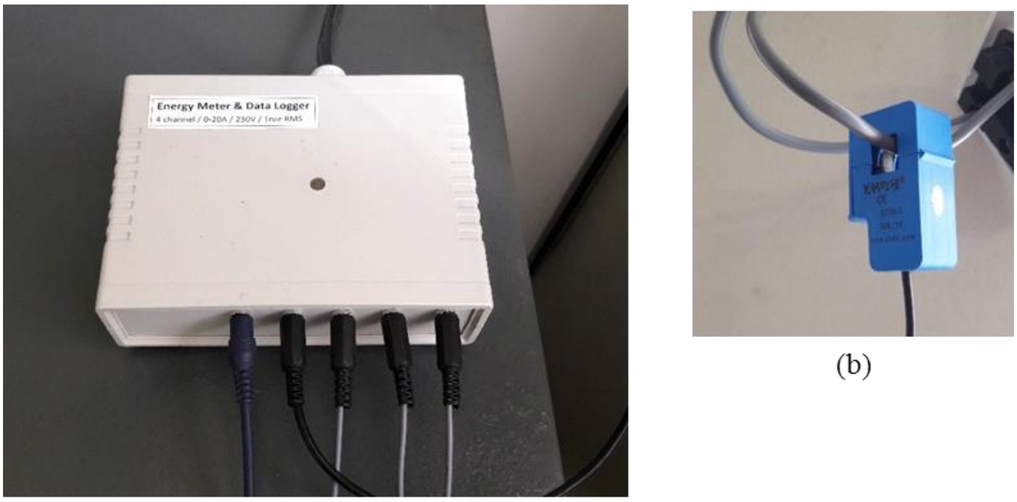
For time sampling signals, RMS calculation involves squaring the signal, taking the average, and obtaining the square root as Equation 4.4.

$$V_{(RMS)} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} V^2(i)} \quad (4.4)$$

In the calculating program initially the DSC microcontroller identify the start point of the negative or positive half of the measuring waveform by comparing the measuring waveform with the bias voltage and then take the voltage measurements on both reference and measuring waveform at 5 kHz of sampling speed for 10 milliseconds or 50 samples. While taking the samples the controller is squaring the read voltage value and add into the temporary register. After completing the sample period or sample count for one half it will take the average of summation and obtaining the square root as $V_{(RMS)}$ as the Equation 4.4. The same procedure applies to the other inputs and finally, the RMS calculated signal voltages scaled and converted into the supply voltage and currents according to the convention factors of the sensors. The obtained

RMS current values are analysed by the load detection algorithm to detect the specific load devices active in the individual current measuring areas.

Finally, a computer-based GUI was implemented as a data logger to observe the real-time energy consumption information and creates an energy report in the form of excel and text files [51]. The energy meter can be connected to the central controller through the ISM band wireless link to monitor the real-time energy consumption information as required [52] [53]. Figure 4.44 shows the developed prototype of four channel smart energy meter based on the DSC controller. Figure 4.45 shows the image of developed computer-based GUI for energy monitoring purpose and Figure 4.46 shows the screen image of generated excel sheet from the developed computer application.



(a) (b)

Figure 4.44: (a) Developed prototype of four channel energy monitoring system (b) Spit type current transformer configuration

Figure 4.45: An image of the developed GUI of energy monitoring system

(a) Data logger settings (b) Voltage indicator (c) Current indicators (d) Power indicator (e) Energy consumption indicators (f) Graphical representation of power consumption details

Time	Ch1 Power	Ch1 Energy	Ch2 Power	Ch2 Energy	Ch3 Power	Ch3 Energy	Ch4 Power	Ch4 Energy
13:56:29	2.91	0.02603	0	0.00018	0	0	2.78	0.02472
13:56:59	2.79	0.04919	3.06	0.01025	0	0	2.64	0.04678
13:57:29	2.91	0.07229	2.81	0.03362	0	0	2.74	0.06938
13:57:59	2.95	0.09591	2.69	0.05654	0	0	2.6	0.0923
13:58:29	2.94	0.11963	2.91	0.08018	0	0	2.65	0.11478
13:58:59	2.73	0.14356	2.7	0.10442	0	0	2.57	0.13692
13:59:29	2.92	0.16677	2.67	0.12683	0	0	2.76	0.15872
13:59:59	2.68	0.19047	2.8	0.15019	0	0	2.59	0.18098
14:00:29	2.88	0.21359	2.7	0.17321	0	0	2.61	0.20358
14:00:59	2.87	0.23668	2.93	0.19693	0	0	2.58	0.22594
14:01:29	2.78	0.26045	2.94	0.22137	0	0	2.58	0.24832
14:01:59	2.88	0.28406	2.76	0.24493	0	0	2.56	0.27076
14:02:29	2.87	0.30756	0.08	0.26018	0	0	2.65	0.29281
14:02:59	0	0.3107	0	0.26023	0	0	2.77	0.31517
14:03:29	0.09	0.31079	0	0.26023	0	0	2.64	0.33707
14:03:59	0	0.31092	0	0.26023	0	0	2.52	0.35915
14:04:29	0	0.31114	0	0.26029	0	0	2.79	0.38144
14:04:59	0	0.31134	0	0.26036	0	0	2.76	0.40369
14:05:29	0	0.31134	0	0.26036	0	0	0	0.40384
14:05:59	0	0.31149	0	0.26036	0	0	0	0.40384
14:06:29	0	0.31155	0	0.26043	0	0	0	0.40384
14:06:59	3.17	0.31453	0	0.26058	0	0	0	0.40391
14:07:29	2.91	0.3396	2.95	0.28224	0	0	0	0.40396
14:07:59	2.93	0.3628	2.7	0.30548	0	0	0.08	0.40404
14:08:29	2.91	0.38716	2.81	0.32938	0	0	2.68	0.42222
14:08:59	2.74	0.41094	2.89	0.35247	0	0	2.48	0.44343
14:09:29	2.94	0.43473	2.95	0.37637	0	0	2.55	0.46554
14:09:59	2.69	0.45834	2.94	0.40003	0	0	2.76	0.48748
14:10:29	2.91	0.48175	2.69	0.42351	0	0	2.78	0.50979
14:10:59	2.8	0.50491	2.89	0.447	0	0	2.75	0.53248
14:11:29	2.84	0.52789	2.8	0.4705	0	0	2.6	0.55487
14:11:59	2.78	0.55099	2.72	0.49387	0	0	2.59	0.57769
14:12:29	2.87	0.57381	2.7	0.51744	0	0	2.7	0.60003
14:12:59	2.8	0.59702	2.85	0.54057	0	0	2.68	0.62241
14:13:29	2.89	0.62014	2.75	0.56375	0	0	2.67	0.64506
14:13:59	2.81	0.64343	2.68	0.58704	0	0	2.74	0.66733

Figure 4.46: An image of the generated energy report in an excel sheet

4.3 Device Control Interface of IHAS

4.3.1 Introduction

After completing the implementation of Multi-sensory system for the IHAS, it enables the IHAS to obtain accurate real-time control decisions for home appliances or device to maintain the comfort and energy efficient environment in a living premises. In this situation, the home appliances are playing an important role to change the environmental factors as user requirements [54]. But in general, the commercially available home appliances or consumer electronic devices don't have the standard control interface for automation purposes. They come from different vendors and for different purposes with own control interfaces such as switch panels, remote controllers. And nowadays the modern devices available with mobile device based GUIs and are controlled trough the Bluetooth or Wi-Fi.

However, the building automation or home automation has been developing since a few decades ago. Therefore some research and developments have been working on to develop building automation standards or protocols which can be integrated to the general building appliances to use in smart automation practices.

BACnet is a widely used communication protocol in building automation and control network compatible with ASHRAE, ANSI, and ISO 16484-5 standard protocol. BACnet was developed to communicate with building appliances including HVAC systems, lighting systems, multimedia systems, safety systems etc. C-Bus is a communications protocol based on a seven-layer OSI model for home and building automation that can handle cable lengths up to 1000 meters using Cat-5 cable. KNX, X10 and Insteon also a building automation protocol developed to use in entire building appliances operate through the twisted pair, power line communication, RF, infrared or Ethernet links in a tree, line or star topology.

As it explained the BACnet, C-Bus, KNX, X10 and Insteon are only the popular example for the building automation protocol. Based on these protocols, recently the specific building appliances have developed such as lighting systems, HVAC systems, multimedia systems etc. to use in building automation application directly.

As an objective of the research, system flexibility and solution for the existing system are the main objectives. And also most of the home appliances and consumer electronics used in general residential buildings don’t have these types of control or network features to implement automation applications. But to make an automation in general residential building through the existing appliances is a challenge. Therefore the device control interface was developed as an external system and can be used to make an interface in between home appliances or devices and IHAS controller.

4.3.2 Teachable IR Remote Controller

As the literature, IR remote control is the best and simple way to control the home appliances through the external device. The teachable remote controller is a device which can be used to operate the entire remote controlled appliances by using a single remote controller. However, when it is used with the automatic controller, it has some advantages as well as disadvantages as follows.

Advantages

- At present, most of the home appliances come with remote controllers. Therefore a universal remote controller can be used to operate most of the appliances installed in premises
- Since the IR remote controller is a wireless device, it does not need hard-wires or any physical infrastructure modification in the premises
- Wider operation functionality and functions

Disadvantages

- No feedbacks
- When it operates under the repeated and hold functions such as volume up/down, the relative states cannot be identified

Since the unavailability of special communication protocols and interfaces with general and existing home appliances, IR remote interface is the only solution to control them via the external controller. Considering these factors, a universal remote controller module was developed as a main appliances interface of the IHAS.

4.3.2.1 Design of Teachable IR Remote Controller for IHAS

IR remote controllers use stream of modulated invisible infrared (IR) light beam that communicate with remote devices. Typical IR based remote control system has main two devises as transmitter and receiver. IR transmitter often an IR LED which is used to emit modulated IR light pattern reference to the information or commands. The IR receiver in the other device capture the transmitted pattern and it will causes the device to respond accordingly the transmitted command.

According to the manufacturer of the devices, IR communication standard can differ. They use different carrier frequencies and different data encoding protocols. As an example NEC code continuous data frames, RC5 code, RC6 code, RCMM, Mitsubishi code 38 kHz, Sony code SIRCS 12 bit, Sony code SIRCS 15 bit, Sony code SIRCS 20 bit, r-map data format 38 kHz, XMP-1, Panasonic/Matsushita command, Sharp data format are some of the IR communication protocols which are used in the different devises. The idea of the universal remote controller is that it can generate the modulated IR remote codes which are related to the specific patterns of different appliances. Based on these factors the design of the universal remote controller can be done in two ways. The First idea is to study and identify the data encoding protocols related to the individual appliances and develop the IR remote controller module to regenerate the required IR codes. This solution isn't simple and not practically possible due to the wide range of available different devices. Another one is to develop a teachable remote controller. The function of the teachable remote controller is that it can copy the IR remote code which is emitted by pressing a button of any type of IR remote controller and it can regenerate the same IR code itself when it is needed as an external command to control appliances. The advantage of this system is that it is not necessary to identify which IR protocol has been used in the device. The system just read and copy the waveform of the IR code to reproduce it.

The developed teachable remote controller is based on an 8-bit microcontroller. It has 38 kHz to 40 kHz tuned IR receiver module to receive encoded IR waveform emitted by handheld remote controllers, when the developed remote controller is in the teachable mode as shown in Figure 4.47.

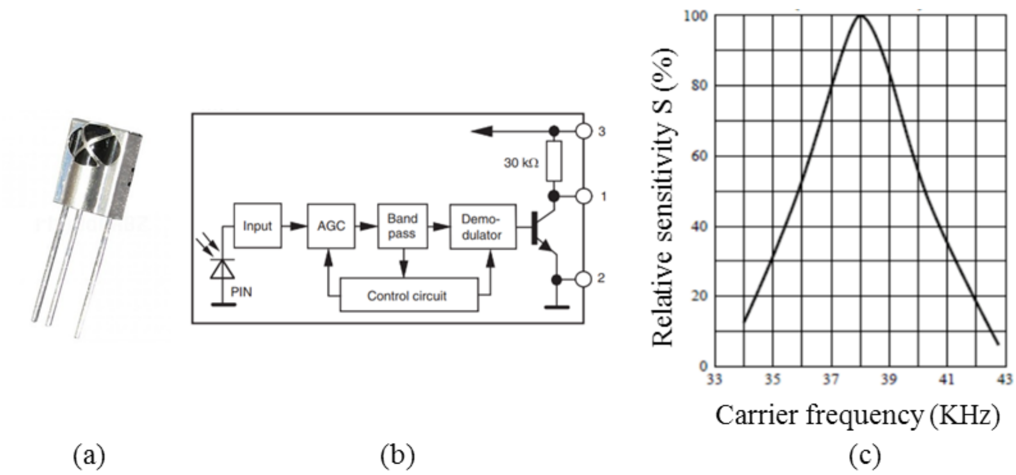


Figure 4.47: IR receiver module (a) TSOP 1738 IR receiver module (b) block diagram of TSOP 1738 module (c) Frequency response curve of TSOP 1738

Figure 4.48 shows the block diagram of the teachable remote controller. The digital logic level of the output waveform is recognized by the microcontroller at 1MHz of sample speed. According to the received waveform, the microcontroller generates an array of integer variables which are having time interval details in between a transition edge of the IR waveform with one microsecond (1us) of time resolution. Since present IR encoding methods are using time resolutions up to 10 us to encode and decode, the IR information with 1 us time resolution of this system helps to improve the capturing and regenerating accuracy of the IR waveform. But it increases the memory usage of the system. Therefore external EEPROM IC which is having 512 KB of memory was integrated to the circuit.

This system was designed to install inside the central controller of IHAS or in an external place as per the requirement. So the control was implemented to control via the UART interface. UART interface facilitates the remote control system to connect with the central controller through wires or through a wireless radio link if it needs to install in an external location. The remote controller has four IR Light Emitting Diodes (LEDs) to convert generated IR waveform to IR rays. Figure 4.49 shows the developed circuit assembly of the remote controller on a PCB.

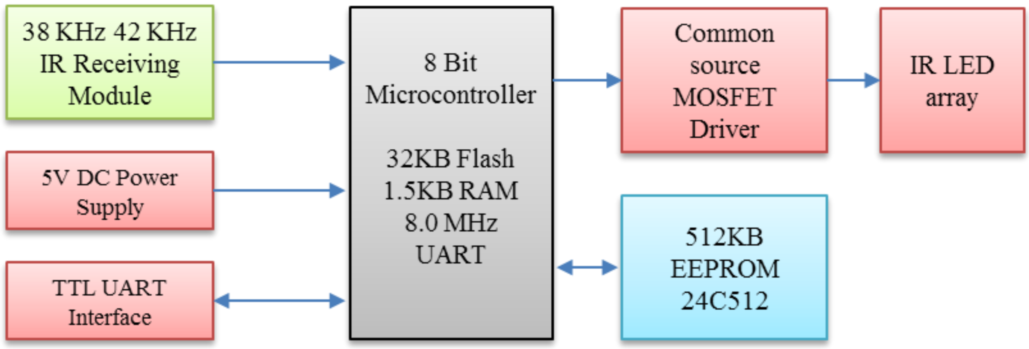


Figure 4.48: Block diagram of teachable remote controller

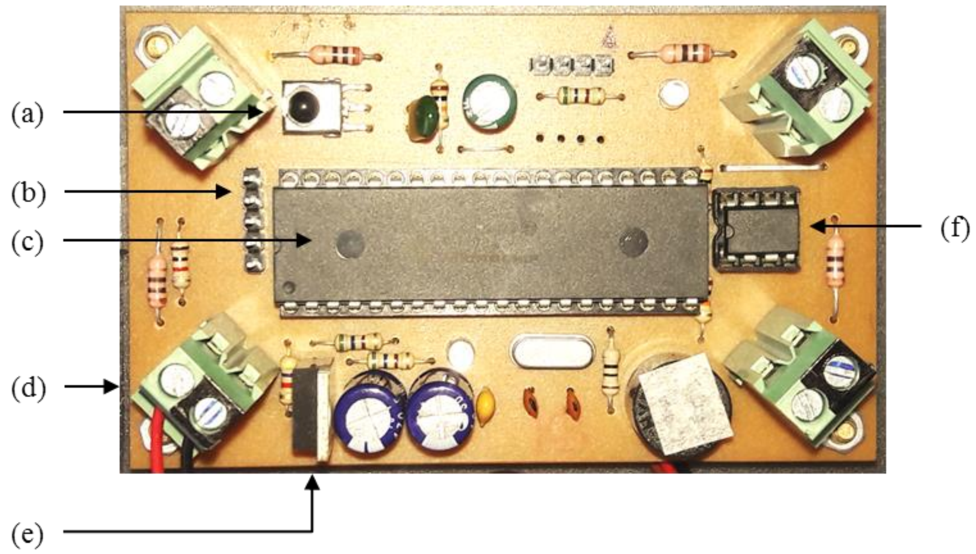


Figure 4.49: Developed circuit of teachable remote controller (a) 38 kHz to 40 kHz IR receiver module (b) TTL UART interface (c) 8 Bit Microcontroller PIC18F452 (d) IR LED connector terminal (e) IR LED driver IRFZ44N (f) External EEPROM Atmel

Finally, a computer-based GUI was implemented to operate the system conveniently as shown in Figure 4.50. The developed GUI has main two section as teaching panel and device panel. The teaching panel can be used to control the IR capturing, testing and assign the captured and tested IR codes to the specific devices defined in the IHAS control system. The device panels show the defined devices in the system and which can be used to test or operate from the developed teachable remote controller. Finally, the developed system was tested for split air conditioners, pedestal fan, television sets, projectors and multimedia system. It has worked in teaching and regenerating of IR commands successfully.

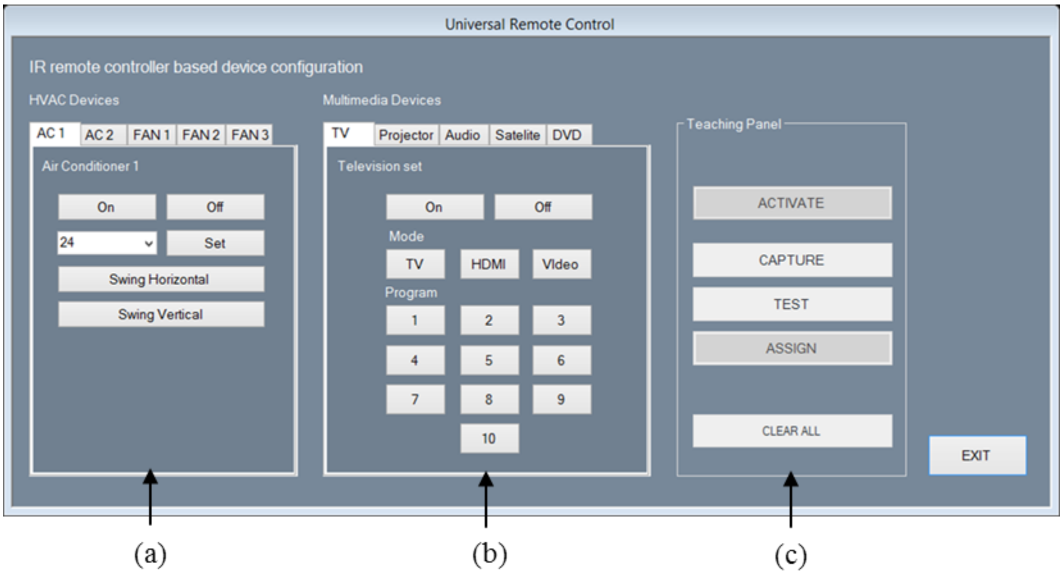


Figure 4.50: Developed GUI of teachable remote controller (a) device panel for HVAC systems (b) device panel for multimedia systems (c) Teaching panel

4.3.3 Wireless Switching Module

4.3.3.1 Introduction

Apart from the remote controlled appliances, there are some other appliances or equipment also being used in a living premises. Some light bulbs and wall mounted ventilation fans are the examples of these types of equipment. Most of the time equipment installed in a fixed location of the building and directly connected to the building electrical circuit through a manual control switching devices (Figure 4.51). Some other appliances such as table fans, table lights, portable air conditioners, multimedia equipment, and safety equipment are used by plugging to the power outlets. However, to develop a convenient and efficient home automation system in a living premises, these appliances also need to be automated by connecting to the IHAS controller. As a solution for this application, a switching device was suggested to implement. The suggested device should have the capability to control the appliances according to the commands of the IHAS controller through the wired or wireless link. Before going to the design stage, it is vital to identify the design aspects by discussing the background of the application.

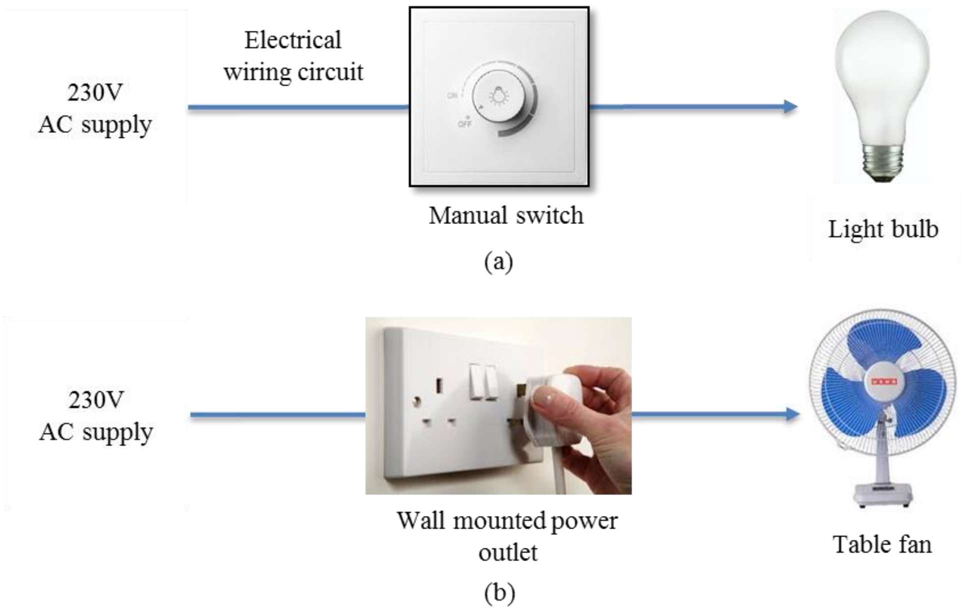


Figure 4.51: The existing control and switching configuration non-remote controlled devices (a) Typical electrical layout of the fixed light bulb (b) Typical electrical layout of the plugin table fan

The switching configuration of different appliances explains how a certain appliance is attached to the building and how it controls. As it is mentioned early, the configuration of the appliances or devices can be categorized as fixed and flexible devices. In general, fixed appliances in a residential buildings are connected to the building electrical circuit through corresponding switching devices. Such as wall switches, dimmer controllers, Fan speed selectors etc. In the flexible devices, there are no fixed or permanent electrical or physical connections in between the devices and buildings. These types of devices, temporally located and plug to the near power outlet when they need to operate. According to these aspects, the suggested switching device should have features for applying to both fixed and flexible appliances which are installed in different locations of the buildings.

Fundamentally, the focused appliances can be categorised into two categories as on-off devices and linear control devices based on their functionalities. In an on-off control device, it can only operate in two states as on state and off state. By giving the 230V direct supply they can be switched to the on state and by giving 0 voltage they can be switched to the off state.

In the linear control devices, they can operate in multiple states in between on and off according to the supply voltage. Usually, this type of devices are controlled by thyristor control based dimmer switches and Series inductor based stepped power selector switches which are installed in power outlet or devices itself.

Electrical characteristics are another important parameter which are required to be considered. In the design of the power switching devices, the power handling capacity and type of the load are important. The general home appliances operate under the 5A of maximum current rating as a resistive or inductive load. Table 4.5 shows the different types of electrical appliances and their specifications commonly used in residential buildings.

Table 4.5: Different types of electrical appliances and there control types

Appliance	Control type	Approximately power rating (max)
CFL and fluorescent lamps	ON-OFF control	100 Watts
Incandescent lamps or array	ON-OFF control / Linear Control	500 Watts
Dimmable CFL	ON-OFF control / Linear Control	100 Watts
Table / celling mounted ventilation fan	ON-OFF control / Linear Control	100 Watts
Water pump	ON-OFF control	1000 Watts
Electric curtain	ON-OFF control	50 Watts
Emergency alarm siren	ON-OFF control	50 Watts
Multimedia devices	ON-OFF control	1000 Watts
Electric Iron	ON-OFF control	1000 Watts
Kitchen equipment	ON-OFF control	1000 Watts

By considering these facts, the following factors were identified to be considered in the design of the proposed switching device.

- Compact and module type design to compatible with fixed and flexible appliances in the existing buildings.
- The wireless control interfaces with the IHAS controller.

- 5A of maximum power handling capacity for resistive and inductive loads.
- On-off and linear control modes.
- Smart and safety.

4.3.3.2 Design of the Wireless Switching Module

According to the identified aspects in the previous discussion, a switching module was proposed to design for controlling the general appliances through the IHAS controller. The proposed system was designed as a flexible module. The proposed system is used to power a particular appliance through the module, it allows controlling the particular appliance according to a command of the IHAS controller via a wireless radio link. The wireless link helps to improve the system mobility and flexibility on the installation. The system was designed as a multimodule system by assigning an individual communication address to each module. Figure 4.52 shows the configuration of a proposed wireless switch module related to two applications.

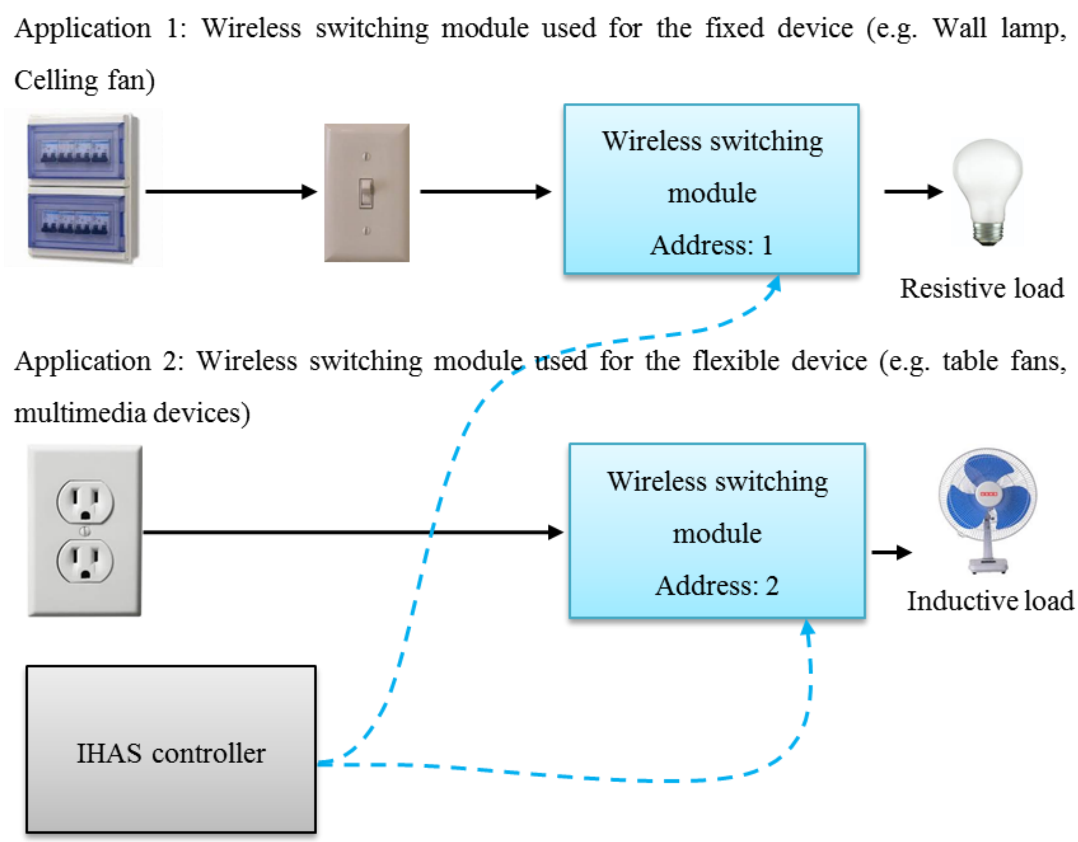


Figure 4.52: The configuration of proposed wireless switch module in two applications

Next stage is to develop a prototype for a wireless switch module. According to the previous discussion, the primary design parameters of the switch module was defined as shown in Table 4.6. Electronic schematics and related data sheets were attached in the Appendix.

Table 4.6: Design parameters of the wireless switching module

Parameters	Value
Voltage	230V AC +/- 10% 50Hz
Current handling capacity	6A Max (Approximately 1400W)
Output control mode	On-off / Linear control
Linear control steps	200 steps (0.5%)
Electrical protection / filters	Over current fuse / Snubber circuit
Control interface	Wireless (RF-ISM band) / 100 meters (indoor)

The output stage of the switch module is very important and according to the above indications, the output stage of the proposed module should capable to operate as an AC voltage controller with the handling capacity of 230V/6A AC under the on-off control mode and linear voltage control mode.

A thyristor is a solid-state semiconductor based switch device which are used to high currents and voltage control applications. Figure 4.53 shows the construction of a thyristor device. Thyristor operates as bi-stable switch. When it receive the gate trigger pulse it will start to conduct until the thyristor is reversed bias.

Phase-fired control, also known as phase cutting or "phase angle control", is a method for power limiting, applied to AC voltages. In phase control, the thyristors are used as switches to connect the load circuit to the input ac supply, partially during every input cycle. That is done by chopping the ac supply voltage using thyristors during each input cycle. The thyristor switch is turned on for a part of every half cycle, so that input supply voltage appears across the load and then turned off during the remaining part of input half cycle to disconnect the ac supply from the load. Figure 4.53 shows a typical circuit diagram of a triac based phase control circuit. By controlling the phase angle or the trigger angle ‘ω’ (delay angle), the output RMS voltage across the load can be controlled. The trigger delay angle ‘α’ is defined as the phase angle (the value of ωt) at which the thyristor turns on and the load current begins to flow.

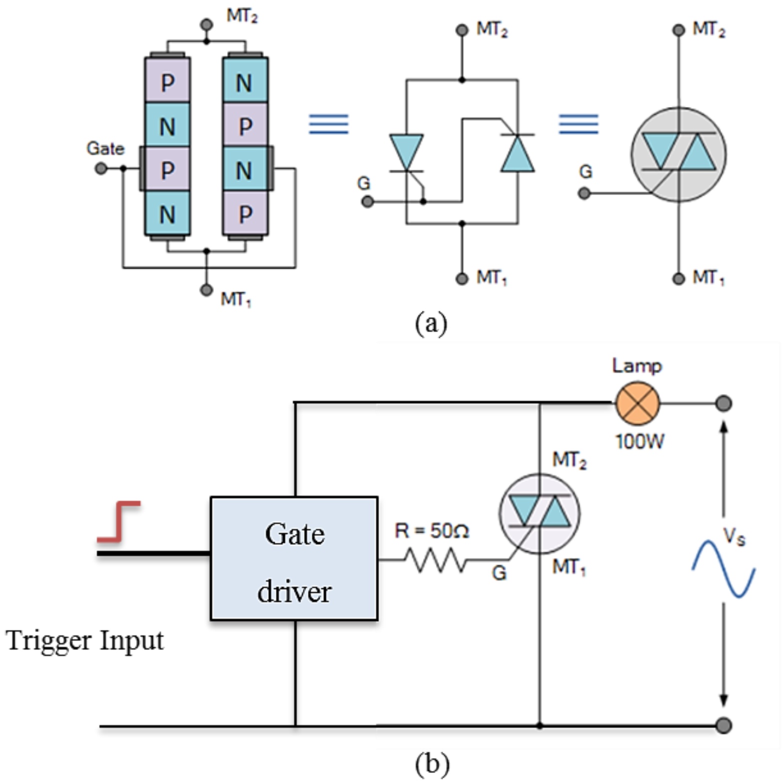


Figure 4.53: (a) Construction of triac device (thyristor family) (b) Basic layout of phase angle control circuit

Figure 4.54 shows the controlling of the output voltage by chopping the input voltage according to the trigger angle (α). The trigger angle is also called the firing angle of the phase control systems. By increasing the firing angle, firing delay of the thyristor can be increased. This will minimize the conduction angle of the output voltage and reduce the RMS voltage across the load. Equation 4.5 represents the RMS voltage output of phase controlled sinusoidal waveform. Equation 4.6 and equation 4.7 were derived from simplifying the equation 4.5, which represent the relationship of input supply voltage ($V_{s(RMS)}$) and duty-cycle of the controlled waveform to the voltage output.

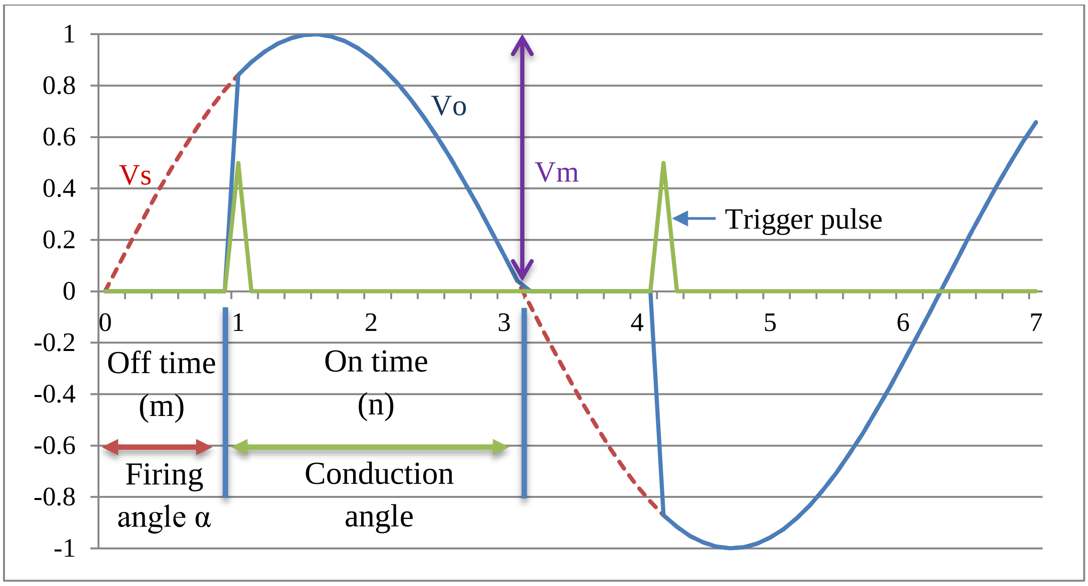


Figure 4.54: Input-output characteristics of single phase ac voltage controller

$$V_{o(RMS)} = \left[\frac{n}{2\pi(n+m)} \int_0^{2\pi} V_m^2 \ sin^2 \ \omega t. d(\omega t)\right]^{1/2} \tag{4.5}$$

$$V_{o(RMS)} = \frac{V_m}{\sqrt{2}} \sqrt{\frac{n}{(m+n)}} \tag{4.6}$$

$$V_{o(RMS)} = V_{s(RMS)} \sqrt{\frac{n}{(m+n)}} \tag{4.7}$$

Where $V_{s(RMS)}$ = RMS value of input supply voltage

By considering the frequency of supply voltage and required control steps, the span of the firing angle and angle resolution were calculated using equation 4.7.

$$Time\ period\ of\ half\ cycle\ (t_h) = \left(1/_f\right)/2$$
$$Firing\ amgle\ resolution = (t_h)/steps$$

Frequency of the supply voltage (f)	= 50 Hz
Required voltage control steps	= 200 steps
Span of the firing angle	= 0 to 10,000 micro seconds
Step resolution of firing angle	= 50 micro seconds

According to the obtained values and the $V_{s(RMS)}$ considering as 230V, the $V_{o(RMS)}$ vs. firing angle was plotted using the equation 4.7 and shown in Figure 4.55.

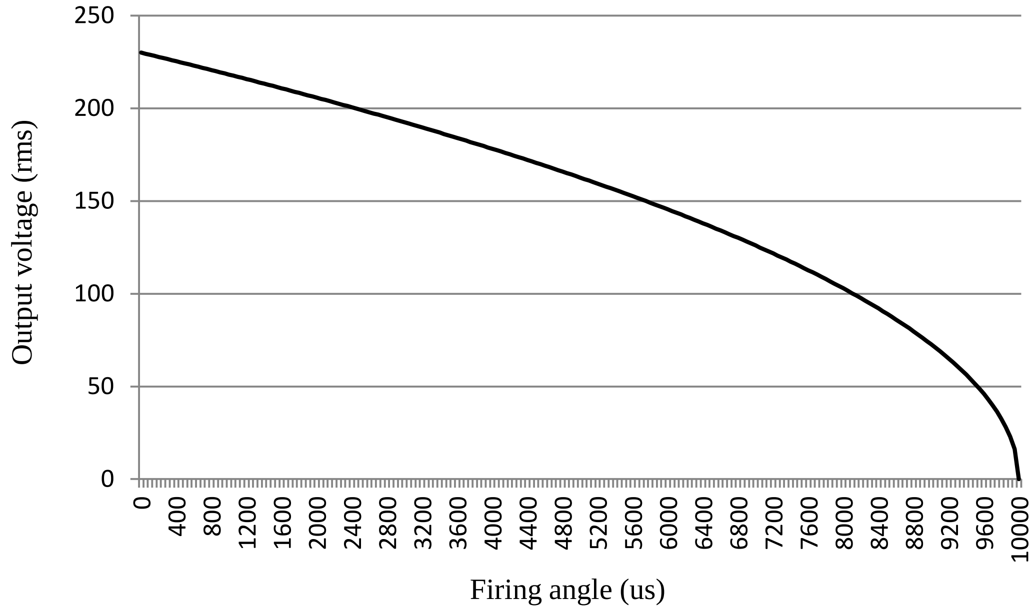


Figure 4.55: Output voltage (rms) variation with firing angle (us)

As a summary, using a 0 to 10,000 us of firing angle (trigger delay) the output voltage of the 50Hz sinusoidal waveform can be controlled within minimum and maximum voltage levels of the input voltage supply. But the firing angle or trigger delay should be counted from the starting point of each and every half. This means the triggering circuit or gate driver need to synchronize with the input waveform. This was done by developing a zero crossing detector circuit based on a step-down transformer. Figure 4.56 shows the schematic diagram of the designed zero-crossing detector circuit.

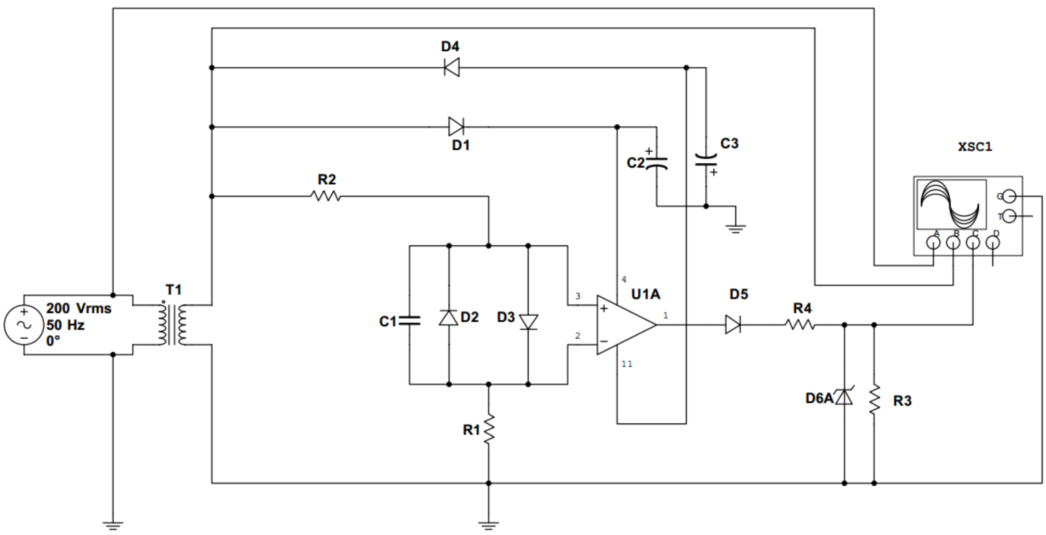


Figure 4.56: Schematic diagram of zero crossing detector circuit

T1 is a step-down transformer, in this circuit, it was used as a reference input and power supply to the circuit. D1, D4, C2 and C3 were used to voltage rectifications and rectified voltages are used to drive the operational amplifier and other control circuits. U1A is an operational amplifier used in comparator mode. According to the voltage levels of inverting and non-inverting terminals, the output states of the operational amplifier will be changed. The scaled waveform of the transformer was fed to the comparator inputs through the R1 and R2 resistors. D2 and D3 signal diodes were used as clipping diodes. This will help to limit the unwanted voltage at the comparator input terminals. C1 is a filtering capacitor. It was used to remove the noises in the input. D4, D6A and R3, R4 are used for signal rectification and clipping circuit. It was used to make the operational amplifier output compatible with TTL interface which can be directly read by the microcontroller device. According to the circuit arrangement, T1 provides step-downed in-phase waveform from the input supply. As the polarity of the input waveform, comparator circuit generates a square wave which represents the logic 0 and 1 with respect to the negative half and positive half of the supply input. The falling and rising transient edges of the square wave are representing the zero crossing position of the supply input. This was used to synchronize the control circuit and the power circuit of the thyristor control system. The circuit was design in NI Multisim simulation software environment and the obtained output waveform from the XSC1 oscilloscope shown in Figure 4.57.

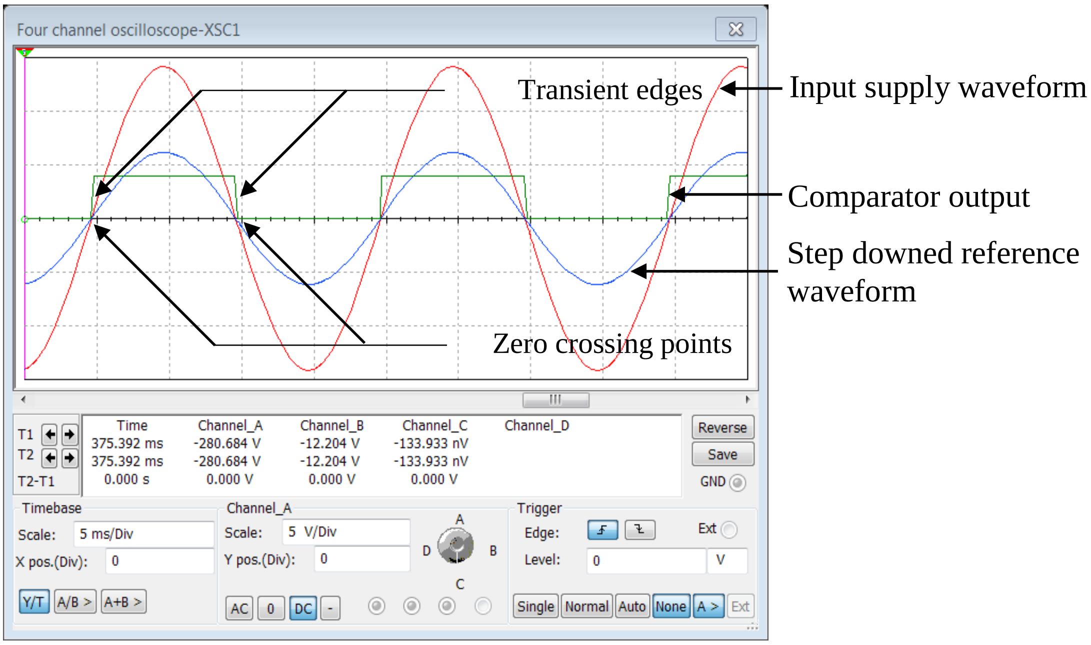


Figure 4.57: Input and output waveforms of the circuit observed by XSC1 oscilloscope

When it uses a triac device cascading with a low voltage control circuit, it requires electrical isolation in between the control circuit and power circuit. In electronics, an optoisolator, also called an optocoupler, photocoupler, or optical isolator is a component that transfers electrical signals between two isolated circuits by using light. Opto-isolators prevent high voltages from affecting the system receiving the signal. In this design, the isolation circuit was developed using a random-phase optoisolator triac driver. "Random" elaborates as the triac switches on for a timing control signal, make optoisolator to switch on, whatever the voltage phase at that moment. So its actual meaning is that it can switch on at any time. The random switch is needed if it wants to build a triac-controlled voltage controller, where it wants control of the phase angle where the controller ignites the triac over the full 180° of a half cycle.

The MOC3052-M is a random-phase optoisolator which consists of an AlGaAs (Aluminium Gallium Arsenide) IR diode optically coupled to a non-zero-crossing silicon bilateral AC switch (triac). Random-phase optoisolator can be used to electrically isolate low voltage control circuit from high voltage main AC lines to provide random phase control of high current triacs or thyristors. Figure 4.58 shows the schematic diagram of MOC3052-M triac driver and isolated hot-line switch application circuit.

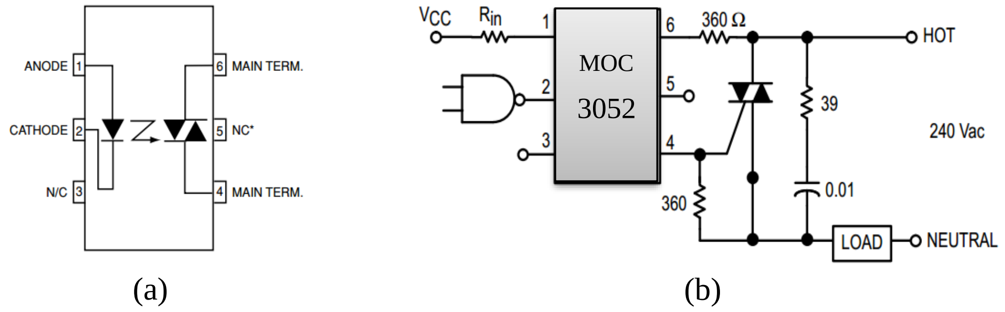


Figure 4.58: (a) Schematic diagram of MOC3052-M random-phase isolating triac drier (b) application circuit of MOC3052-M as a hot-line isolated triac driver

After completing the design of the output stage and reference input system, the next stage is to develop the controller of the wireless switch module. The function of the controller identifies the zero crossing point of the input supply and ignite the triac device to produce the desired output voltage in the output terminals. To achieve this a control circuit was designed as shown in Figure 4.59. The system was designed on an 8-bit microcontroller which is having sufficient hardware and software features to implement the controller.

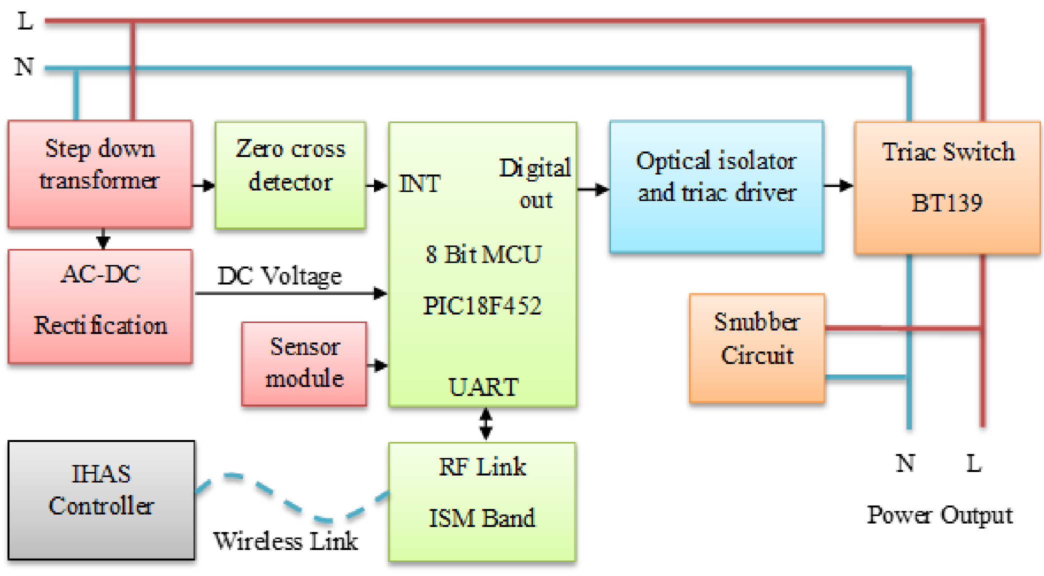


Figure 4.59: Block diagram of wireless switch module

The working principle of the controller can be described as follow. Initially, the controller has established a wireless communication link between the IHAs controller and switch device by using the RF radio link. The microcontroller identifies the starting point of each and every sin wave cycles by detecting the transient edges of the zero cross detecting circuit. This was read by the external interrupt input pin of the microcontroller. After identification of the transient edges, microcontroller reset the internal timer which was pre-configured to automatically count in every 50 microseconds. While counting the timer, microcontroller compares the timer value and trigger delay value which represents by the voltage set point register. After reaching the timer value same as the setpoint value then microcontroller suddenly ignite on the triac through the optical isolator. This allows switching on the triac after a desired time period and it controls the voltage of the load device as required of IHAS controller. The controller was protected by a current limiting fuse and RC snubber circuit. According to the limitation of the existing power distribution switch gears, the fuse was selected as carrying maxim of 5A through the device.

4.3.3.3 Smart Features of the Wireless Switch Module

Since the wireless switch device is a part of the IHAS, apart from the basic functionality some of the additional features were implemented on the same device which will be a help to improve the system performance and safety functionalities.

Automatic Power Fail Recovery

After switching on a particular appliance by the IHAS controller, if there is a power failure occurred and recovered, then the device setting will be lost and reset. By enabling this feature, the enabled appliances is kept remain in the on state after the device will get the power again.

Automatic Safety Timer

An automatic safety timer is an internal timer which counts minute by minute up to 1440 of minutes (24 hours). When the IHAS has commanded the device to switch on the appliances, this timer will be reset and after the desired time interval the appliances are automatically switched off by the controller itself. The time value can be changed and it comes with the control command. This allows obtaining two advantages.

- Minimized the required attention of IHAS controller on the output devices
  If some appliance requires switching on and switching off after the desired time, the central controller of the IHAS does not need to pay attention to counting and switch of the device by giving a command. It can be automatically switched off by the controller itself by giving the required time with the switching command.
  Examples: Mosquito vaporizer, staircase illuminator etc.
- Master controller fail recovery
  If master controller got fail after switching on the particular appliance, there is no any mechanism to switch off the appliance again. By setting the maximum possible operation time related to the appliance it can be automatically switched off by the controller.

External Sensor Module

The device was designed with an external sensor interface. This interface allows connecting an analog or digital sensor to the system which can read by IHAS controller. In the developed prototypes LDR sensors were used as an external sensor which can be used to measure the light intensities at installed locations of the wireless switching devices.

The next step is to implement the communication protocols for the device. Based on the multiple device configurations, the wireless data protocol was designed working on a unicast, multicast and broadcast modes. Then according to the developed features and standards of the IHAS central controller protocol, the communication protocol for the wireless switching device was defined. The additional information on these communication systems will be discussed in the chapter 4.4.3 under the rf-based wireless communication system protocol implementation.

Function **Test device availability in the network**

Command 0x00

<Start byte> <slave address> <command> <stop byte>

Reply <Start byte> <slave address> <command> <stop byte>

Ex. Syntax Test availability of the slave device which is represent by the address 0x10

Command **FF 10 00 FE**

Reply **FD 10 00 01 FC**

Function **Set the output voltage of the system**

Command <Start byte> <slave address> <command> <output_value> <timer value_low_byte> <timer value_high_byte> <power_fail_recovery> <stop byte>

command = 1 Switching mode + Output is on

command = 2 Switching mode + Output is off

command = 3 Linear voltage mode

output_value output voltage in linear voltage mode

0-200 steps [1 step = 0.5% * $V_{s(RMS)}$]

timer_low_byte and timer_high_byte

Safety timer value

0-1440 minutes (0x00 0x00 to 0x05 0xA0)

power_fail_recovery 0= Power fail recovery off

1= Power fail recovery on

Ex. Syntax Set the output value of the device (address = 0x10) to the 100 steps in linear mode for 10 minutes with powers fail recovery features.

Command **FF 10 03 64 00 0A 01 FE**

Reply **FD 10 00 01 FC**

Function	**Read the external sensor value**
Command	0x04
	<Start byte> <slave address> <command> <stop byte>
Reply	<Start byte> <slave address> <command> <sensor_value_low_byte> <sensor_value_high_byte> <stop byte>
Ex. Syntax	Read the sensor module of the device addressed as 0x10
	Command **FF 10 04 FE**
	If sensor value is = 2000
	Reply **FD 10 04 07 D0 FC**

Multicast commands (Master to selected multiple slave devices)

Function	**Set the output voltage to the value x of all wireless switching device active in the network**
Command	<Start byte> <0x98> <value> <stop byte>
Reply	No Acknowledgement
Ex. Syntax	Output voltage value = 50%, x=100
	Command **FF 98 64 FB**
	Reply **No Acknowledgement**
	Output voltage value = 0%, x=0
	Command **FF 98 00 FB**
	Reply **No Acknowledgement**

Broadcast commands (Master to all slave devices)

Function	**Switch all wireless nodes to the standby mode (off mode)**
Command	<Start byte> <0x64> <value> <stop byte>
Reply	No Acknowledgement
Ex. Syntax	Command **FF 64 00 FB**
	Reply **No Acknowledgement**

Function	**Switch all wireless nodes to the on mode**	
Command	<Start byte> <0x65> <value> <stop byte>	
Reply	No Acknowledgement	
Ex. Syntax	Command	**FF 65 00 FB**
	Reply	**No Acknowledgement**

A computer GUI was implemented to configure and test the wireless switching devices through the computer as a part of the main GUI of IHAS. Using this software interface wireless switch devises can be initialized to the IHAS central controller via the individually assigned device addresses as shown in the Figure 4.60 and Figure 4.61.

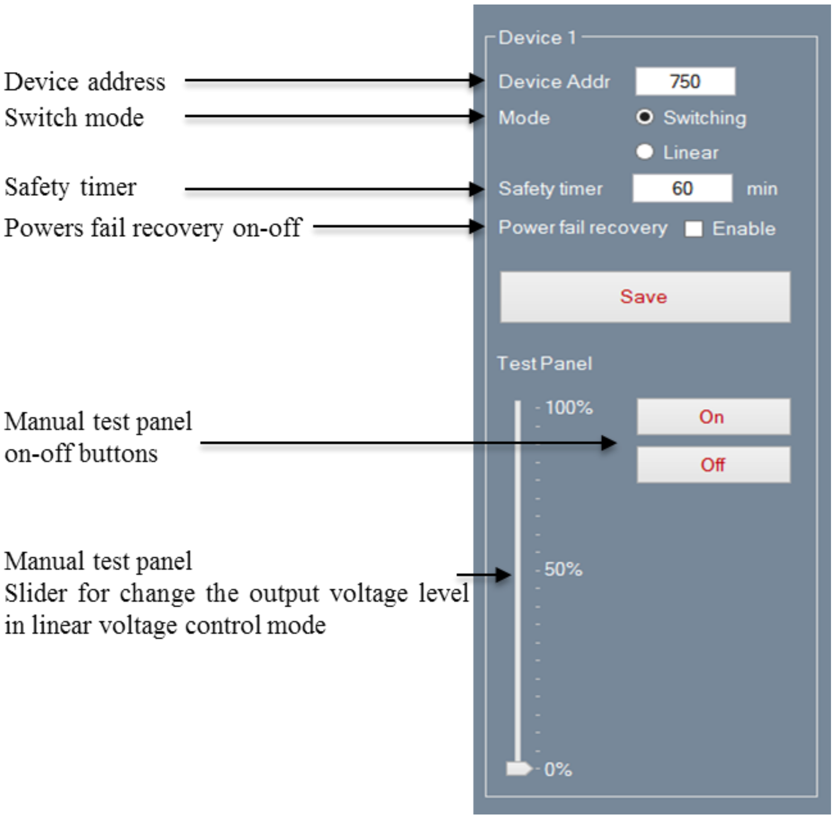


Figure 4.60: A sectional view of the developed GUI for the test and configuration of wireless switching devices

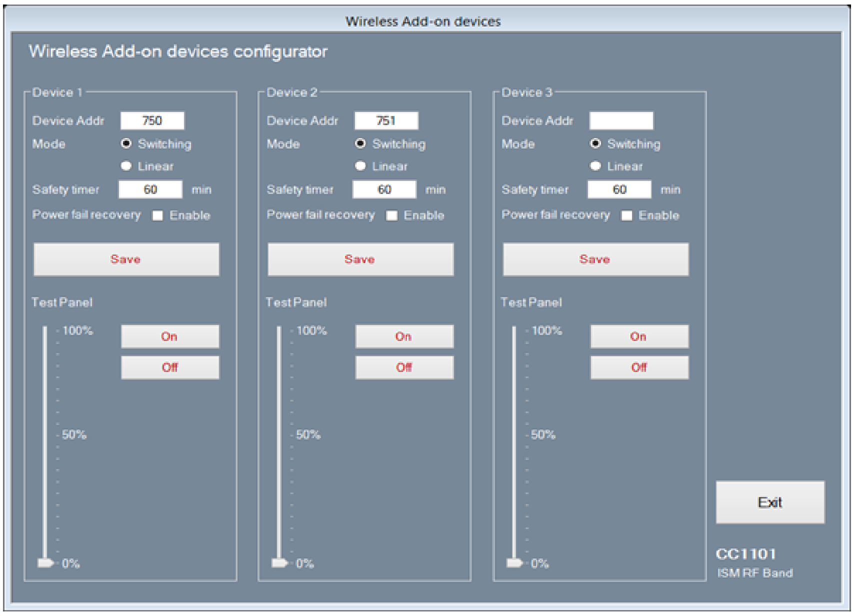


Figure 4.61: The developed GUI for the test and configuration of wireless switching devices

Figure 4.62 and Figure 4.63 shows the hardware implementation of the developed wireless switch module.

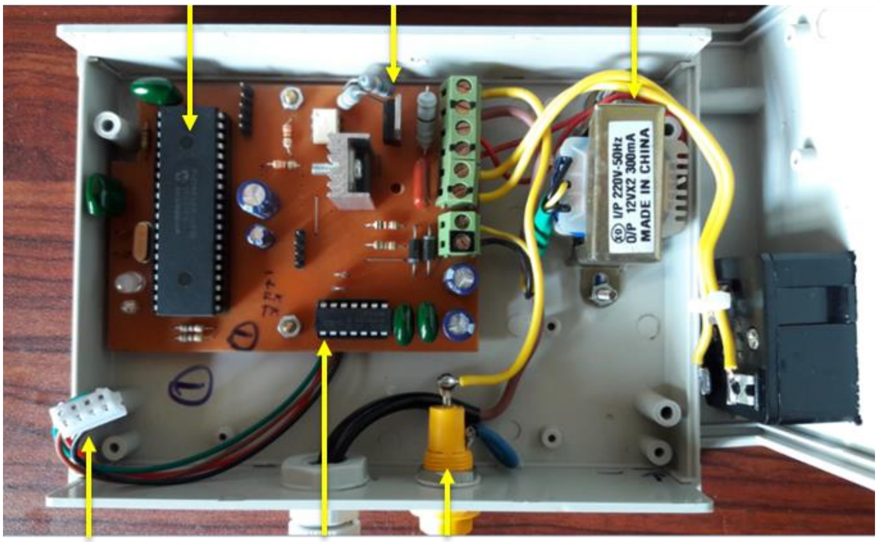


Figure 4.62: The inside image of the wireless switching module

(a) PIC18F452 Microcontroller (b) Triac (c) Step-down transformer (d) RF radio

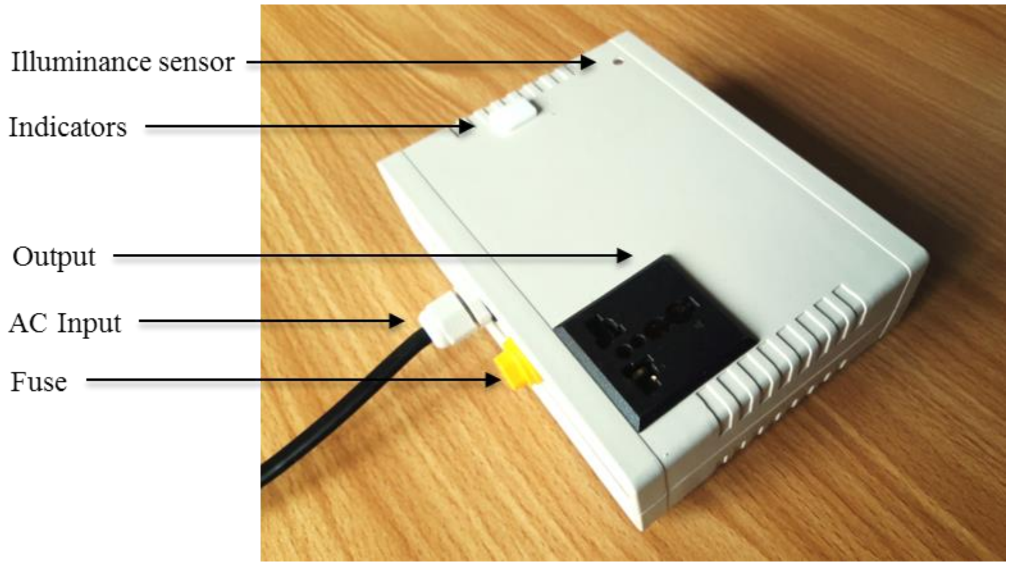


Figure 4.63: Image of the wireless switch module

Finally, the developed system was tested using different types of devices up to 1000 watts of power rating and the system was operated in both modes (switching mode and linear voltage control mode) successfully. Some of the electronics devise such as CLF lights, LED lights small fluorescent lamp sets which are having an internal AC-DC converter with smoothing capacitors got some flickers at the off states of the devices. This is due to the leakage current of the snubber circuit which is fixed in parallel to the thyristor switch. Therefore a small switch was fixed inside the wireless switching devices to disconnect the snubber circuit when it not needed.

4.4 The Central Controller

4.4.1 Introduction

The IHAS can be summarized as a control system. IHAS was developed to control the home appliances automatically to improve the user comfort while maintaining the energy usage at an optimum level. According to the design of IHAS, it has an enhanced sensor systems such as real-time indoor and outdoor climatic monitor, occupancy identification and localization, occupant activity tracking and energy monitoring which are used to monitor the environment according to deferent factor and appliances control interface to switch the appliances automatically. Then IHAS need to observe on this sensory information and generates the correct decisions for appliances. Finally, the obtained decisions communicate to the field devices which are connected to the controller.

Nevertheless, these sensor systems are yet restricted in interactivity and adaptability to varying environments directly. The primary cause for that is unpredictable and dynamic changes occurred in the environment related factors. On the other hand, to design an automated control system that best adapts to those environments should include proper control systems with multi-objective decision making and intelligent control.

4.4.1.1 Control System

A control system is a system, which provides a desired response of the system by controlling the output. Figure 4.64 shows the simplified block diagram of a control system.

Figure 4.64: The block diagram of typical control system

Based on some parameters, the control systems can be classified into the following ways.

4.4.1.2 Continuous Time and Discrete Time Control Systems

Based on type of the signal is being used, control Systems can be identified as discrete-time control systems and continuous-time control systems. In discrete time control systems, there can be seen only one or more discrete time signals. But, in continuous time control systems, all the signals are continuous in time.

4.4.1.3 SISO, SIMO, MISO and MIMO Control Systems

Based on the available number of inputs and outputs, Control Systems can be classified as follows,

- SISO (Single Input and Single Output) are the control systems only having one input and one output.
- SIMO (Single Input and Multiple Outputs) are the control systems having one input and more than one output.
- MISO (Multiple Inputs and Single Output) are the control systems having more than one input and one output.
- MIMO (Multiple Inputs and Multiple Outputs) are the control systems having more than one input and more than one output.

4.4.1.4 Open Loop and Closed Loop Control Systems

Control Systems are differentiated as closed-loop control systems and open loop control systems accordingly on the feedback signal path

4.4.1.5 Open Loop Control Systems (Manual Controller)

In open loop control systems, the output is not fed-back to the input. So, the control action is independent of the desired output. Figure 4.65 shows the block diagram of an open loop control system.

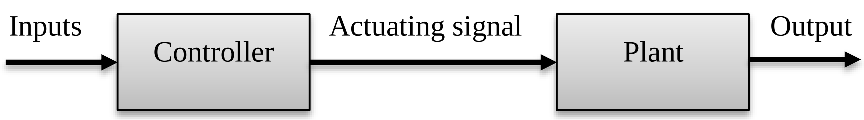


Figure 4.65: The block diagram of open loop control system

In this scenario, an input is given to a controller and the controller produces a resulting signal or controlling signal, which can be used as an actuator signal given to a plant or process which is to be controlled. The plant produces a controlled output.

4.4.1.6 Closed Loop Control Systems (Automatic controller)

In a closed-loop control system, the output is fed back to the input path to compensate the error between desired output and the actual output. Consequently, the controlling is dependent on the desired output. Figure 4.66 shows a block diagram of negative feedback closed-loop control system.

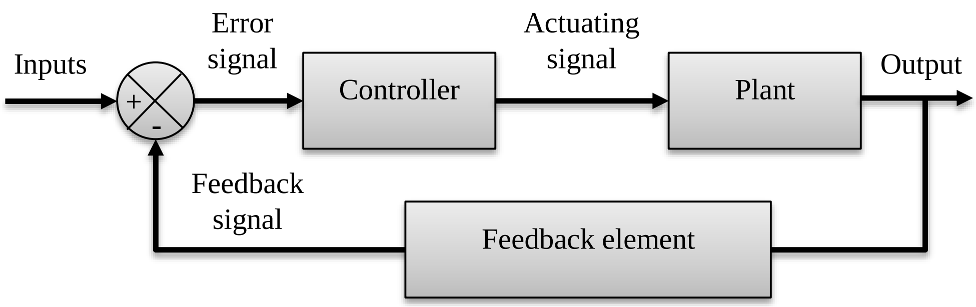


Figure 4.66: The block diagram of closed loop control system

The error differentiator produces an error signal by accounting the difference between the input and the feedback signal. The feedback signal is obtained from a control block by inputting the output of the overall system as an input. The output from this block is applied to the error differentiator and Instead of the direct input, the error signal is applied as an input to the controller.

And, the controller produces an actuating signal which controls the plant. In this manner, the output of the control system is adjusted automatically until the desired response is obtained. Hence, the closed-loop control systems are also called automatic control systems.

4.4.1.7 Intelligent Controller

Intelligent control describes as the emulation of biological intelligence in order to achieve automation. It either intent to replace a human who performs a control task (e.g., a chemical process operator) or it borrows ideas from how biological systems solve problems and applies them to the solution of control problems (e.g., the use of neural networks for control). There are several intelligent paradigms that are capable of solving intelligent control problems in various applications. Connectionist theory (NN - neural networks), fuzzy logic (FL), and theory of evolutionary computation (GA - genetic algorithms) are of great importance in the development of intelligent control algorithms. Due to their strong learning and cognitive abilities and good tolerance of uncertainty and imprecision, intelligent techniques have found wide applications in the area of advanced control of automation.

However, in the previous research, it has shown that the many control applications areas still operate using the manual and semi-automatic controller systems in the residential buildings. By automating these applications by using different control methods the system performance can be improved as the figure shown in Figure 4.67.

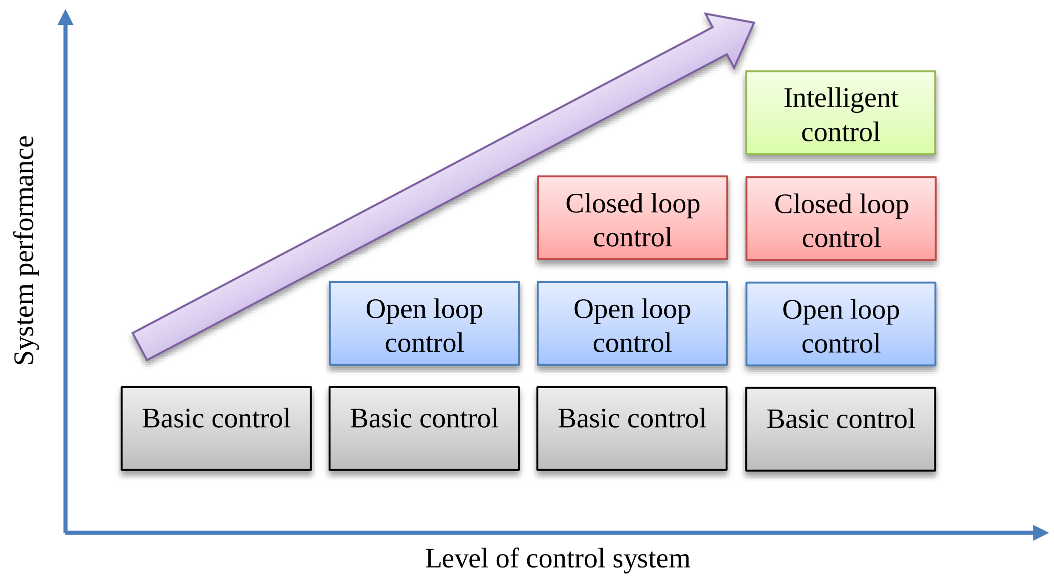


Figure 4.67: The controller system level vs. system performance

According to these facts and the focused control applications of the IHAS, the hardware platform of the IHAS controller should have the capability to compute the open loop and closed loop control algorithms under the multi-input multi-output system configurations. And also it has the capability to compute complex algorithms which are related to the artificial intelligence based control applications of the system.

4.4.2 Controller Architecture

Since the availability of wider input-output systems and complex multi-input multi-output control configurations, the central controller of the IHAS divided into the three main sections as operation layers to perform a specific task effectively as shown in Figure 4.68. According to the configuration of this architecture, the sensory systems and output systems directly connected to an interface controller via the digital and analog communication channels and the interface controller allowed to read and write the input-output devices to the decision-making controller as required. The decision-making controller is a main controller of the system. The function of this controller is to read the real-time sensory information and make the control decisions by computing different types of control algorithms related to the automation applications.

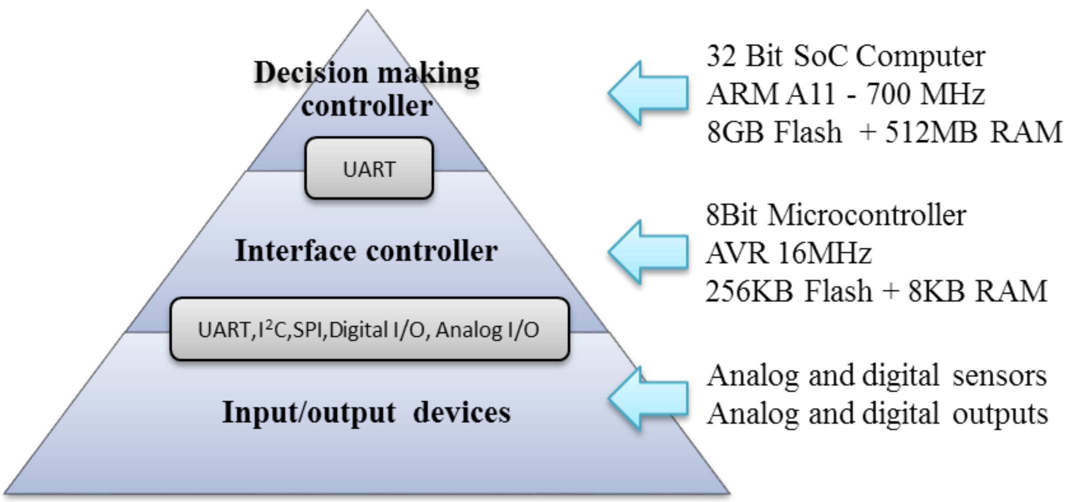


Figure 4.68: The control architecture of centralized controller of the IHAS

4.4.2.1 Decision-Making Controller

The decision-making controller is the top layered controllers of the IHAS and it is used to compute the high-level control algorithms which cannot be computed by the low-level controllers itself due to the limitation of computation power. These algorithms include multi-input multi-output fuzzy logic systems, complex sequential control systems, large data manipulation and storages and GUI control. This controller does not interact with input-output devices directly. But through the interface controller, the decision-making controller can read all the sensory information and make the control command for the output devices through a single UART data link.

The next task is to select a hardware platform to implement the decision-making controller. A single-board computer (SBC) is a complete computer built on a single circuit board, with a microprocessor(s), memory, input/output (I/O) and other features required to function as a computer. Single-board computers were made as demonstration or development systems, for educational systems, or for use as embedded computer controllers. Many types of home computers or portable computers integrate all their functions onto a single printed circuit board.

A Raspberry Pi is a credit card-sized computer originally designed for education, inspired by the 1981 BBC Micro. Creator Eben Upton's goal was to create a low-cost device that would improve programming skills and hardware understanding at the pre-university level. The Raspberry Pi is open hardware, with the exception of the primary chip on the Raspberry Pi, the Broadcomm SoC (System on a Chip), which runs many of the main components of the board–CPU, graphics, memory, the USB controller, etc. The Raspberry Pi is slower than a modern laptop or desktop but is still a complete Linux computer and can provide all the expected abilities that imply, at a low-power consumption level.

The decision-making controller chooses to develop on a single board computer. Raspberry Pi model B+ is a 32 Bit, 700 MHz, 512 MB RAM single board computer powered by the ARM 11 CPU based on the BCM2835 SoC. This computer has 26 GPIO channels including the UART, I^2C and SPI interface and 10/100 Mbps Ethernet port as shown in Figure 4.69 and Figure 4.70.

Raspbian is the Foundation's official supported OS (Operating System) for the raspberry pi computers. For this implementation, the raspbian was used as the computer operating system and control firmware was developed using python which is provided by the raspbian OS. The programming of the SBC was done via a windows computer which connected to the SBC through Ethernet using "Putty" as a remote desktop application as shown in Figure 4.71.

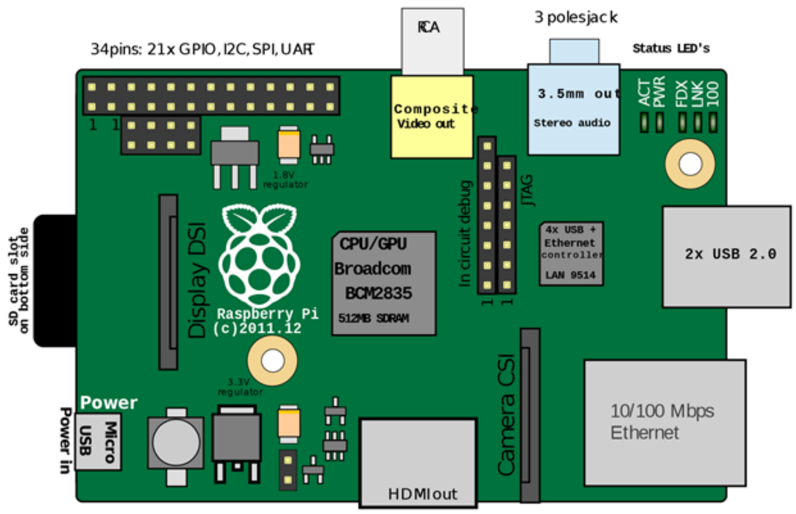


Figure 4.69: The PCB layout of the raspberry pi model B+ single board computer

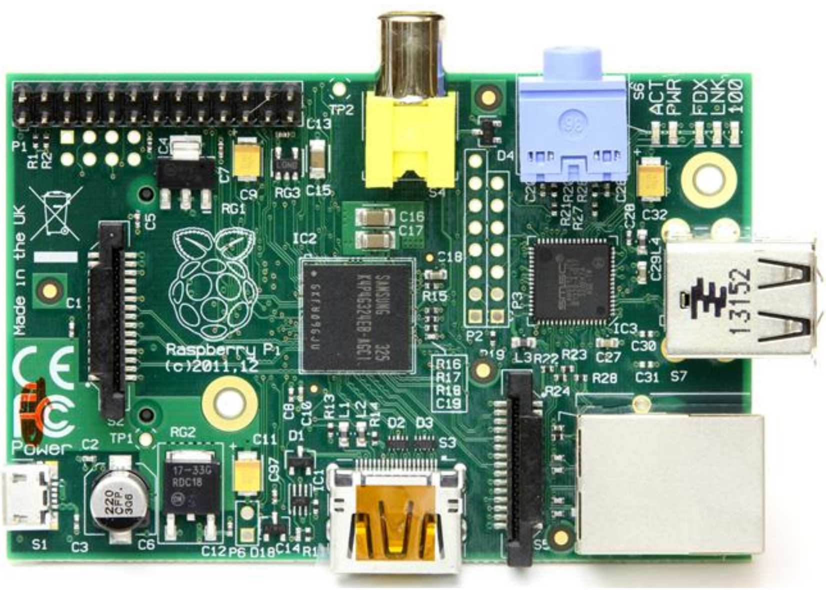


Figure 4.70: The image of the raspberry pi model B+ single board computer

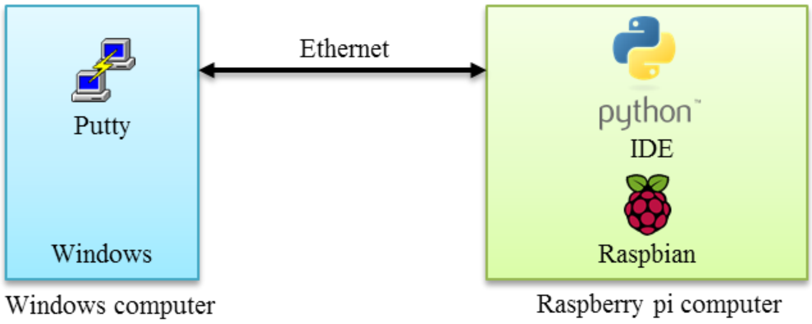


Figure 4.71: The control architecture of centralized controller of the IHAS

4.4.2.2 Interface Controller

Interface controller is the middle layer controller of the central controller. This controller can be introduced as a hub. According to the controlling purpose, the decision-making controller needs to connect with input-output systems at deferent times. And these systems have different hardware and protocol interfaces. As a solution for that, Interface controller introduced to the IHAS central controller.

The function of this controller is to read and write the input and output devices as the request of decision-making controller. Therefore the interface controller was hardware wise connected to all the input-output devices directly through different protocols and according to the request of the main controller, it makes the temporary interface between the main controller and particular input-output devices to perform specific control events. Figure 4.72 shows the example of how the decision-making controller communicates with different sensor systems through the interface controller.

As per the design objectives of the interface controller, it should capable to handle the large numbers of input-output devices which are from different communication protocols. But this controller does not use to compute the sophisticated control algorithms itself. Therefore a microcontroller was selected to implement the interface controller which is having sufficient GPIOs and communication modules to work with identified input-output devises or systems.

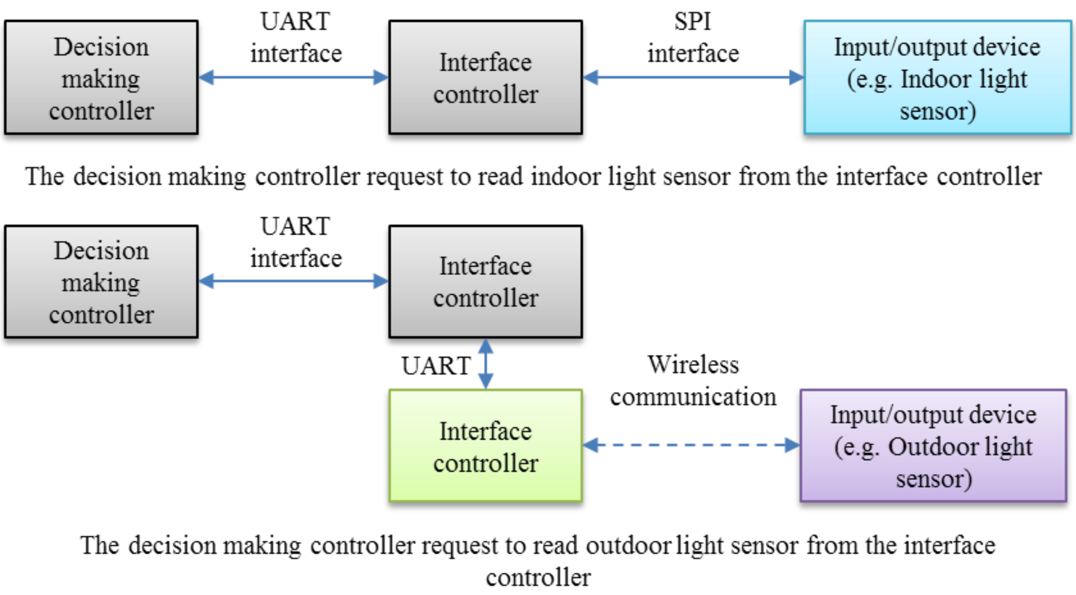


Figure 4.72: The operation of interface controller

The AT mega 2560 is an 8-bit microcontroller which can be operated up to 16 MIPS at 16 MHz clock speed. This microcontroller has 256 KB of programmable flash memory and 8 KB of RAM and 4 KB of EEPROM with 86 of total GPIOs which are sufficient to implement firmware and hardware interfaces of the interface controller. The summary of AT mega 2560 is given in bellow.

CPU	8 Bit - Up to 16 MIPS throughput at 16MHz
Memory	256 KB of flash - 4 KB of EEPROM - 8 KB of RAM
GPIOs	86 total GPIOs - 16 ADC channels - 12 PWM channels
Peripherals	Four UART modules - SPI module - I2C module - One wire module
	16 Bit PWM - 10 Bit ADC - External interrupts

The AT mega 2560 chip comes with the 100-pin thin quad flat package (TQFP) and it is difficult to develop PCB for the prototype. Nowadays AT mega 2560 based open source development boards are commercially available from different vendors as shown in Figure 4.73.

Arduino is an open source computer hardware and software company that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices and interactive objects. Considering the hardware design and availability of libraries and support tutorials to firmware development, Arduino Mega open source development board was used to implement the interface controller.

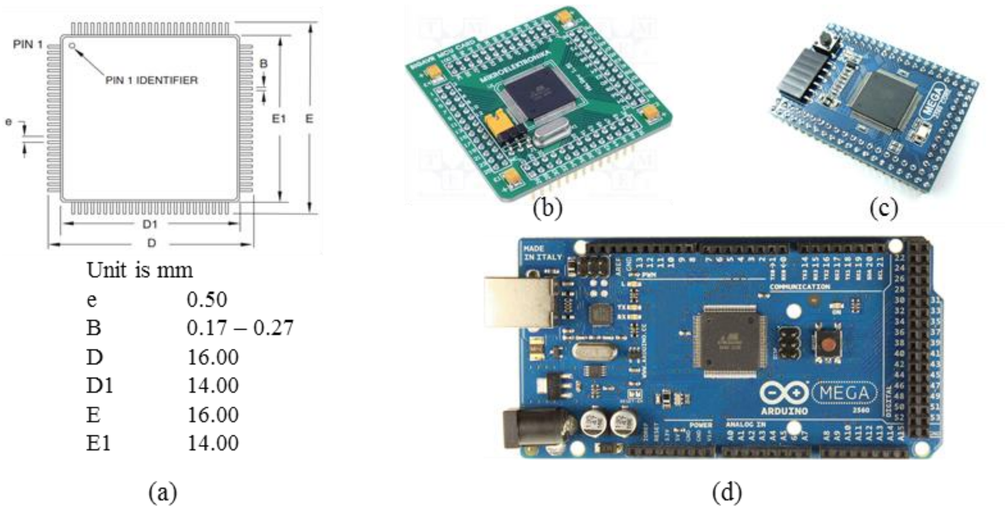


Figure 4.73: (a) the physical dimension of the AT mega 100-pin TQFP chip (b) MCU CARD ATMEGA2560 from Microelectronica (c) Mega2560-CORE mini 2560 from INHAOS (d) Arduino MEGA development board from Arduino

The Figure 4.74, Figure 4.75, Figure 4.76 and Figure 4.77 shows the images of the developed prototype of the central controller. Finally a computer-based common GUI was developed for the central controller of the IHAS to control and monitor the entire system through the GUI. All the other sub GUIs related to different sensor systems and output control systems were linked to the main GUI to operate on a common GUI. Figure 4.78 shows an image of the developed main GUI for the IHAS and Figure 4.79 shows the block diagram of the entire system configuration.

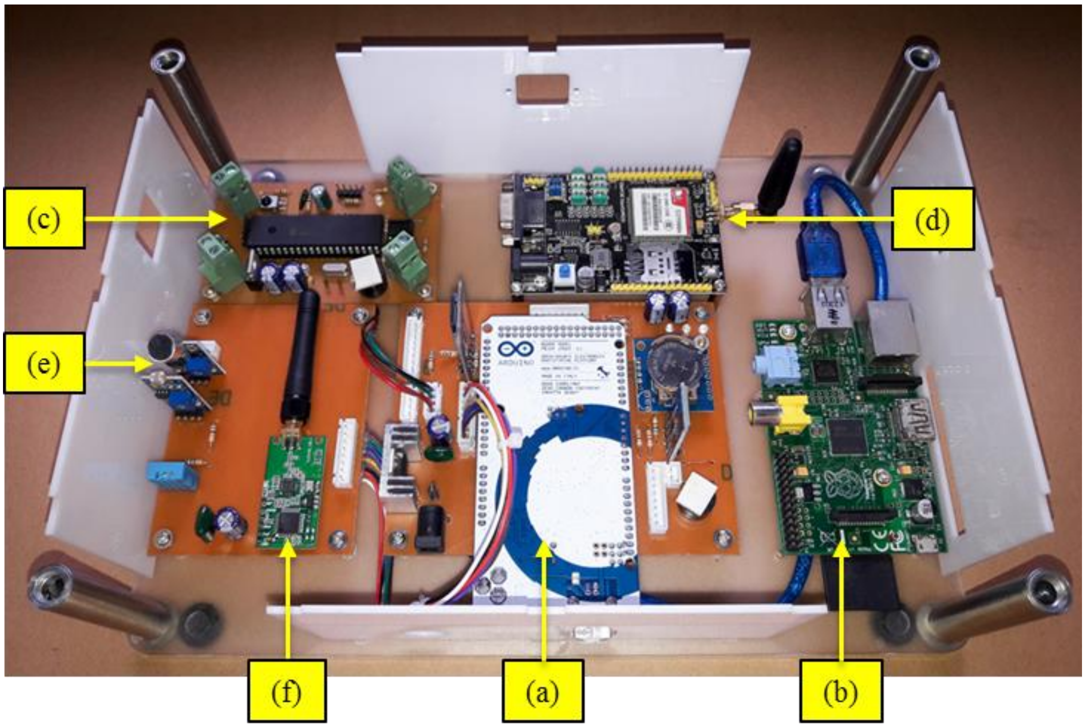


Figure 4.74: Inside image of the central controller (a) AT mega 2560 based interface controller (b) single board computer (c) IR universal remote controller (d) SIM800A GSM/GPRS communication module (e) Indoor climate sensors

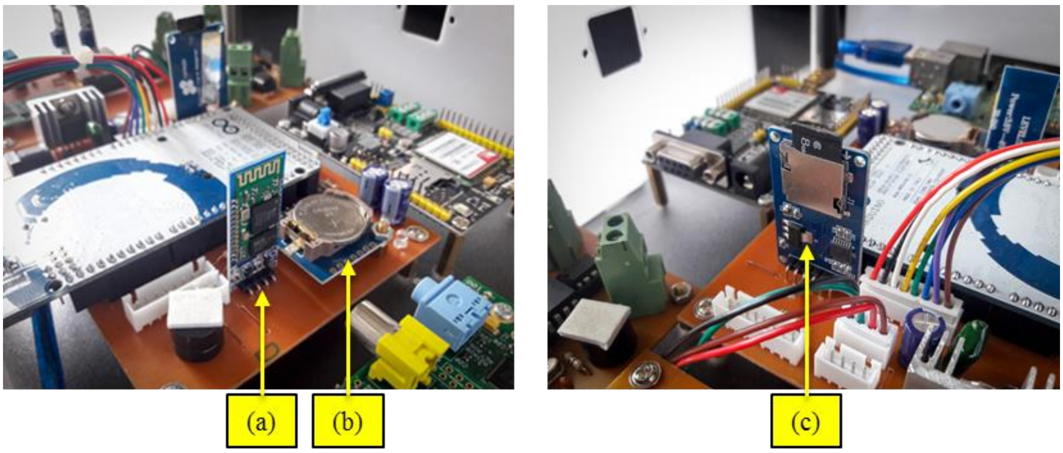


Figure 4.75: Inside image of the central controller (a) Bluetooth module (b) real time clock module (c) SD card module

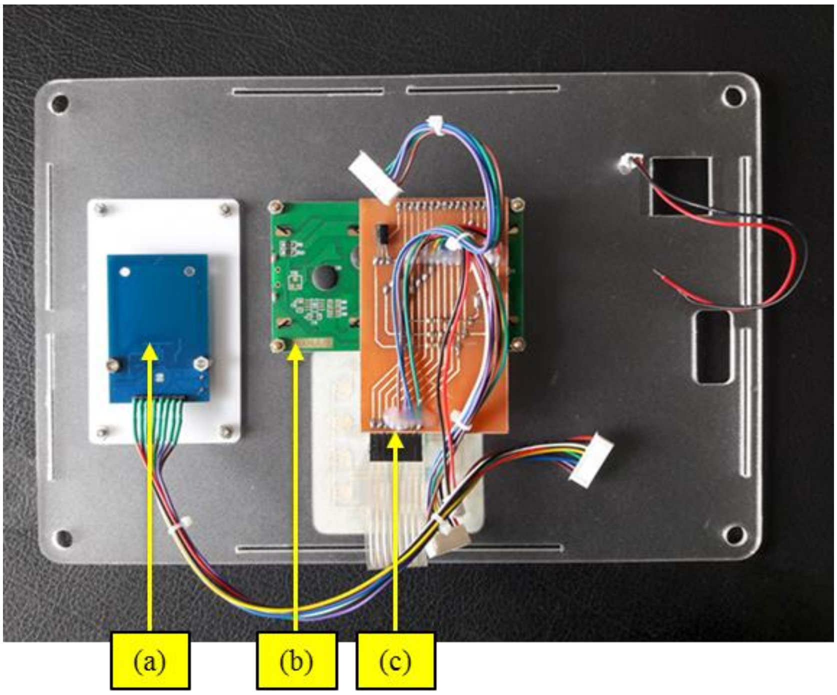


Figure 4.76: Inside image of the central controller (a) MFRC522 RFID scanner (b) 20 x 4 character LCD (c) 16 key keypad

Figure 4.77: An image of the central controller

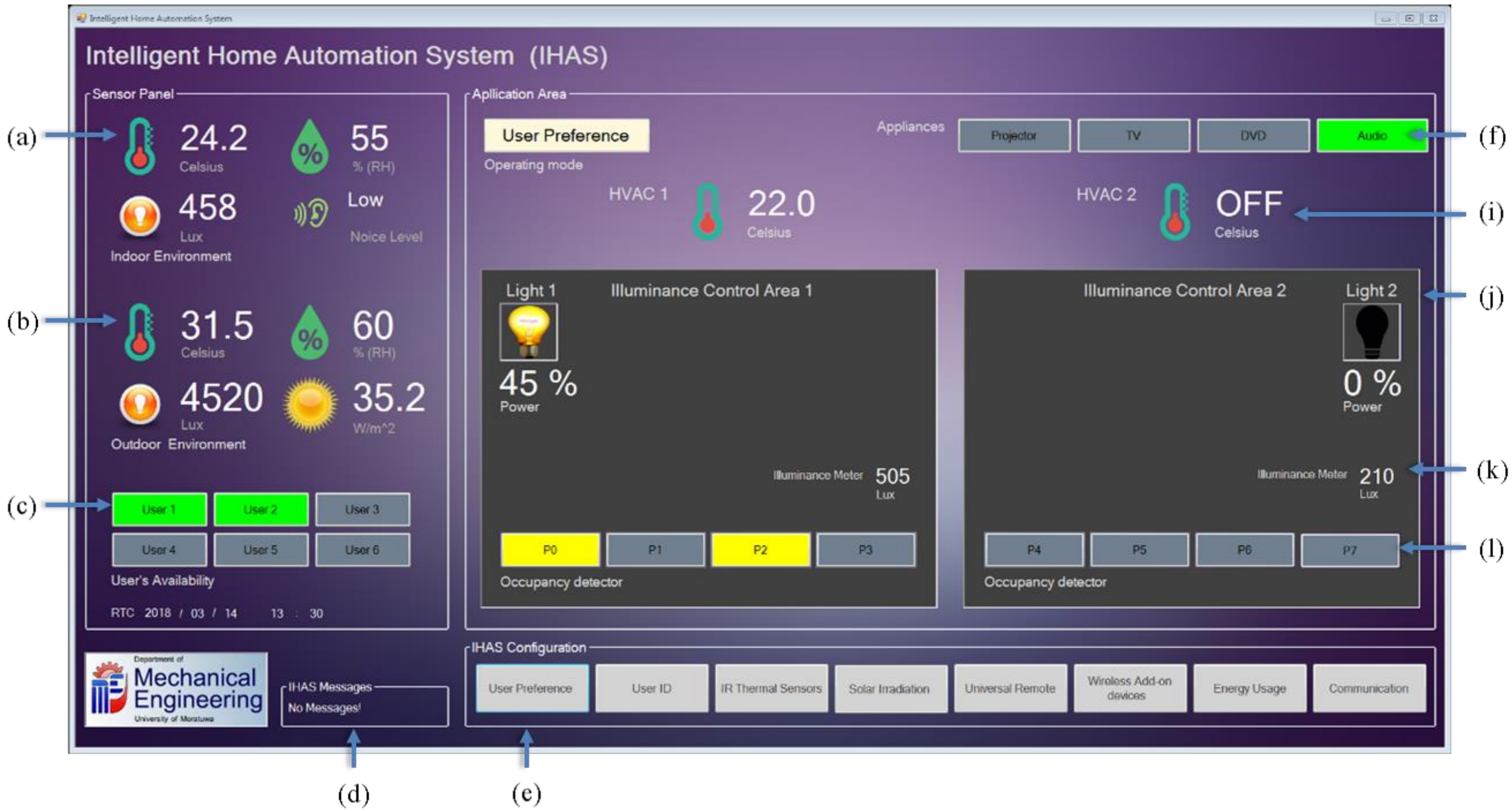


Figure 4.78: The image of the main GUI of IHAS central controller (a) Indoor environment information (b) outdoor environment information (c) User identification results (d) Message and alerts window (e) Switch buttons (Icons) to open the sub GUIs related to the sub system of the IHAS (f) Multimedia status (i) status of the HVAC systems operates in the application area (j) status of the lighting systems operates in the application area (k) Localized sensor information from wireless switching modules (l) occupants localization status

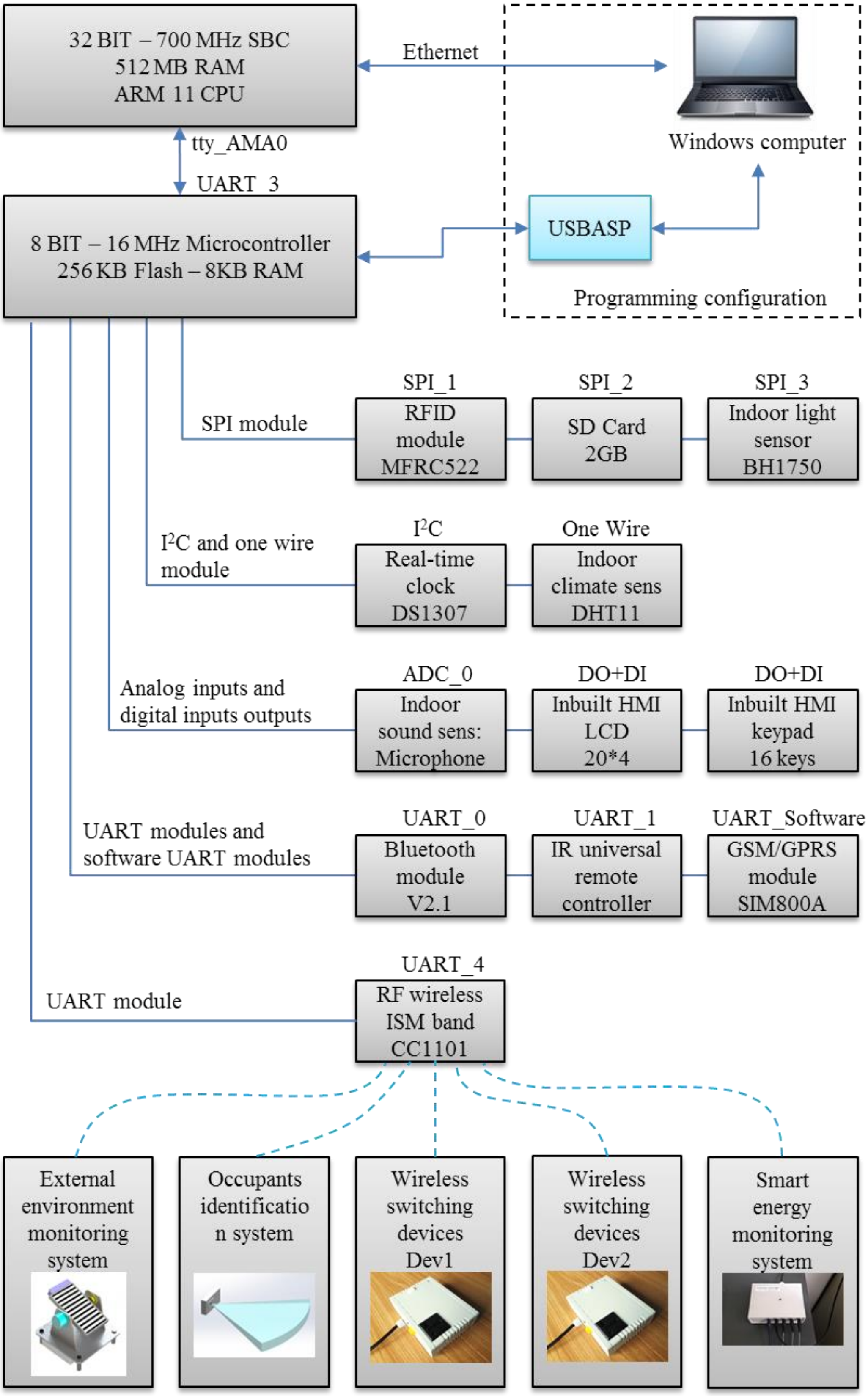


Figure 4.79: The layout of central controller of IHAS

4.4.3 The RF-based Wireless Communication System

The flexibility is one of the main objectives of the development of the IHAS. The IHAS needs to develop as a plug and play system with minimum system configuration on installation. But the entire system has different subsystems such as sensory systems and remote output devices. Some systems are located inside the building and some systems need to be located outside of the building. Therefore a wireless communication system is an important and necessary system for the IHAS to make convenient and efficient communication link between the entire systems [55].

In the development stage of a wireless communication system for IHAS, these factors are considered. Since the IHAS wireless network is a multi-node system, as the first factor, the system should have features to addressable duplex data communication. This feature enables the central controller to communicate with respective nodes with minimum interruptions. And another factor is operating range and power consumption. According to the application, node to node distance can be limit to maximum of 50 meters inside the building and 200 meters outside. The supply voltage up to 5V and finally unit cost per node.

4.4.3.1 CC 1101 Low-Power Sub-1 GHz RF Transceiver

CC1101 is an ISM (Industrial, Scientific and Medical) band RF transceiver module design for low cost low power wireless communication applications. CC1101 can be operate on different frequency ranges at 315, 433, 868, and 915 MHz as per the configuration and communication data rate can be configured up to 600 kbps with 64 byte of packet size. CC1101 has SPI interface to communicate with external microcontroller device and it requires few external passive components in circuit design. The Figure 4.80 shows the internal block diagram of the CC1101 Transceiver unit and Figure 4.81 shows the typical application circuit of the transceiver. Nowadays the compacted CC1101 based communication modules with USART interface available in the commercial market as shown in Figure 4.82. This module was selected to implement the wireless communication system of the IHAS.

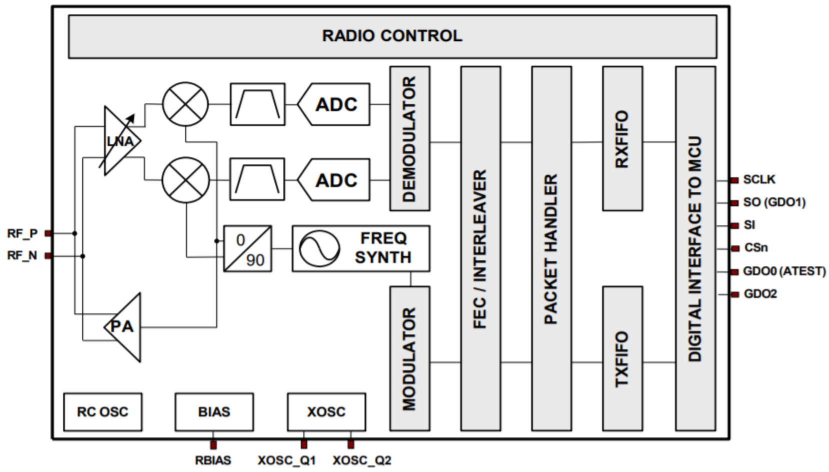


Figure 4.80: Simplified Block Diagram CC1101

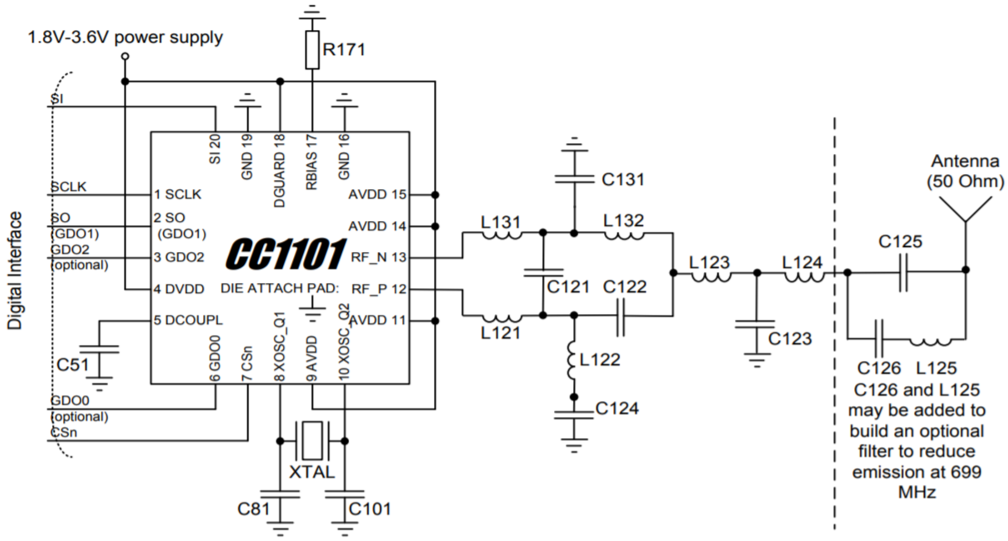


Figure 4.81: Typical Application and Evaluation Circuit 868/915 MHz

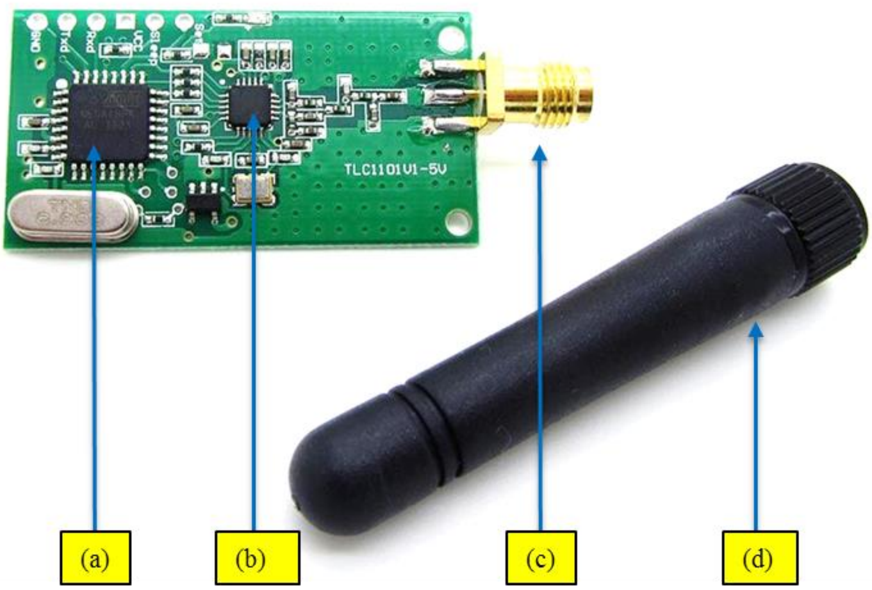


Figure 4.82: CC1101 RS232 Wireless Transceiver Module with Rod Antenna (a) 8 Bit microcontroller - Digital interface to USART converter (b) CC1101 chip with 20 pin VQFNP package (c) Antenna connector (d) Rod antenna

The selected module has a few configurations need to make through the UART bus. This configuration can be saved to the communication module itself. Or else it can be modified by the external microcontroller. Table 4.7 shows the protocol of module configurations.

Table 4.7: CC1101 communication module configuration description

Parameter	Command Code	Data range	Description
Set serial port baud rate	0xA3, 0x3A	0x01/0x02/0x03	0x01: 4800
			0x02: 9600
			0x03: 19200
Set channel	0xA7, 0x7A	0x00-0xFF	(256 channels)
Set module ID	0xA9, 0x9A	0xFF, 0xFF	(256 IDs)
Set TX power	0xAB, 0xBA	0x00/0x05/0x07/0x0A	0x00 = 0 dBm 0x05 = 5 dBm 0x07 = 7 dBm 0x0A = 10 dBm

According to the Table 4.7, the modules initially configured to operate at 9600 bps of baud rate with maximum transmission power. And set the communication channels to decimal 40 and device IDs to decimal 10 by sending following hex values to the module.

0xA3, 0x3A, 0x02	set baud rate to 9600 bps
0xA7, 0x7A, 0x28	set communication channel to the decimal 40
0xA9, 0x9A, 0x0A	set devise IDs to the decimal 10
0xAB, 0xBA, 0x0A	set TX power to the maximum (10 dBm).

4.4.3.2 Implementation of Wireless Communication Protocol

In communication systems, data protocol is a set of rules which allow two or more communication system to share information through variation of physical quantities. Data protocol systems include rules, syntax and synchronization systems and data collision recovery methods. Protocols can be developed by incorporate with hardware systems, software systems or combination of both.

The IHAS's wireless communication system operates under three modes as unicast (duplex), broadcast (simplex) and multicast (simplex) as shown in Figure 4.83.

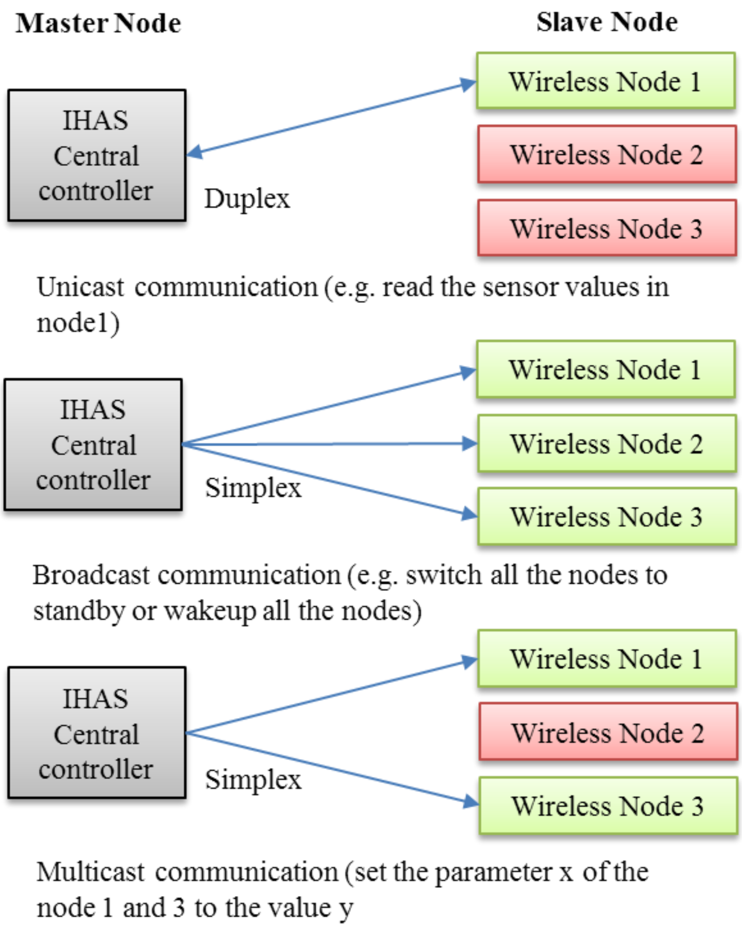


Figure 4.83: Wireless communication modes used in the central controller

In the developed wireless communication system, the unicast is used as a duplex communication method to make communication between central controller as a master node and one wireless node as a slave node.

The term broadcast is used to define communication where the data information is sent from one node to all other nodes. In this case, the IHAS central controller is the sender and the command information is sent to all other connected receiver nodes. This mode used to send the commands which need to perform simultaneously. As an example, using this mode the central controller can switch on or off or restart all the wireless nodes at one time.

Multicast is the same as broadcasting but in this mode, the central controller can be a command for the specific wireless devices for different actions.

Unicast Protocol

In the unicast method, each sender is using the 1st byte to indicate the starting of the new command and direction of the command. The hex FF indicates the command from the central controller or master node to a slave node and FD is indicated command from a slave node to the master node.

The second byte represents the address of the slave device or specific commands of broadcasting and multicasting modes. The range of 00-99 of the decimal is used to introduce the specific slave nodes and the 100-199 range is used to indicate the broadcasting and multicasting operations.

The third byte is the command address and the fourth byte to n-1 bytes are the specific values corresponding to the function of the nodes. And nth byte is the final byte which indicates the end of the specific command and direction. Table 4.8, 4.9, 4.10 and 4.11 shows the structure of the unicast command and command description.

Table 4.8: The structure of the master to slave unicast command

Value (hex)	FF	00-63	00-C7	00-C7	00-C7	FE
Index	0	1	2	3	n-1	n

Table 4.9: The command description of the master to slave unicast command

Byte Index	Type	Range	Description
0 byte	Constant	255 (FF)	FF represents the starting of a new command from the master node
1 byte	Variable	0-99	Specific node address
2 byte	Variable	0-199	Specific command address
3 byte	Variable	0-199	1st value
n byte	Variable	0-199	nth value
n+1 byte	Constant	254 (FE)	FE represents the end of the command of the master node

Table 4.10: The structure of the slave to master unicast command

Value (hex)	FD	00-63	00-C7	00-C7	00-C7	FC
Index	0	1	2	3	n	n+1

Table 4.11: The command description of the slave to master unicast command

Byte Index	Type	Range	Description
0 byte	Constant	253 (FD)	FD represents the starting of a new command from a wireless node
1 byte	Variable	0-99	Wireless node address
2 byte	Variable	0-199	Specific command address
3 byte	Variable	0-199	1st value
n byte	Variable	0-199	nth value
n+1 byte	Constant	252 (FC)	FC represents the end of the command of wireless node

Broadcast and Multicast Protocol

The broadcast and multicast method is simplex. Each and every time the master will be the sender and slaves are the receivers. In this method, only four bytes are used in one command. The first byte is constant and the value of 0xFF or decimal 255. Which represent the command starting and command from the master node as same as unicast. The second byte is in range of 0x64-0xC7 or decimal 100-199. Which represent the specific broadcast and multicast commands as shown in Table 4.12, Table 4.13 and Table 4.14. The third byte represents a command value which used in some of the commands and fourth or last byte is a constant with a value of 0xFB or 251 which represents the end of the broadcast or multicast command and in this mode, slave nodes do not provide the feedback message to the master node.

Table 4.12. Broadcast and multicast commands descriptions

Command Decimal (hex)	Communication mode	Description
100 (64)	Broadcast	Switch all wireless nodes to the standby mode (off mode) • All sensor nodes • All output device control nodes e.g. code = FF 64 00 FB
101 (65)	Broadcast	Switch all wireless nodes to the on mode • All sensor nodes • All output device control nodes e.g. code = FF 65 00 FB

102 (66) to 149 (95)	Broadcast	Not used
150 (96)	Multicast	Switch all wireless switching device to standby mode e.g. code = FF 96 00 FB
151 (97)	Multicast	Switch all wireless switching devise to on mode e.g. code = FF 97 00 FB
152 (98)	Multicast	Change the percentage of output voltage of the wireless switching devise to value x e.g. code = FF 98 00 FB x=0% e.g. code = FF 98 64 FB x=50% e.g. code = FF 98 C7 FB x=100%
153 (99) to 199 (C7)	Multicast	Not used

Table 4.13: The structure of the broadcast and multicast command

Value (hex)	FF	64-C7	00-C7	FB
Index	0	1	2	3

Table 4.14: The command description of the broadcast and multicast command

Byte Index	Type	Range	Description
0 byte	Constant	255 (FF)	FF represents the starting of a new command from the master node
1 byte	Variable	100-199	Specific broadcast or multicast commands
2 byte	Variable	0-199	Command value
3 byte	Constant	251(FB)	FB represents the end of the broadcast or multicast command from the master

5 PERFORMANCE AND ENERGY ENHANCEMENT OF IHAS

Under the energy enhancement and system validation, several testing were conducted to evaluate the system performance under the different conditions and systems [56]. The thermal comfort controller and visual comfort controller drive the main comfort parameters as well as a large amount of total energy consumption of the building. Therefore the system validation was conducted focused on HVAC systems and lighting systems which are operated through the IHAS system.

In these experiments the related devices such as HVAC systems or lighting systems operated under the default control modes (manual control modes) by giving usual parameters and settings such as set-points, on-time, and off-time. During the experiments, the energy consumption and comfort levels were recorded using developed smart energy meter as discussed in a previous chapter. Then these systems were controlled in automatic mode through the IHAS based on different control algorithms and modes and energy results were recorded. Finally, the obtained results were compared and the system performance was evaluated under different conditions. The Figure 5.1 shows the configuration layout of the carried out testing under the two-modes as without controller and with a controller.

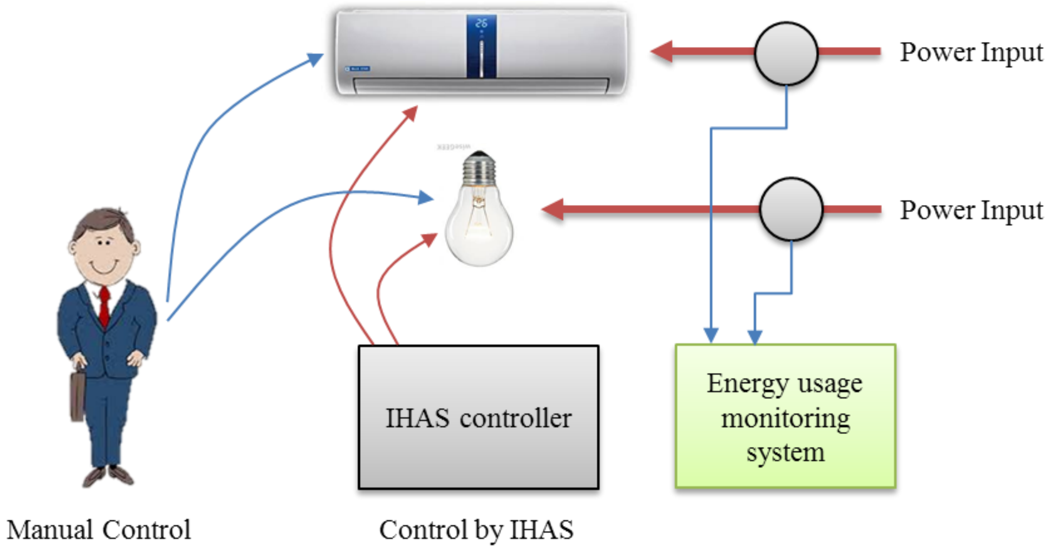


Figure 5.1: The configuration of system validation experiments under the energy

5.1 Energy Performance on Thermal Comfort Systems

In this experiment, three 24000 BTU HVAC systems were installed in a laboratory and controlled in the manual mode and the automatic mode during two days. In the first day, the HVAC systems were switched and configured by a lab officer as usual. And in the next day HVAC system was allowed to operate by the IHAS under the user preferences mode according to the details given,

Parameters of HVAC systems

- Type Split type
- Capacity 3 * 24000 BTU
- Power consumption 2.75 kW per unit
- Area 1650 Square foots

Parameters related to the manual control experiments

- Outdoor temperature 30-32 Celsius
- Specific Load conditions 5 occupants
- HVAC set point Static (24 Celsius)

Parameters related to the automatic mode (**User preference mode**)

- Outdoor temperature 30-32 Celsius
- Specific Load conditions 5 occupants
- HVAC set point Dynamic
- The preferred temperature for user 1 25 Celsius
- The preferred temperature for user 2 27 Celsius
- The preferred temperature for user 3 25 Celsius
- The preferred temperature for user 4 27 Celsius
- The preferred temperature for user 5 26 Celsius

The preferred temperature values of users were entered to the IHAS system and during the experiment, the presence of the users were identified by using the RFID tags specific to the users. Figures 5.2 to 5.7 shows the energy consumption of the HVAC systems during the experiments and in the same situations, the comfort feedbacks of users were stated.

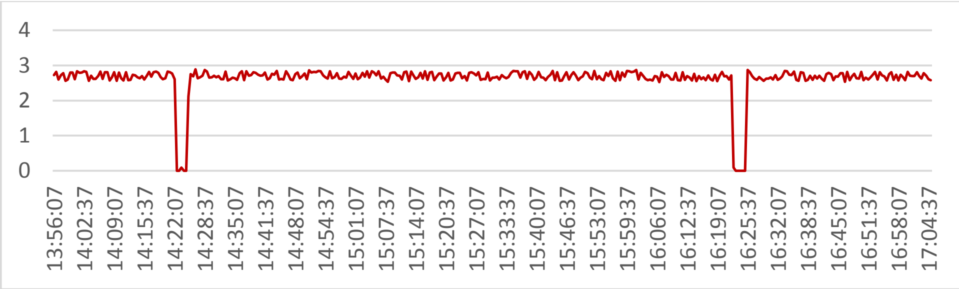


Figure 5.2: Energy usage of HVAC system 1 during the first day in manual mode

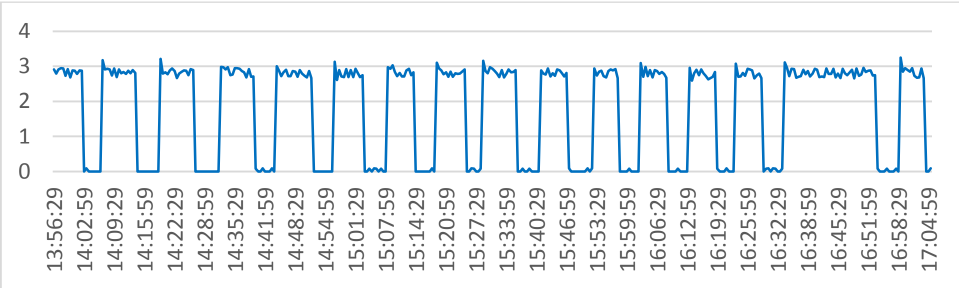


Figure 5.3: Energy usage of HVAC system 1 during the second day in automatic mode through the IHAS

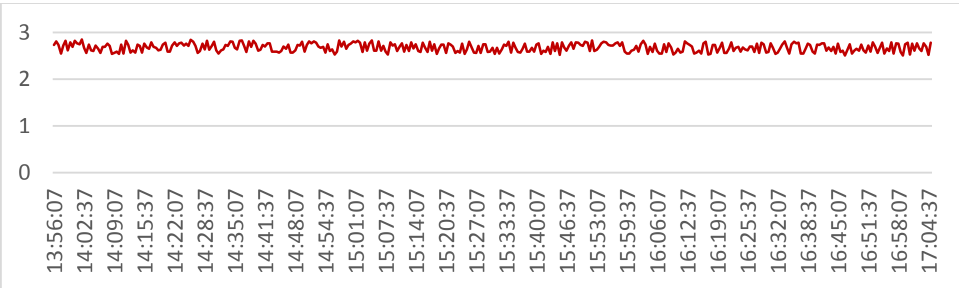


Figure 5.4: Energy usage of HVAC system 2 during the first day in manual mode

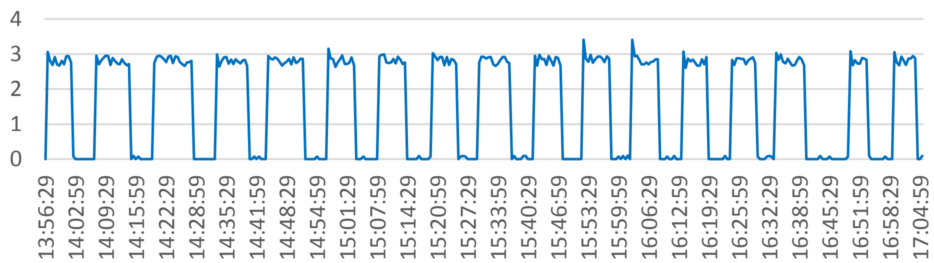


Figure 5.5: Energy usage of HVAC system 2 during the second day in automatic mode through the IHAS

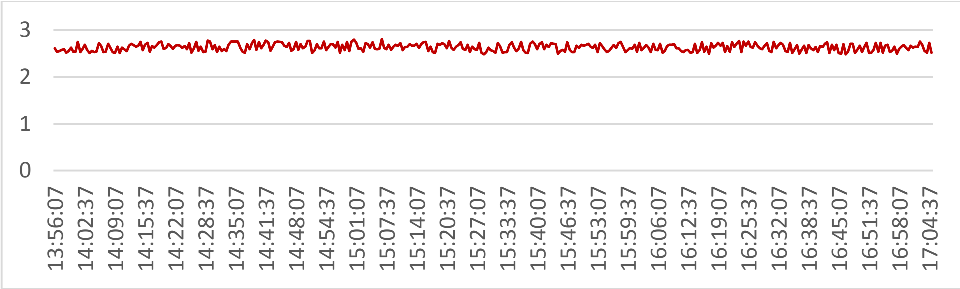


Figure 5.6: Energy usage of HVAC system 3 during the first day in manual mode

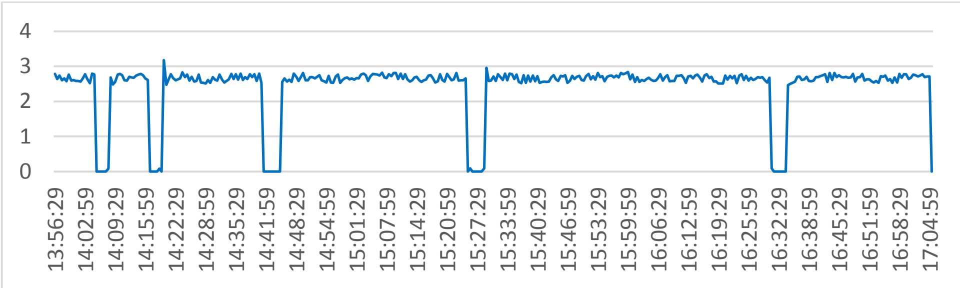


Figure 5.7: Energy usage of HVAC system 3 during the second day in automatic mode through the IHAS

According to the result of the experiment, the total energy improvement was calculated as shown in Table 5.1.

Table 5.1: Experiment results of HVAC systems on manual mode and user preference mode

Time 14:00 - 17:00	Energy consumption without controller (kW)	Energy consumption with a controller (kW)
HVAC system 1	8.25	5.53
HVAC system 2	8.43	5.03
HVAC system 3	8.3	7.63
Total	**24.98 kW**	**18.19 kW**
Saving	**-**	**28.2% of energy reduction**

According to the above experiments, it has shown that the 28.2 % energy reduction from the HVAC systems under the automatic control mode. From this experiment, several characteristics were found related to the HVAC system operating conditions.

In manual control mode, usually, the HVAC systems are set to 24 Celsius as the set point which was defined by usually. But according to the climatic conditions of the specific day the load condition of the particular building has caused to overload condition of the HVAC system to maintain 24 Celsius of indoor temperature level as user set point. This cause for running the compressor units of HVAC systems continuously and increase the total energy consumption of the building as shown in Figure 5.2, Figure 5.4 and Figure 5.6.

In automatic control mode, initially the controller calculates the optimum margin for the indoor thermal set-point based on the read-time indoor load condition and outdoor climate parameters to avoid the overloading conditions of the HVAC systems. And then, the controller changes the set point of the HVAC systems by time to time according to the presence and abuse of specific user in the living premises automatically. This will helps to avoid unnecessary energy usage due to maintaining unwanted and overloaded thermal parameters in the living premises.

6 CONCLUSION

The home automation systems are used to control the home appliances and devices automatically in residential building to improve the comfort and convenience while maintaining the energy consumption at an optimum level. Over the past decade, there have been found different types of home automation systems and controllers working on the automation and control system principles. These each and every automation systems have their own advantages, disadvantage and functionalities, hence it needs further development and research on the automation parameters such as intelligent controls, smart sensor networks and flexible and efficient control configurations to develop more efficient control systems to a particular application.

In this research, the main motive was to develop an intelligent home automation system for enhanced energy performance. The overall research work can be divided into several key areas. As the initial stage of this research, a closed loop control architecture was proposed to implement the efficient home automation system based on the residential buildings. The implementation of sensory systems was started. As a result of initial work, the outdoor climate monitoring system was designed, fabricated and conducted the validation for the developed sensory system. Then moved to the implementation of the indoor sensor system. Using the miniaturized sensors and interface controller, the indoor climate sensory system was implemented.

Occupancy identification and localization is an important factor in home automation systems. Which allows controlling the lighting and HVAC systems based on the presence and presence location of the occupants. An occupancy identification and localization system was designed and validated using a MEMS-based non-contact IR thermal sensor as the next stage of this research. Energy monitoring is an important factor during this research under the system validations and energy monitors are the common devices which are available in the commercial market. A smart energy monitoring system with load identification functionalities was design fabricated and tested to use as sensory devices of the IHAS.

After completing the implementation of the sensory system of the IHAS, hardware platforms were implemented to make the common control interface with the building appliances as devices control interface. The main objective of this implementation was to improve the system flexibility by avoiding the automation barriers occurred in existing buildings and appliances. With this developed device interface, an experiment was carried out to verify the feasibility to use this system for the home automation applications.

As the final stage of this research a hardware platform for the IHAS was designed and fabricated based on a 32-bit single board computer and 8-bits and 16-bits microcontroller devices including the RF-based wireless communication system. By using the implemented control platform, sensory system and device interfaces, the different types of control algorithms were implemented to automate the home in order to achieve the improved comfort in living premises while maintaining the energy consumption at an optimum level. Using the implemented system several experiments were conducted in different home residential applications and results were discussed illustrating the improved energy performance in the building.

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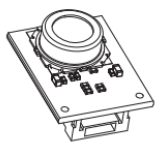
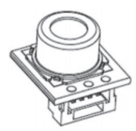
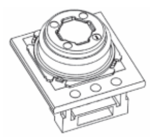
APPENDICES

Appendix A: Specifications of Omron D6T IR thermal sensor (Part A)

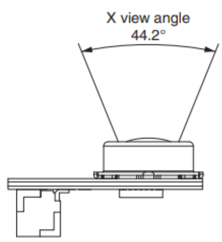
Thermal Sensors

Element type	Model	Shape
4×4	D6T-44L-06	
1×8	D6T-8L-09	
1×1	D6T-1A-01	
	D6T-1A-02	

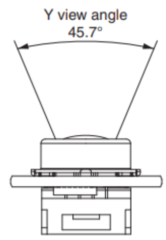
Field of View Characteristics

D6T-44L-06

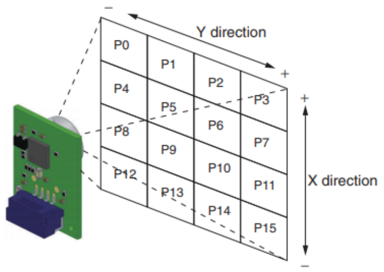
Field of view in X Direction



Field of view in Y Direction



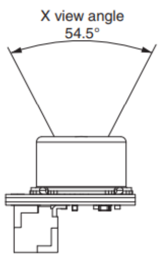
Detection Area for Each Pixel



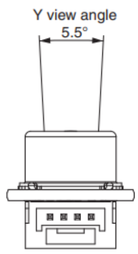
Note: Definition of view angle: Using the maximum Sensor output as a reference, the angular range where the Sensor output is 50% or higher when the angle of the Sensor is changed is defined as the view angle.

D6T-8L-09

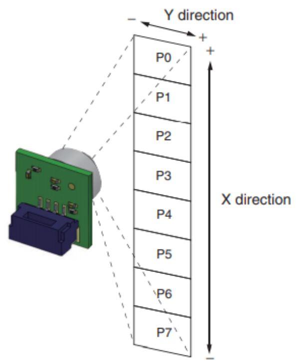
Field of view in X Direction



Field of view in Y Direction



Detection Area for Each Pixel

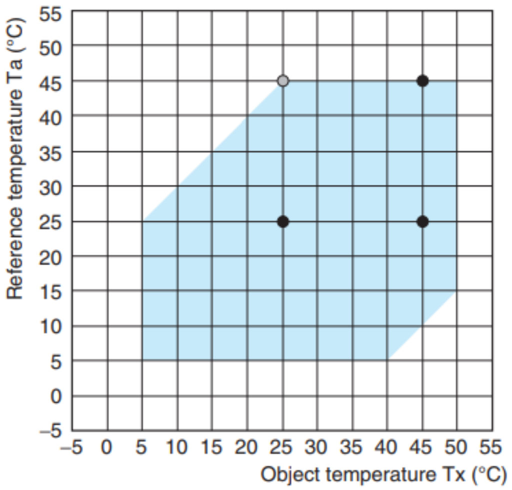


Note: Definition of view angle: Using the maximum Sensor output as a reference, the angular range where the Sensor output is 50% or higher when the angle of the Sensor is changed is defined as the view angle.

Appendix B: Specifications of Omron D6T IR Thermal Sensor (Part B)

Object Temperature Detection Range

D6T-44L-06, D6T-8L-09, D6T-1A-01



Characteristics

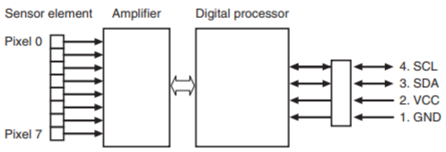
Item	Model	D6T-44L-06	D6T-8L-09	D6T-1A-01	D6T-1A-02
View angle [*1]	X direction	44.2°	54.5°	58.0°	26.5°
	Y direction	45.7°	5.5°	58.0°	26.5°
Object temperature output accuracy [*2]	Accuracy 1	±1.5°C max. Measurement conditions: Vcc = 5.0 V (1) Tx = 25°C, Ta = 25°C (2) Tx = 45°C, Ta = 25°C (3) Tx = 45°C, Ta = 45°C			
	Accuracy 2	±3.0°C max. Measurement conditions: Vcc = 5.0 V (4) Tx = 25°C, Ta = 45°C			
Current consumption		5 mA typical		3.5 mA typical	

Functions

Item / Model	D6T-44L-06	D6T-8L-09	D6T-1A-01	D6T-1A-02
Object temperature detection range [*2]	5 to 50°C	5 to 50°C	5 to 50°C	-40 to 80°C
Reference temperature detection range [*2]	5 to 45°C	5 to 45°C	5 to 45°C	-40 to 80°C
Output specifications	Digital values that correspond to the object temperature (Tx) and reference temperature (Ta) are output from a serial communications port.			
Output form	Binary code (10 times the detected temperature (°C))			
Communications form	I2C compliant			
Temperature resolution (NETD) [*3]	0.06°C	0.03°C	0.02°C	0.06°C

Connections

Thermal Sensor Configuration Diagram



Note: The 4×4 type has pixels 0 to 15.
The 1×1 type has pixel 0.

Terminal Arrangement

Terminal	Name	Function	Remarks
1	GND	Ground	
2	VCC	Positive power supply voltage input	
3	SDA	Serial data I/O line	Connect the open-drain SDA terminal to a pull-up resistor.
4	SCL	Serial clock input	Connect the open-drain SCL terminal to a pull-up resistor.

Appendix C: Hardware Specification of Digital Signal Controller (Device – dsPIC30F4013)

MICROCHIP **dsPIC30F3014/4013**

dsPIC30F3014/4013 High-Performance Digital Signal Controllers

Note: This data sheet summarizes features of this group of dsPIC30F devices and is not intended to be a complete reference source. For more information on the CPU, peripherals, register descriptions and general device functionality, refer to the *dsPIC30F Family Reference Manual* (DS70046). For more information on the device instruction set and programming, refer to the *dsPIC30F Programmer's Reference Manual* (DS70030).

High-Performance Modified RISC CPU:

- Modified Harvard architecture
- C compiler optimized instruction set architecture
- Flexible addressing modes
- 84 base instructions
- 24-bit wide instructions, 16-bit wide data path
- Up to 48 Kbytes on-chip Flash program space
- 2 Kbytes of on-chip data RAM
- 1 Kbyte of non-volatile data EEPROM
- 16 x 16-bit working register array
- Up to 30 MIPs operation:
  - DC to 40 MHz external clock input
  - 4 MHz-10 MHz oscillator input with PLL active (4x, 8x, 16x)
- Up to 33 interrupt sources:
  - 8 user selectable priority levels
  - 3 external interrupt sources
  - 4 processor traps

DSP Features:

- Dual data fetch
- Modulo and Bit-reversed modes
- Two 40-bit wide accumulators with optional saturation logic
- 17-bit x 17-bit single cycle hardware fractional/integer multiplier
- All DSP instructins are single cycle
  - Multiply-Accumulate (MAC) operation
- Single cycle ±16 shift

Peripheral Features:

- High current sink/source I/O pins: 25 mA/25 mA
- Up to five 16-bit timers/counters; optionally pair up 16-bit timers into 32-bit timer modules
- Up to four 16-bit Capture input functions
- Up to four 16-bit Compare/PWM output functions
- Data Converter Interface (DCI) supports common audio Codec protocols, including I^2S and AC'97
- 3-wire SPI™ module (supports 4 Frame modes)
- I^2C™ module supports Multi-Master/Slave mode and 7-bit/10-bit addressing
- Up to two addressable UART modules with FIFO buffers
- CAN bus module compliant with CAN 2.0B standard

Analog Features:

- 12-bit Analog-to-Digital Converter (A/D) with:
  - 100 Ksps conversion rate
  - Up to 13 input channels
  - Conversion available during Sleep and Idle
- Programmable Low Voltage Detection (PLVD)
- Programmable Brown-out Detection and Reset generation

Special Microcontroller Features:

- Enhanced Flash program memory:
  - 10,000 erase/write cycle (min.) for industrial temperature range, 100K (typical)
- Data EEPROM memory:
  - 100,000 erase/write cycle (min.) for industrial temperature range, 1M (typical)
- Self-reprogrammable under software control
- Power-on Reset (POR), Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Flexible Watchdog Timer (WDT) with on-chip low power RC oscillator for reliable operation
- Fail-Safe Clock Monitor operation:
  - Detects clock failure and switches to on-chip low power RC oscillator

Appendix D: Hardware Specification of 8-bit Microcontroller (Device – PIC18F452)

MICROCHIP

PIC18FXX2

28/40-pin High Performance, Enhanced FLASH Microcontrollers with 10-Bit A/D

High Performance RISC CPU:

- C compiler optimized architecture/instruction set
  - Source code compatible with the PIC16 and PIC17 instruction sets
- Linear program memory addressing to 32 Kbytes
- Linear data memory addressing to 1.5 Kbytes

Device	On-Chip Program Memory		On-Chip RAM (bytes)	Data EEPROM (bytes)
	FLASH (bytes)	# Single Word Instructions		
PIC18F242	16K	8192	768	256
PIC18F252	32K	16384	1536	256
PIC18F442	16K	8192	768	256
PIC18F452	32K	16384	1536	256

- Up to 10 MIPs operation:
  - DC - 40 MHz osc./clock input
  - 4 MHz - 10 MHz osc./clock input with PLL active
- 16-bit wide instructions, 8-bit wide data path
- Priority levels for interrupts
- 8 x 8 Single Cycle Hardware Multiplier

Peripheral Features:

- High current sink/source 25 mA/25 mA
- Three external interrupt pins
- Timer0 module: 8-bit/16-bit timer/counter with 8-bit programmable prescaler
- Timer1 module: 16-bit timer/counter
- Timer2 module: 8-bit timer/counter with 8-bit period register (time-base for PWM)
- Timer3 module: 16-bit timer/counter
- Secondary oscillator clock option - Timer1/Timer3
- Two Capture/Compare/PWM (CCP) modules. CCP pins that can be configured as:
  - Capture input: capture is 16-bit, max. resolution 6.25 ns ($T_{CY}/16$)
  - Compare is 16-bit, max. resolution 100 ns (T_{CY})
  - PWM output: PWM resolution is 1- to 10-bit, max. PWM freq. @: 8-bit resolution = 156 kHz
10-bit resolution = 39 kHz
- Master Synchronous Serial Port (MSSP) module, Two modes of operation:
  - 3-wire SPI™ (supports all 4 SPI modes)
  - I²C™ Master and Slave mode

Peripheral Features (Continued):

- Addressable USART module:
  - Supports RS-485 and RS-232
- Parallel Slave Port (PSP) module

Analog Features:

- Compatible 10-bit Analog-to-Digital Converter module (A/D) with:
  - Fast sampling rate
  - Conversion available during SLEEP
  - Linearity ≤ 1 LSb
- Programmable Low Voltage Detection (PLVD)
  - Supports interrupt on-Low Voltage Detection
- Programmable Brown-out Reset (BOR)

Special Microcontroller Features:

- 100,000 erase/write cycle Enhanced FLASH program memory typical
- 1,000,000 erase/write cycle Data EEPROM memory
- FLASH/Data EEPROM Retention: > 40 years
- Self-reprogrammable under software control
- Power-on Reset (POR), Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own On-Chip RC Oscillator for reliable operation
- Programmable code protection
- Power saving SLEEP mode
- Selectable oscillator options including:
  - 4X Phase Lock Loop (of primary oscillator)
  - Secondary Oscillator (32 kHz) clock input
- Single supply 5V In-Circuit Serial Programming™ (ICSP™) via two pins
- In-Circuit Debug (ICD) via two pins

CMOS Technology:

- Low power, high speed FLASH/EEPROM technology
- Fully static design
- Wide operating voltage range (2.0V to 5.5V)
- Industrial and Extended temperature ranges
- Low power consumption:
  - < 1.6 mA typical @ 5V, 4 MHz
  - 25 µA typical @ 3V, 32 kHz
  - < 0.2 µA typical standby current

Appendix E: Hardware Specification of 8-bit Microcontroller (Device – AT mega 2560)

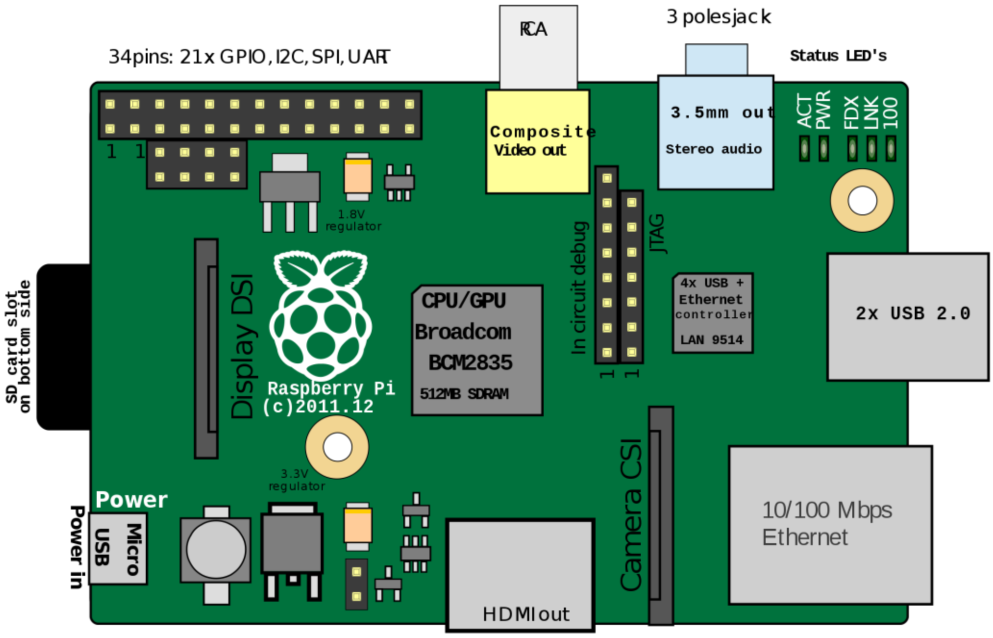
Atmel ATmega640/V-1280/V-1281/V-2560/V-2561/V

8-bit Atmel Microcontroller with 16/32/64KB In-System Programmable Flash

Features

- High Performance, Low Power Atmel® AVR® 8-Bit Microcontroller
- Advanced RISC Architecture
  - 135 Powerful Instructions – Most Single Clock Cycle Execution
  - 32 × 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16MHz
  - On-Chip 2-cycle Multiplier
- High Endurance Non-volatile Memory Segments
  - 64K/128K/256KBytes of In-System Self-Programmable Flash
  - 4Kbytes EEPROM
  - 8Kbytes Internal SRAM
  - Write/Erase Cycles:10,000 Flash/100,000 EEPROM
  - Data retention: 20 years at 85°C/ 100 years at 25°C
  - Optional Boot Code Section with Independent Lock Bits
    - In-System Programming by On-chip Boot Program
    - True Read-While-Write Operation
  - Programming Lock for Software Security
    - Endurance: Up to 64Kbytes Optional External Memory Space
- Atmel® QTouch® library support
  - Capacitive touch buttons, sliders and wheels
  - QTouch and QMatrix acquisition
  - Up to 64 sense channels
- JTAG (IEEE® std. 1149.1 compliant) Interface
  - Boundary-scan Capabilities According to the JTAG Standard
  - Extensive On-chip Debug Support
  - Programming of Flash, EEPROM, Fuses, and Lock Bits through the JTAG Interface
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescaler and Compare Mode
  - Four 16-bit Timer/Counter with Separate Prescaler, Compare- and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Four 8-bit PWM Channels
  - Six/Twelve PWM Channels with Programmable Resolution from 2 to 16 Bits (ATmega1281/2561, ATmega640/1280/2560)
  - Output Compare Modulator
  - 8/16-channel, 10-bit ADC (ATmega1281/2561, ATmega640/1280/2560)
  - Two/Four Programmable Serial USART (ATmega1281/2561, ATmega640/1280/2560)
  - Master/Slave SPI Serial Interface
  - Byte Oriented 2-wire Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
  - Interrupt and Wake-up on Pin Change
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby, and Extended Standby
- I/O and Packages
  - 54/86 Programmable I/O Lines (ATmega1281/2561, ATmega640/1280/2560)
  - 64-pad QFN/MLF, 64-lead TQFP (ATmega1281/2561)
  - 100-lead TQFP, 100-ball CBGA (ATmega640/1280/2560)
  - RoHS/Fully Green
- Temperature Range:
  - -40°C to 85°C Industrial
- Ultra-Low Power Consumption
  - Active Mode: 1MHz, 1.8V: 500µA
  - Power-down Mode: 0.1µA at 1.8V
- Speed Grade:
  - ATmega640V/ATmega1280V/ATmega1281V:
    - 0 - 4MHz @ 1.8V - 5.5V, 0 - 8MHz @ 2.7V - 5.5V
  - ATmega2560V/ATmega2561V:
    - 0 - 2MHz @ 1.8V - 5.5V, 0 - 8MHz @ 2.7V - 5.5V
  - ATmega640/ATmega1280/ATmega1281:
    - 0 - 8MHz @ 2.7V - 5.5V, 0 - 16MHz @ 4.5V - 5.5V
  - ATmega2560/ATmega2561:
    - 0 - 16MHz @ 4.5V - 5.5V

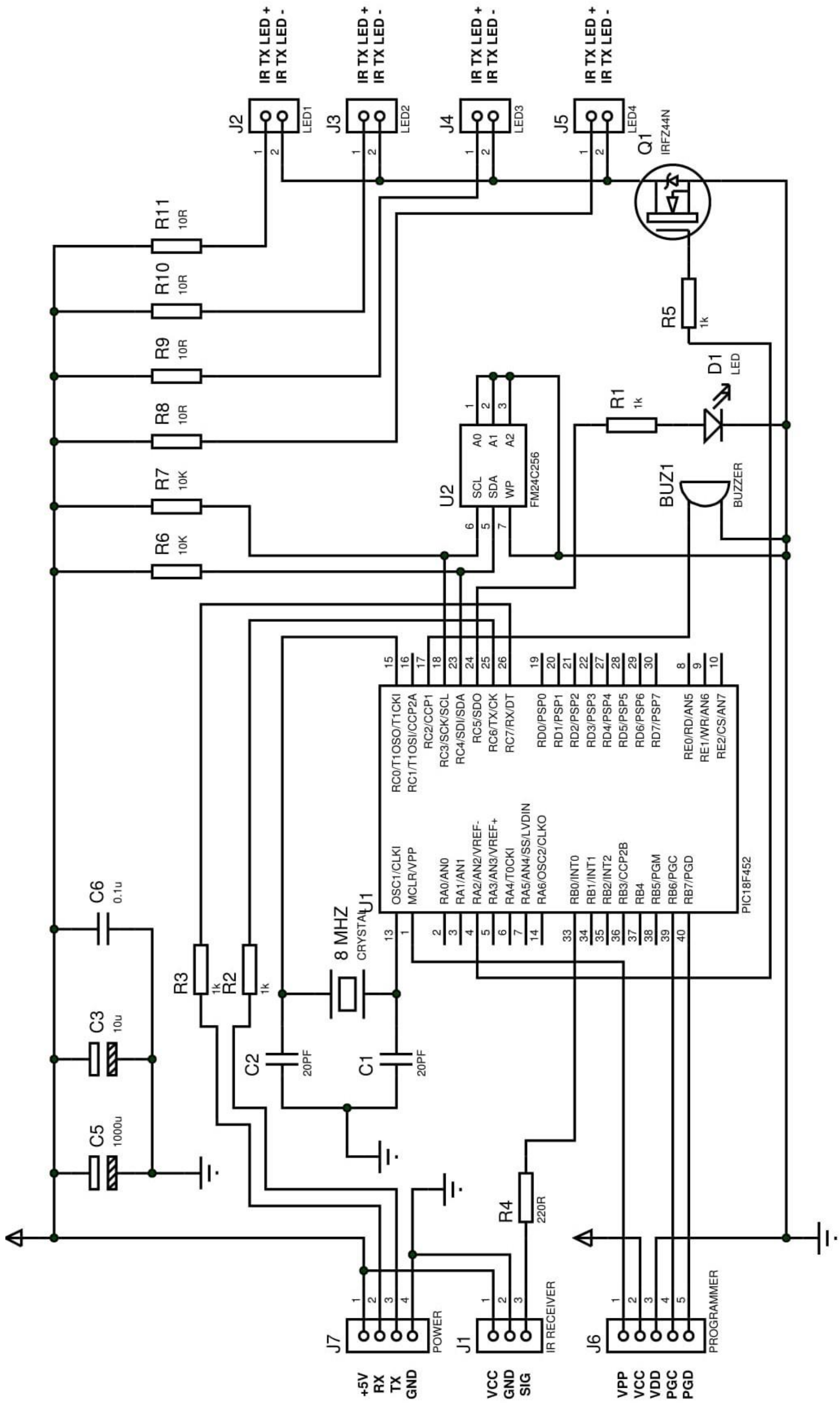
Appendix F: Hardware Specifications of Single Board Computer (Raspberry pi Model B+)



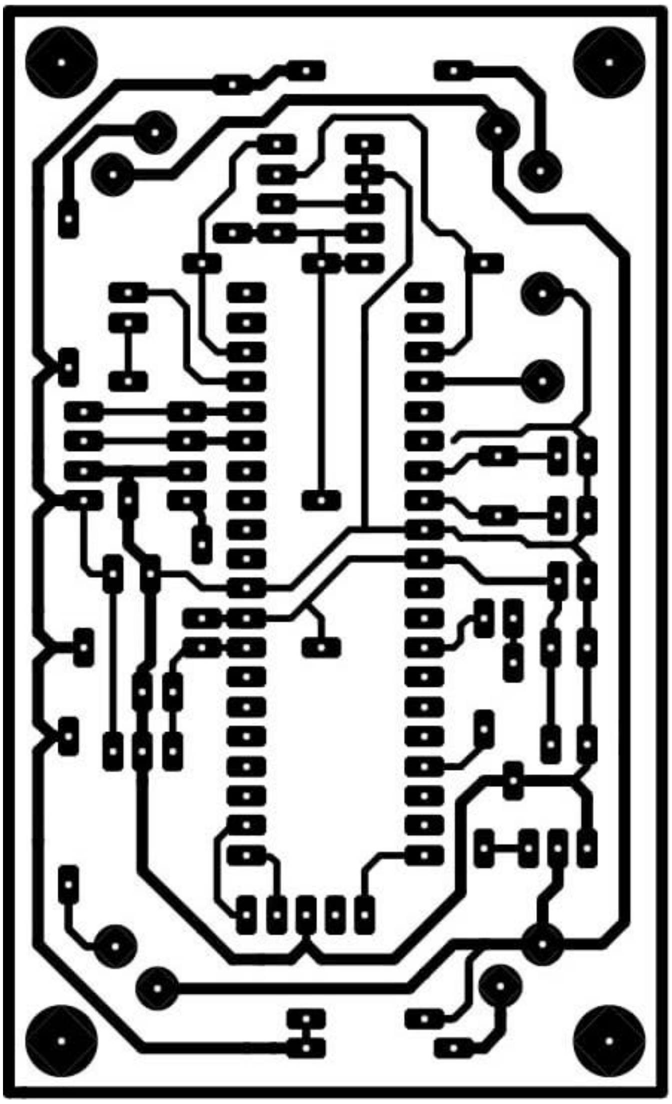
Raspberry Pi A/B
Rev 2 P1 GPIO Header

	Pin No.		
3.3V	1	2	5V
GPIO2	3	4	5V
GPIO3	5	6	GND
GPIO4	7	8	GPIO14
GND	9	10	GPIO15
GPIO17	11	12	GPIO18
GPIO27	13	14	GND
GPIO22	15	16	GPIO23
3.3V	17	18	GPIO24
GPIO10	19	20	GND
GPIO9	21	22	GPIO25
GPIO11	23	24	GPIO8
GND	25	26	GPIO7

Appendix G: Schematic Diagram of Teachable IR Remote Controller



Appendix H: PCB Layout of Teachable IR Remote Controller



Appendix I: Microcontroller Firmware Implementation of Teachable IR Remote Controller


```c
// Project              : Teachable IR remote controller
// Microcontroller      : PIC18F452
// System clock         : 8 MHz Crystal oscillator
// Programmer           : PICKIT2 ICD

// system variable initialization ********************************************
char txt[7];
char pol_flag=0;
char t1,th;
signed int period[650];
unsigned int array_limit=650;
signed int temp=0;
unsigned int i=0;
unsigned int j=0;
char send,clear_array,transmit;
char uart_rd=0;
char data_read=0;
char c0,c1,c2,c3;
char polarity=0;
unsigned int d0,d1,d2,d3,d4,dataval,read_value;

unsigned int t_low,t_high;
char t1l=0;
char t1h=0;
char t2l=0;
char t2h=0;

sbit buzzer at latc.b1;
sbit red at latc.b5;
sbit blue at late.b0;
sbit ir_led at lata.b2;

void main() {
     trisa.f2=0;
     trisb=255;
     trisc.f5=0;
     trisc.f1=0;
     trisd=255;
     trise.f0=0;

     portb=0;
     lata=0;
     latc=0;
     late=0;

     intcon2.rbpu=0;

     UART1_Init(9600); // ___________________Initialize UART module at 9600 bps
     Delay_ms(100);

     buzzer=1;
     delay_ms(200);
     buzzer=0;

     blue=1;
     red=1;
     delay_ms(100);
     red=0;
     blue=0;

     intcon.int0if=0; // _____________Initialize Interrupt for RB0 external int
     intcon.int0ie=0;
```

```
    intcon.gie=1;
    intcon2.intedg0=0;

    intcon.gie=1; // _____________________Initialize interrupt for UART module
    intcon.peie=1;
    pir1.rcif=0;
    pie1.rcie=1;

    t0con=0b10000000; // ____________________________________Initialize timer0
    I2C1_Init(100000); // ________________________Initialize I2C communication

     i=0;
     while(i<array_limit){
     period[i]=0;
     i++;
     }

     send=0;
     clear_array=0;
     transmit=0;

     while(1){ //)___________________________________________________Main loop

       if(send==1){
       send=0;
       uart1_write_text("S");
       i=1;
       temp=period[i];
         while(temp!=0){
         //while(i<array_limit){
          temp=period[i];
           if(temp<0){
            polarity=1;
            temp=temp*-1;
           }else{
            polarity=0;
           }
          inttostr(temp,txt);
          uart1_write_text("R");
          uart1_write_text(txt);
           if(polarity==1){
           uart1_write_text("N");
           }else{
           uart1_write_text("P");
           }
          i++;
         }
       uart1_write_text("s");
       i=0;
       red=0;
          intcon.int0ie=0;
          intcon.int0if=0;
       }

       if(clear_array==1){
       clear_array=0;
       buzzer=1;
       i=0;
       while(i<array_limit){
       period[i]=0;
       i++;
       }
```

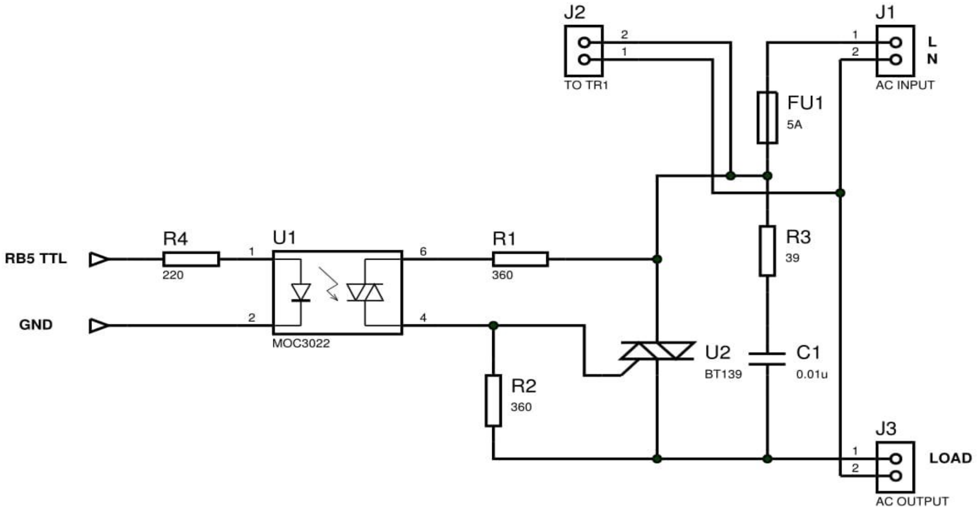
```
        i=0 ;
        buzzer=0;
        red=0;
        }

        if(transmit==1){
        transmit=0;
        buzzer=1;
        intcon.int0ie=0;
        intcon.gie=0;
        blue=1;

        i=1;
        temp=period[i];
        if(temp<0) temp=temp*-1;
        temp=65535-temp;
        t_high=temp/256;
        t_low=temp%256;
        t1h=t_high;
        t1l=t_low;
        i++;
        temp=period[i];
        if(temp<0) temp=temp*-1;
        temp=65535-temp;
        t_high=temp/256;
        t_low=temp%256;
        t2h=t_high;
        t2l=t_low;

        while(i<array_limit){

         tmr0h=t1h;
         tmr0l=t1l;
         intcon.tmr0if=0;
         if(t1h==255)intcon.tmr0if=1;
         while(intcon.tmr0if==0){
          ir_led=1;
          delay_us(12);
          ir_led=0;
          delay_us(11);
         }

         tmr0h=t2h;
         tmr0l=t2l;
         intcon.tmr0if=0;
         if(t2h==255)intcon.tmr0if=1;

              i++;
              temp=period[i];
              if(temp<0) temp=temp*-1;
              temp=65535-temp;
              t_high=temp/256;
              t_low=temp%256;
              t1h=t_high;
              t1l=t_low;
              i++;
              temp=period[i];
              if(temp<0) temp=temp*-1;
              temp=65535-temp;
              t_high=temp/256;
              t_low=temp%256;
              t2h=t_high;
```

```
              t2l=t_low;

         while(intcon.tmr0if==0){

         }
        }

        buzzer=0;
        blue=0;
        i=0;

        delay_ms(100);
        intcon.gie=1;
        }

        while(pol_flag==1){
        pol_flag=0;
        delay_us(100);
        if(portb.f0==1) intcon2.intedg0=0;
        if(portb.f0==0) intcon2.intedg0=1;
        }
      }
}

void interrupt() { //___________________________________MAIN Interrupt handler

     if(intcon.int0ie==1 && intcon.int0if==1){ //_____________RB0 external int
      intcon.int0if=0;
      tl=tmr0l;
      th=tmr0h;
      tmr0h=0;
      tmr0l=0;
      temp=(th*256)+tl;
      if(intcon2.intedg0==1) temp=temp*-1;
      period[i]=temp;
      i++;
      blue=0;
      red=1;
      pol_flag=1;
     }

     if(pir1.rcif==1){ //________________________________________UART read int
     pir1.rcif=0;
     uart_rd = UART1_Read();

         if (uart_rd==119){ //_________________________________________Send "w"
          send=1;
         }

         if (uart_rd==99){ // ________________________________________clear "c"
          clear_array=1;
         }

         if (uart_rd==116){ // ____________________________________transmit "t"
          transmit=1;
         }

         if (uart_rd==97){ // _____________________________"a" Start IR capture
           intcon.int0if=0;
           intcon.int0ie=1;
           intcon.gie=1;
           blue=1;
```

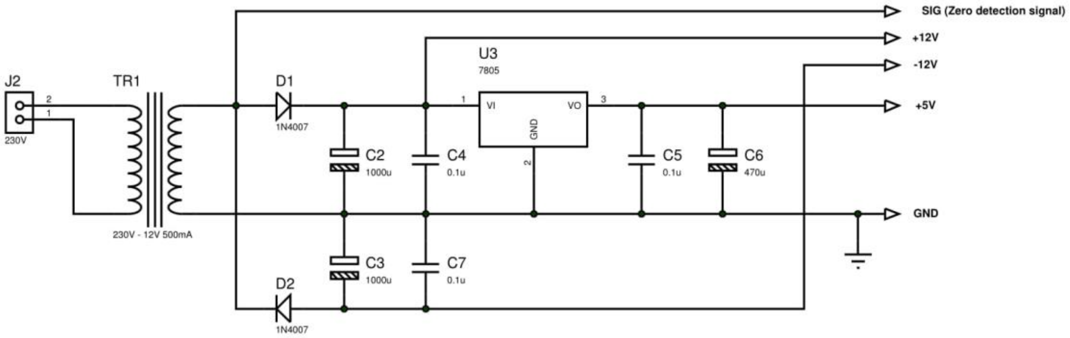
```
           buzzer=1;
           i=0;
           while(i<array_limit){
           period[i]=0;
           i++;
           }
           i=0 ;
           buzzer=0;
          }

          if (uart_rd==98){ // ______________________________"b" Stop IR capture
            intcon.int0ie=0;
            intcon.int0if=0;
            intcon.gie=0;
            blue=0;
          }

          // ____________________________________________________ram_writing loop

          if (uart_rd==83){ // __________________________"S" start bit od string
          data_read=1;
          i=1;
          blue=1;
          }

          if (uart_rd==115){ // _________________________"S" start bit od string
           data_read=0;
           blue=0;
          }

          // ex-protocol SR1234PR5678Ns
          if (data_read==1){
            if (uart_rd==82){ //____________________________"R" is reset command
            d0=0;
            d1=0;
            d2=0;
            d3=0;
            d4=0;
            dataval=0;
            uart_rd=48;
           }

           if(uart_rd==80){ //__________________________________P positive value
           dataval=d0+(d1*10)+(d2*100)+(d3*1000)+(d4*10000);
           period[i]=dataval;
           i++;
           d0=0;
           d1=0;
           d2=0;
           d3=0;
           }

           if(uart_rd==78){ //__________________________________N Negative value
           dataval=d0+(d1*10)+(d2*100)+(d3*1000)+(d4*10000);
           dataval=dataval*-1;
           period[i]=dataval;
           i++;
           d0=0;
           d1=0;
           d2=0;
           d3=0;
```

```
          }

          if (uart_rd==48) read_value=0;
          if (uart_rd==49) read_value=1;
          if (uart_rd==50) read_value=2;
          if (uart_rd==51) read_value=3;
          if (uart_rd==52) read_value=4;
          if (uart_rd==53) read_value=5;
          if (uart_rd==54) read_value=6;
          if (uart_rd==55) read_value=7;
          if (uart_rd==56) read_value=8;
          if (uart_rd==57) read_value=9;

          d3=d2;
          d2=d1;
          d1=d0;
          d0=read_value;
          uart_rd=0;
        }
         uart_rd=0;
     }
}
```

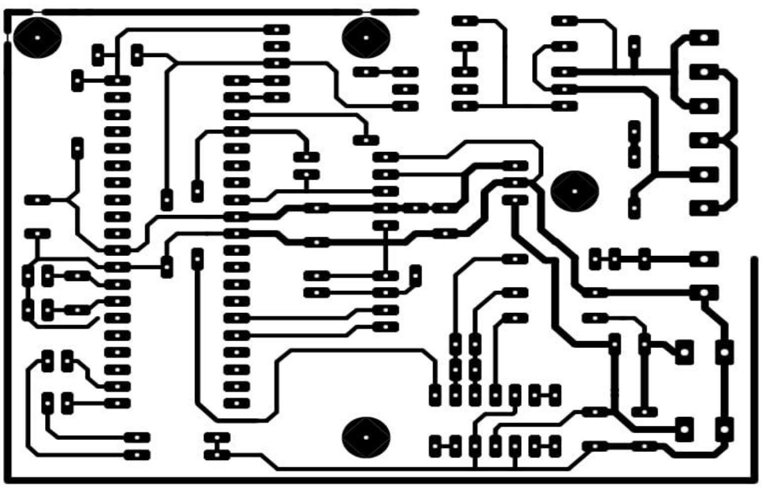
Appendix J: Schematic Diagrams and PCB Design of Wireless Switching Module



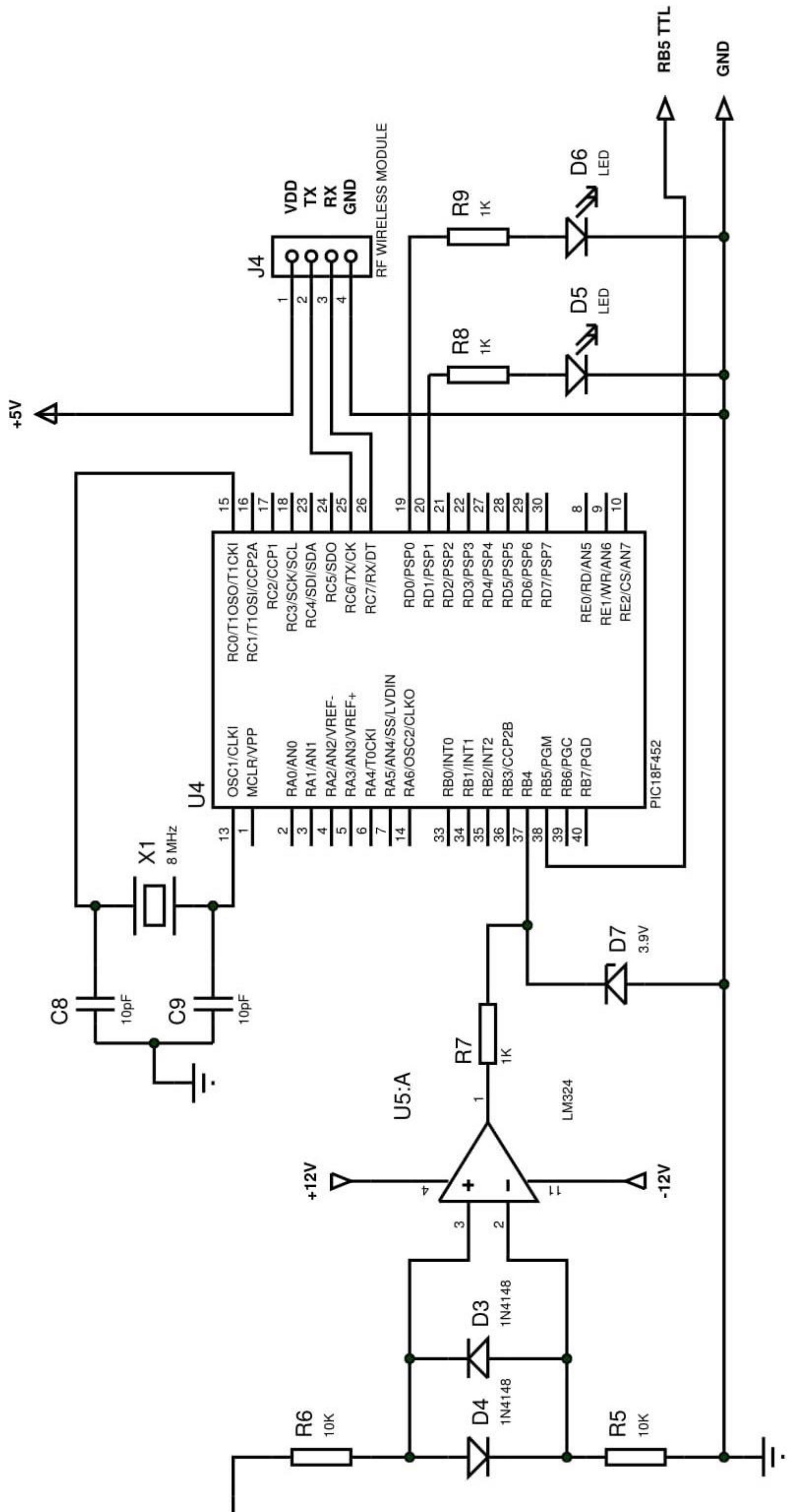
Optically isolated triac driver circuit and load configuration



A step down transformer based DC power supply circuit with zero detection signal interface



PCB layout



PIC18F452 8 bit microcontroller based digital thyristor control circuit

Appendix K: Microcontroller Firmware Implementation of Wireless Switching Module


```
// Project              : Wireless switching module
// Microcontroller      : PIC18F452
// System clock         : 8 MHz Crystal oscillator
// Programmer           : PICKIT2 ICD

// system variable initialization ********************************************
sbit red at latd.b0;
sbit blue at latd.b1;
sbit out at latb.b5;

unsigned short angle,angle_cnt,angle_runing,trigger,new_data,op_mode,temp_short;
unsigned int uart_rd,d0,d1,d2,d3,read_value,addr,mode,value,time,a_key;
unsigned int minuit=0;
unsigned short rf_key,rf_flag;
unsigned int module_key=751;
unsigned short rf_channel = 27;
short auto_key=0;
unsigned int minuit_temp =0;
short timer_flag=0;
short revover_disable=0;
int lux=0;
short lux_rqst=0;
short lux_send=0;
char txt[7];

void main() { //_________________________________________________Main progrram

     trisb=0b11011111;
     trisd=0b11111100;

     latb=0;
     latd=0;

     intcon2.rbpu=0;

     UART1_Init(19200); //____________initialize UART and test CC1101 RF module
     Delay_ms(100);
     UART1_Write(163);
     UART1_Write(58);
     UART1_Write(2);

     UART1_Init(4800);
     Delay_ms(100);
     UART1_Write(163);
     UART1_Write(58);
     UART1_Write(2);

     UART1_Init(9600);
     Delay_ms(100);
     UART1_Write(171);
     UART1_Write(186);
     UART1_Write(10);
     delay_ms(100);

     while(UART1_Data_Ready()) {
      rf_key = UART1_Read();
     }
     rf_key=0;
     rf_flag=0;

     UART1_Write(167);
     UART1_Write(122);
```

```
    UART1_Write(rf_channel);
    delay_ms(1000);

    while(UART1_Data_Ready()) {
     rf_key = UART1_Read();
     if(rf_key==170){
      rf_flag=1;
     }
    }

    while(rf_flag==0){
     red=1;
     delay_ms(100);
     red=0;
     delay_ms(150);
     blue=1;
     delay_ms(100);
     blue=0;
     delay_ms(150);
    }

     red=1;
     delay_ms(200);
     red=0;
     delay_ms(300);
     blue=1;
     delay_ms(200);
     blue=0;
     delay_ms(300);

     red=1;
     delay_ms(500);
     red=0;
     blue=1;
     delay_ms(500);
     blue=0;

     latd=0;

    auto_key=EEPROM_Read(4);
    if(auto_key==1){
      op_mode = EEPROM_Read(0);
      angle = EEPROM_Read(1);

      temp_short = EEPROM_Read(2);
      minuit=temp_short*256;

      temp_short = EEPROM_Read(3);
      minuit= minuit + temp_short;
      red=1;
    }else{
      op_mode =0;
      blue=1;
    }

    t0con=0b10000000; // timer0 settings for control the firing angle of triac
    intcon.tmr0if=0;  // delay (50us*200 = 10ms)
    intcon.tmr0ie=1;
    intcon2.tmr0ip=1;

    intcon.int0if=0; //__________interrupt settings for zero crossing detector
    intcon.int0ie=1;
```

```
    intcon.gie=1;

    new_data=0;
    angle_runing=200;
    minuit_temp=0;

    ADC_Init; //______________________Initilize ADC for optional sensor module

    while(1){ // ____________________________________________________Main loop

       while(UART1_Data_Ready()) {
       uart_rd = UART1_Read();

         if (uart_rd==63){ //___________________________"?" data request (LDR)
           lux_rqst=1;
           lux=0;
         }

         if (uart_rd==107){ //____________________________"j,k" data send(LDR)
           lux_send=1;
         }

         if (uart_rd==114){ //____________________________"r" is reset command
          d0=0;
          d1=0;
          d2=0;
          d3=0;
          uart_rd=48;
          addr=0;
          value=0;
          time=0;
         }

         if (uart_rd==63){ //___________________________"?" data request (LDR)
          d0=0;
          d1=0;
          d2=0;
          d3=0;
          uart_rd=48;
          addr=0;
          value=0;
          time=0;
         }

         if(uart_rd==97){ //______________________________________ a - address
         addr=d0+(d1*10)+(d2*100)+(d3*1000);
         d0=0;
         d1=0;
         d2=0;
         d3=0;
         uart_rd=48;
         }

         if(uart_rd==98){ //__________________________________________ b - mode
         mode=d0+(d1*10)+(d2*100)+(d3*1000);
         d0=0;
         d1=0;
         d2=0;
         d3=0;
         uart_rd=48;
         }

```

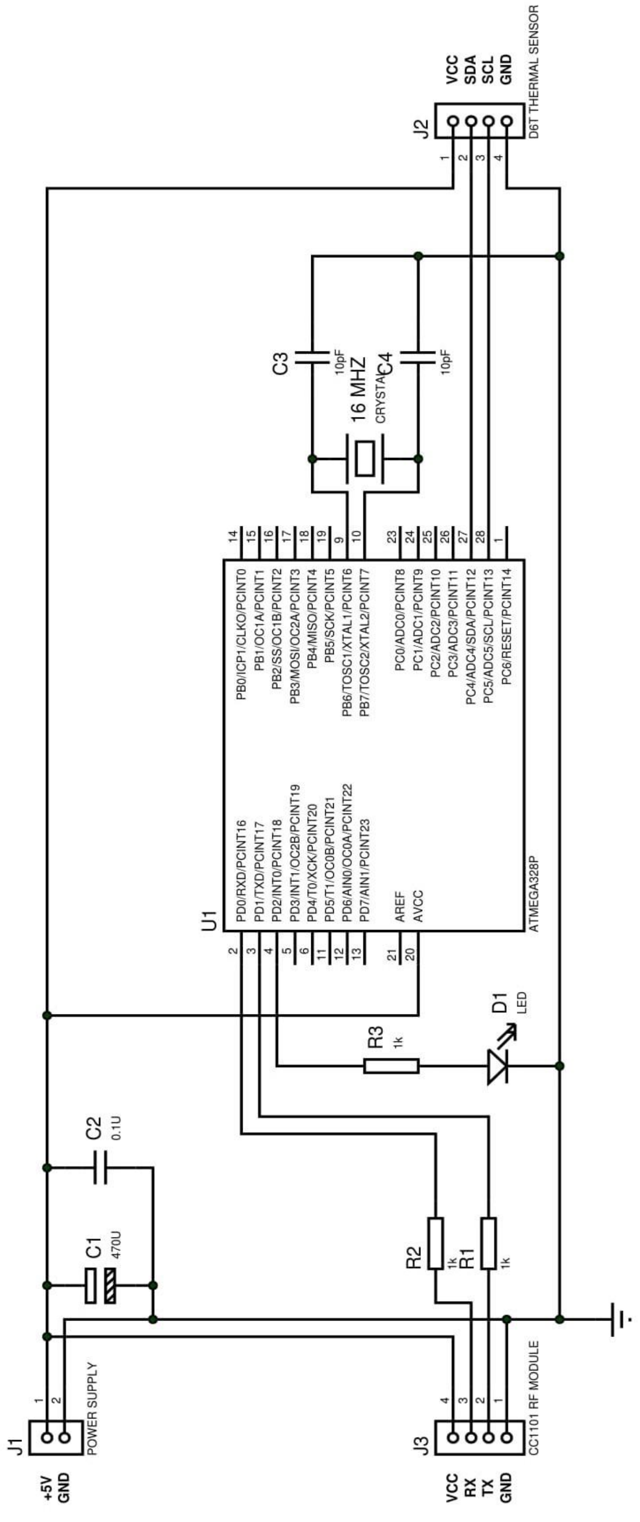
```
      if(uart_rd==99){ //____________________________________________ c - value
      value=d0+(d1*10)+(d2*100)+(d3*1000);
      d0=0;
      d1=0;
      d2=0;
      d3=0;
      uart_rd=48;
      }

      if(uart_rd==100){ // _____________________________________________d - time
      time=d0+(d1*10)+(d2*100)+(d3*1000);
      d0=0;
      d1=0;
      d2=0;
      d3=0;
      uart_rd=48;
      }

      if(uart_rd==101){ //__________________________________________e - auto_key
      a_key=d0+(d1*10)+(d2*100)+(d3*1000);
      d0=0;
      d1=0;
      d2=0;
      d3=0;
      uart_rd=48;
       if(addr==module_key){
         addr=0;
         new_data=1;
       }
      }

      if (uart_rd==48) read_value=0;
      if (uart_rd==49) read_value=1;
      if (uart_rd==50) read_value=2;
      if (uart_rd==51) read_value=3;
      if (uart_rd==52) read_value=4;
      if (uart_rd==53) read_value=5;
      if (uart_rd==54) read_value=6;
      if (uart_rd==55) read_value=7;
      if (uart_rd==56) read_value=8;
      if (uart_rd==57) read_value=9;

      d3=d2;
      d2=d1;
      d1=d0;
      d0=read_value;
      uart_rd=0;
    }

    if(lux_rqst==1){
      lux_rqst=0;
      lux = ADC_Read(1);
      inttostr(lux,txt);
    }

    if(lux_send==1){
      lux_send=0;
      UART1_Write_Text(txt);
      inttostr(0,txt);
    }

    if(new_data==1){
```

```
          new_data=0;

          minuit_temp=0;
          timer_flag=0;

          if(value==0){
           mode=0;
          }

          if(value>195) value=195;
          if(value<20) value=20;

          value=200-value;
          angle=value;

          if(mode==1){
           op_mode=1;
           red=1;
           blue=0;
          }else if(mode==2){
           op_mode=2;
           red=1;
           blue=0;
          }else{
           op_mode=0;
           red=0;
           blue=1;
           angle_runing=195;
          }

          if(time>1440) time=1440;
          minuit=time;

          if(a_key==1){
           EEPROM_Write(4,1);
          }else{
           EEPROM_Write(4,0);
          }

          // save config

         EEPROM_Write(0,op_mode);
         EEPROM_Write(1,angle);

         temp_short=minuit/256;
         EEPROM_Write(2,temp_short);
         temp_short=minuit%256;
         EEPROM_Write(3,temp_short);

         UART1_Write_Text("++");
        }

        if(timer_flag==1){
         if(revover_disable==0){
         revover_disable=1;
         EEPROM_Write(4,0);
         }
        }

     }
}

```

```
void interrupt() {

     if(intcon.tmr0if==1){ // _______________timer0 interrupt for 50us counter
        intcon.tmr0if=0;
        tmr0h=0b11111111;
        tmr0l=0b11010100;

        angle_cnt++;
        if(op_mode==1){
         if(angle==5){
          out=1;
          angle_runing=0;
         }else{
          out=0;
          angle_runing=195;
         }
        }else if(op_mode==2){
         if(angle_cnt>angle_runing) out=1;
         if(angle_cnt>195) out=0;
        }else{
         out=0;
         if(timer_flag==1){
           if(minuit_temp>50){
            minuit_temp=0;
            blue=~blue;
            red=0;
           }
         }else{
          blue=1;
          red=0;
          minuit=1440;
         }
        }
     }

     if(intcon.int0if==1){ // __________RB change interrupt for zero detection
      intcon.int0if=0;
      out=0;

      delay_us(50);

      if(portb.f0==1){
       intcon2.intedg0=0;
      }else{
       intcon2.intedg0=1;
      }

      angle_cnt=0;

      if(minuit_temp>5999){
       minuit_temp=0;

       if(minuit>0)minuit--;
       if(minuit==0){
        op_mode=0;
        red=0;
        blue=0;
        timer_flag=1;
       }
      }

      minuit_temp++; // ________________________________ Safety timer updates
```

```

    if(op_mode==2){
      if(angle==angle_runing){

      }else if(angle<angle_runing){
       angle_runing--;
      }else if(angle>angle_runing){
       angle_runing++;
      }
    }

   }
}
```

Appendix L: Schematic Diagrams of D6T Thermal Sensor Module



Appendix M: Microcontroller Firmware Implementation of D6T Thermal Sensor Module

```
      // Project          : D6T IR Thermal Sensor Module
      // Microcontroller  : ATmega328P (Arduino
developmentboard)
      // System clock     : 8 MHz Crystal oscillator
      // Programmer       : Arduino ISP

      #include <Wire.h>        // include wire lib to
communicate with I2C sensor module
      byte adress = 0x0A;     // sensor address
      byte comand = 0x4C;     // sensor read command
      byte count = 19;

      byte i = 0;
      byte j = 0;
      byte in[20];
      int temp_cel;
      int temp;
      boolean send_thermal_data = 0;
      boolean cal = 0;
      short p[9];
      int c[9];
      int t[9];
      int error = 5;
      String thermal_error = "";

      void setup()          // Setup the I2C and UART
communications and initialize the variables
      {
       Wire.begin();
       Serial.begin(9600);
       pinMode(13, OUTPUT);
       thermal_error.reserve(20);
        c[0] = 500;   c[1] = 500;
        c[2] = 500;   c[3] = 500;
        c[4] = 500;   c[5] = 500;
        c[6] = 500;   c[7] = 500;
        c[8] = 500;
      }

      void loop() {         // Main loop
       while (Serial.available()) {
```

```
char inChar = (char)Serial.read();

 if (inChar == 'T') {
   send_thermal_data = 1;
 }
 if (inChar == 't') {
   send_thermal_data = 0;
 }
 if (inChar == 'C') {
   cal = 1;
 }
 if (inChar == 'Z') {
   thermal_error = "";
 } else if (inChar == 'z') {
   error = thermal_error.toInt();
 } else {
   thermal_error += (char)inChar;
 }
}

if (cal == 1) {
  cal = 0;
  c[0] = t[0];
  c[1] = t[1];
  c[2] = t[2];
  c[3] = t[3];
  c[4] = t[4];
  c[5] = t[5];
  c[6] = t[6];
  c[7] = t[7];
  c[8] = t[8];
}

if (send_thermal_data == 1) {
  Wire.beginTransmission(adress); // start send write
(14h)
  Wire.write(byte(comand)); // send command byte
  Wire.endTransmission();
  delay(1);
  Wire.requestFrom(adress, count);
  for (i = 0; i < count; i++) {
```

```
            in[i] = Wire.read(); // read char 0-18
(2*(8+1)+1=19)
          }
        Wire.endTransmission();
        Serial.print("T");
        i = 0;
        j = 0;
        while (i < 18) {
          temp = 0xFF * in[i + 1] + in[i];
          temp_cel = temp;
          t[j] = temp_cel;
          Serial.print(t[j]);
          Serial.print(",");
          i++;
          i++;
          j++;
        }
        j = 0;
        while (j < 9) {
          if ( t[j] > (c[j] + error)) {
            p[j] = 1;
          } else {
            p[j] = 0;
          }
          j++;
        }
        j = 0;
        while (j < 9) {
          Serial.print(p[j]);
          Serial.print(",");
          j++;
        }
        Serial.print("t");
        Serial.println();
        delay(250);
      }
    }
```