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Artificial Intelligence Based Smart Building Automation Controller for Energy Efficiency Improvements in Existing Buildings

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Abstract—**This paper presents the design and implementation details of an Artificial Intelligent based smart building automation controller (AIBSBAC). It has the capability to perform intelligently adaptive to user preferences, which are focused on improved user comfort, safety and enhanced energy performance. The design of AIBSBAC consists of subsystems of smart user identification, internal and external environment observation subsystems, an artificial intelligent decision making subsystem and also a universal infrared communication system. Furthermore, the design architecture of AIBSBAC facilitates quick install flexible plug and play concept for most of the residential and buildings automation applications without a barrier to infrastructure modifications in installation.**

Index terms -Building automation; Smart controller; Smart appliances; Artificial intelligence; Energy optimization

I. INTRODUCTION

Building Automation Systems (BAS) are mostly adapted in industries and large scale buildings at present and it has rarely adapted in domestic (Household) environment and existing buildings due to flexibility issues, reliability limitations, complexities and high costs.

According to Ceylon Electricity Board (CEB) statistical digest, issued in 2013, 33.4% of electricity is used for domestic purposes. 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% is from thermal-coal [1]. Since domestic component requirements contain a larger share of energy demand any savings from that demand will result in reduction of Carbon emissions, cost of procuring thermal fuel and cost to the consumers. Hence, there is a huge demand in the domestic environment to develop smart building automation systems with required flexibility and adaptability at affordable cost saving to recover investment that will bring in energy savings while maintaining desired comfort levels and end user requirements [2].

The some of the researches done in the past on BAS are reviewed bellow. The main feature in following BAS researches were based on static automation structures combining wireless remote control & monitoring systems through various communication techniques and Smart devices [3, 4, 5, 6]. Smart home implementation devices were developed using artificial intelligence focusing on creating a system which are capable of controlling home appliances based on direct and indirect users' guidelines [7]. Arduino Uno open source hardware platform based wireless home automation system was developed to control home appliances in wireless mode [8]. Voice integrated home automation security systems were developed through telephone line to control home appliances [6]. Research adapting to resident preferences in smart environments was introduced to adaptive smart home system that discovers and adapts to changes in the resident's preferences in order to generate satisfactory automation policies [9]. Atmel AVR microcontroller based temperature Monitoring and Controlling system was introduced by using ZigBee in MATLAB [3] as a low cost wireless remote system. Internet interfaced and controlled personal computer based home automation systems were introduced with Voice control [10]. Speech recognition based Interactive home automation systems were developed to analyze, extract and characterize information from the command uttered by the human entity [11]. Smart home security systems were introduced using ANFIS [12]. Multi-user preferences model and service provision systems were introduced to learn multiple users' preferences and relationships among users as well as dependency between service and sensor observations [13].

The absence in the development of mini scale Self-controlling intelligent systems, the necessity of infrastructure modifications and the flexibility limitation in existing installations are the major barriers for using BAS in general residential applications and existing buildings. To address those, it is crucial to develop an Artificial Intelligent based Smart Building Automation Controller (AIBSBAC) and this project is an endeavor towards an effective design and development of a smart building automation controller for energy efficiency improvements in existing buildings.

II. DESIGN CONCEPT

A. Introduction to design concept

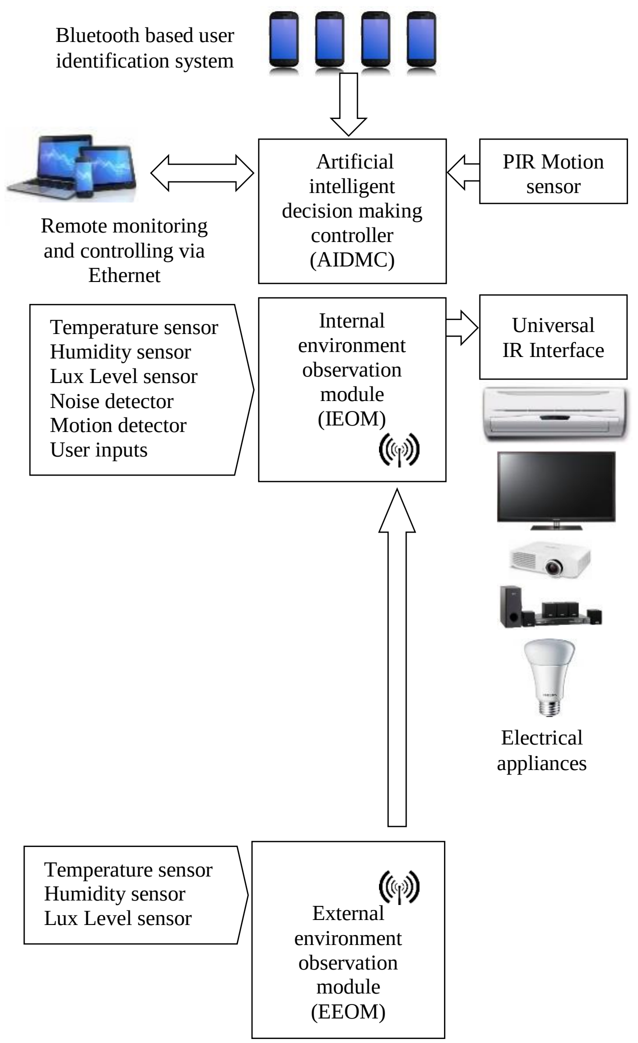

Figure 1. System layout of AIBSBAC

AIBSBAC is comparatively a wide information collecting system over the general BAS as shown in Fig. 1. Control algorithms or Decision making process of the AIBSBAC is designed specifically based on user preferences and relative observations of internal and external climatic conditions such as temperature, humidity, luminance and environmental noise etc. AIBSBAC is a pre-programmable system for multiple users which provides features to individual user preferences for various services at diverse situations. It provides control over parameters such as indoor air temperature, indoor air humidity level, indoor illumination level, speed of ventilation fan, sound level of audio setup, program of television set, position of Electrically operated curtain, water temperature of shower bath etc.

At the operation stage AIBSBAC identifies the users in application area (E.g. Managing Director/ Directors/ Managers/ Engineers/ other Offices) then AIBSBAC categorizes identified users to priority levels as pre-defined. And also AIBSBAC identifies the individual user preferences from the pre-defined internal data base. Based on the prioritize user preference details, AIBSBAC selects the proper service configurations automatically and communicates to respective appliances. AIBSBAC also studies the real-time internal and external climatic conditions and physical conditions such as temperatures, Humidity, illumination, Noise levels and motion detection. Based on these observations AIBSBAC changes the automation guide lines for maximum energy enhancement and optimum user comfort. Beyond that AIBSBAC can be configure for the pre-defined events such as calendar events, Emergency events, periodic events etc. integration of those features avoid unnecessary energy usages from the controlling of HVAC provision, lighting and other services to energy efficient, comfortable and safety focused environment.

The use of ultra-low power consumption embedded single board computer will results more energy efficient and precise automation process compared to the use of personal computer based automation systems [7]. Integrated standard Ethernet interface facilitates the development of wired or wireless real-time remote system interface through a remote application [4]. Bluetooth based user identification system is introduced for comfort user identifications. This can be achieved by avoiding self-authorization process in access compared to general Radio Frequency identification (RFID) or Password protected access system. In this research a pre-programmable universal infrared interface module (UIRIM) was designed for AIBSBAC to communicate with electrical appliances in the control area. Further the controller is designed as a plug and play type system for building and residential automation applications complimented with the existing building automation control systems [4, 6, 8].

B. Fuzzy logic based control model

AIBSBAC is introduced as an intelligent controller with a wider information collecting system and multiple appliances control interface. Based on these multi information such as climatic conditions, multiple user preferences and time varying inputs the decision making process is complex compared to the single input single output (SISO) control system model. Fuzzy logic is a problem-solving control technique which is can be implementing on a microprocessor. It provides decisions for multiple control nodes based on multiple inputs.

The control model of AIBSBAC is based on a fuzzy logic controlled closed loop control system as shown in Fig. 2. Observed information from sensor network and externally entered or pre-programmable time varying parameters are the inputs of the system. The fuzzy model of AIBSBAC continuously executes these multiple inputs for the optimum solutions.

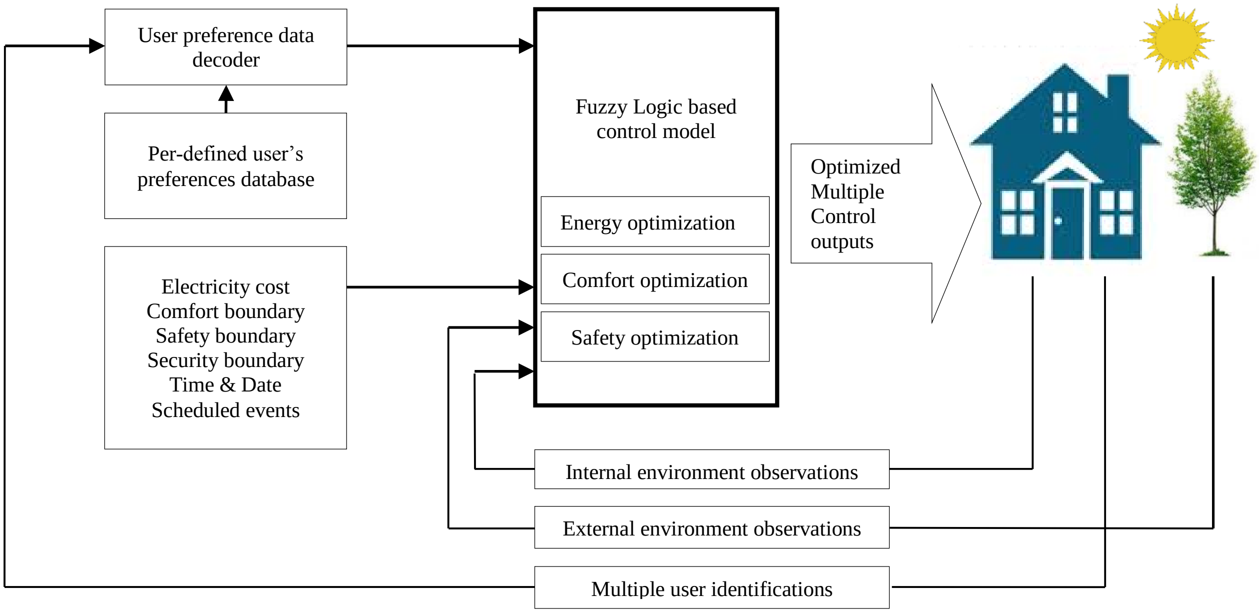

Figure 2. Control System block diagram of AIBSBAC

C. Single board computer

At present many types of open source mini computer hardware platforms are available. Uses of single board computers instead of personal computers (PC) for building automation systems are more beneficial. Raspberry Pi model B from Raspberry Pi Foundation is a power-full single board computer which is having 700 MHz single-core ARM1176JZF-S CPU based on Broadcom BCM2835 system on a chip (SoC) architecture with 512 MB of inbuilt internal random access memory shown in Fig. 3. Pre-installed Linux based operating system on SD card (Secure Digital) operates in the computer platform. Further Raspberry Pi model B comes with USB 2.0 dual ports, single 15-pin MIPI camera interface, HDMI multimedia port, Analog audio port, 100 Mbit/s Ethernet port and 8 General purpose Input Output (GPIO) which is having interface of UART (Universal asynchronous receiver/transmitter), I²C bus (Inter-Integrated Circuit), SPI bus (Serial Peripheral Interface), I²S audio (Inter-IC Sound). Equipped with these specifications Raspberry Pi model B computer runs with 5V DC power supply with a maximum power consumption of 3.5W.

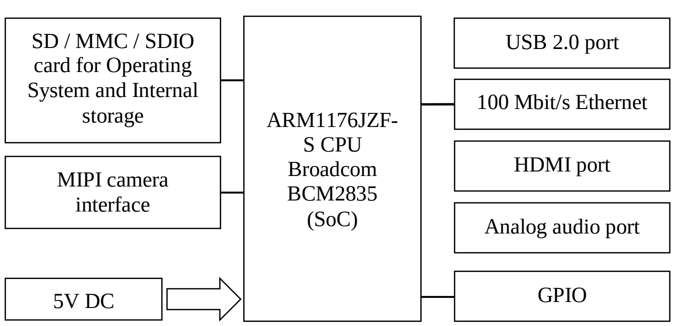

Figure 3. Block diagram of Raspberry pi model B single board computer

Also due to the compact design, this computer platform requires low three dimensional space comparing with a PC. Hence, Raspberry Pi model B has been chosen as the central processor of AIBSBAC.

D. Bluetooth user identification system (BUIS)

Bluetooth user identification system is based on Bluetooth transceiver module which is connected with a single board computer shown in the Fig. 4. This module continuously searches for another Bluetooth devices in application range. If any Bluetooth enabled device ex. Smart phone, Tabs etc. is reached within the identification range, CPU will identify the device and verify with the pre-defined identification keys to identify the specific users. Internally Integrated PIR motion sensors are used for further confirmation of user's location.

E. Universal infrared (IR) interface module (UIRIM)

Most of the Electrical appliances come with its own hand held IR remote controller. (E.g. Air conditioner machine

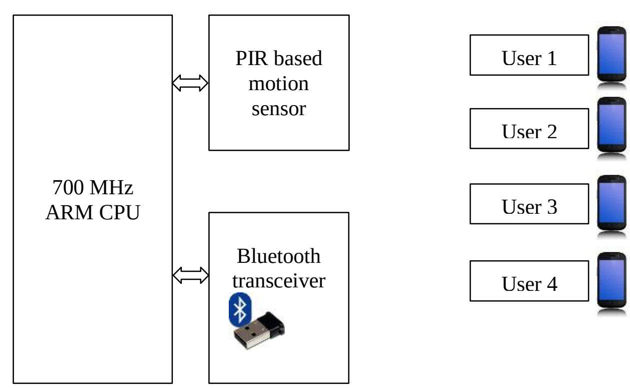

Figure 4. Block diagram of Bluetooth user identification system

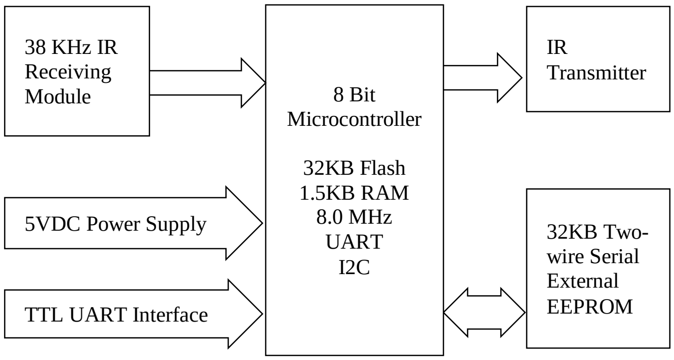

Figure 5. Design layout of Universal infrared interface module (UIRIM)

(HVAC Systems), lighting systems, multimedia systems (audio/visual), portable consumer product etc. Such devices communicate using specific modulated IR light beams. UIRIM is developed as a teachable universal remote controller to communicate with appliances. Hence, the UIRIM has the capability to control most of the building appliances without any modifications to the building infrastructure systems as well as individual consumer appliances. Design layout of UIRIM is shown in Fig. 5. UIRIM is based on an 8 Bit microcontroller. It's having 38 KHz Demodulated IR receiver module and 4-LED (Light Emitting Diode) IR transmitter which is powered by MOSFET (Metal Oxide Semiconductor Field Effect Transistor). In the teaching mode UIRIM captures the specific IR command from consumer remote controller. Then it's saved to externally attached EEPROM (Electrically Erasable Programmable Read Only Memory) with specific defined address. UIRIM has the capability of storing 200 different IR remote commands. UIRIM is drive through the Full-Duplex TTL interfaced UART port.

F. System integration of AIBSBAC

AIBSBAC consists of tree sub systems. Artificial Intelligent Decision Making Controller (AIDMC) which plays the command role of AIBSBAC by performing artificial intelligence decision making for the smart environment as the brain of AIBSBAC. Other two systems are Internal Environment observation module (IEOM) and External Environment observation module (EEOM) which are contributing to observe internal/external sensor network and control of appliances from AIDMC.

III. SYSTEM DESIGN

AIBSBAC is developed by integrating several open source hardware control platforms, sensor modules and communication modules shows in Fig. 1.

A. Artificial Intelligent Decision Making Controller (AIDMC)

AIDMC is powered by a credit card size 700MHz single-core ARM1176JZF-S CPU single board computer, which is an inexpensive low power consuming open source hardware platform from Raspberry pi Foundation as Raspberry pi Model B as shown in Fig. 2. The overall controlling process of AIBSBAC is done by AIDMC. The AIDMC communicates with whole system through an inbuilt UART of hardware platform.

B. Internal Environment observation module (IEOM)

IEOM is the second major sub system of AIBSBAC which is used to observe the internal environment conditions and communicate with EEOM and UIRIM as shown in Fig. 6. IEOM is powered by an ATmega 2560 8-bit Atmel microcontroller from Arduino as open source hardware platform. IEOM has four different types of sensors for the environment observations such as inbuilt temperature and humidity sensor, Lux level sensor and Environment noise level sensor. IEOM is wirelessly connected with EEOM through a RF communication module installed on UART1 and UIRIM through the UART2. UART3 of EEOM is directly connected with AIDMC and it facilitate AIDMC to communicate with all of sub systems of the AIBSBAC.

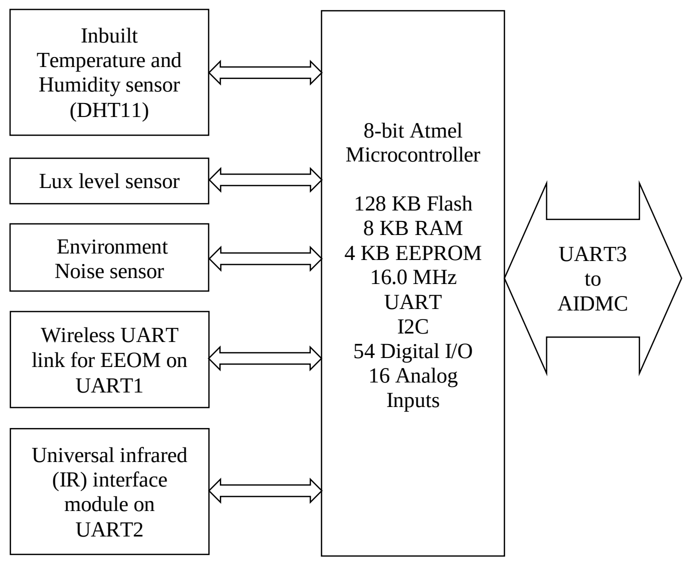

Figure 6. Block diagram of Internal Environment observation module.

C. External Environment observation module (EEOM)

EEOM is another sub system of AIBSBAC which is used to observe the external environment condition from IEOM as shown in Fig. 7. EEOM is powered by ATmega328 8-bit

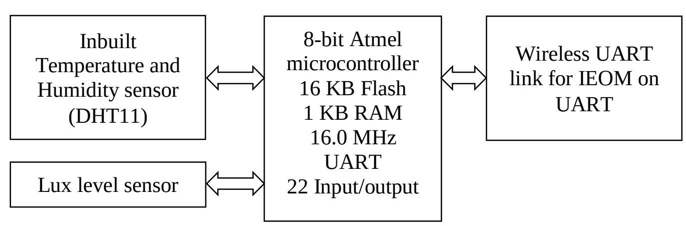

Figure 7. Block diagram of External Environment observation module

Atmel microcontroller from Arduino as open source hardware platform. EEOM has three different types of sensors for the environment observations such as inbuilt temperature and humidity sensor and Lux level sensors. EEOM is wirelessly connected with IEOM through a RF communication module installed on UART0.

IV. Hardware Implementation and Experiment

A. Experimental setup

The experiment was conducted on a conference room which is having 48 m2 (8 m x 6 m) floor space and an electrically operated curtained window with 4 m2 of area. The room was air conditioned by 12000 BTU/h split type air condition machine and illumined by the fluorescent lamp array which is having six numbers of 40W Dual lamp sets as shown in Fig. 8. According to the window orientation and common climatic condition of the building location, the room can be well illuminated by natural lighting up to 600 -700 Lux in day time.

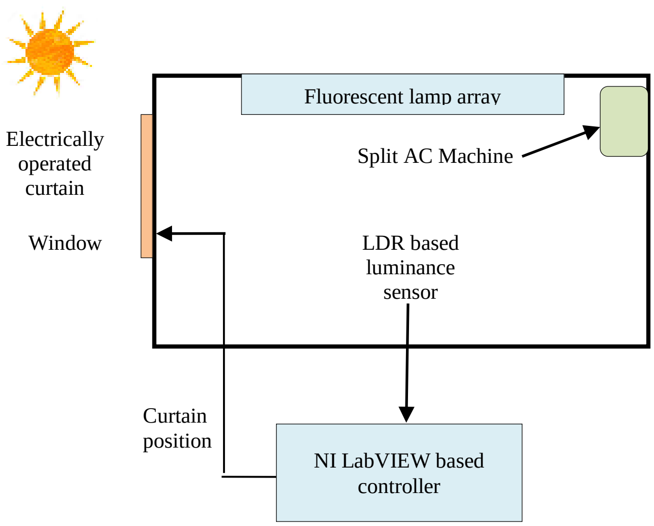

Figure 8. Layout of conference room

For the conducted experiment, the controller was developed using NI LabVIEW environment. Necessary sensors and control actuators were connected to NI LabVIEW application through an Arduino Mega 2560 open-source microcontroller platform. A LDR (Light dependent resistors) sensor was physically installed in middle of the room to measure the real-time illumination level. Position of the electrically operated curtain was controlled by a PID (proportional-integral-derivative) controlled positioning system and light array was controlled by the direct digital output of microcontroller platform. User preference details and additional simulation inputs were entered to control system through the software interface as shown in Fig. 9. Control decisions and outputs results of the simulation were presented by numerical displays and data graphs for further data analysis.

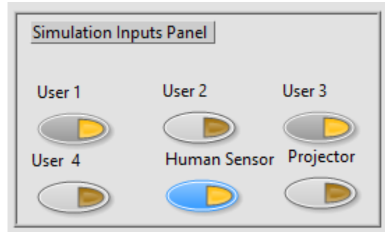

Figure 9. Additional simulation inputs panel

B. Observations

Observations of this experiment were carried out considering two main categories; thermal comfort and illumination level. Optimization of these two categories according to the environmental changes were expected through the developed system.

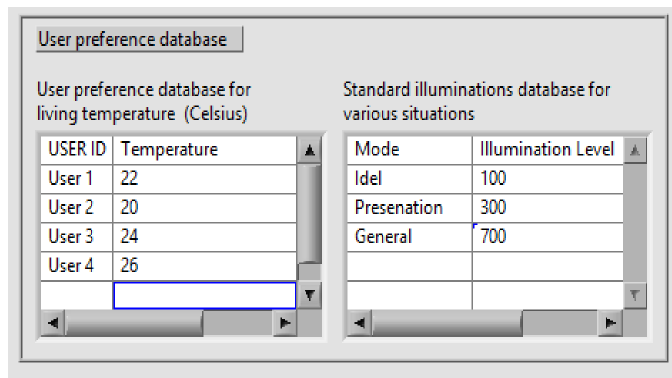

Figure 10. User Preference database

During the experiment, controller was able to decide the best temperature settings for the HVAC system based on the identified users and corresponding user preference as shown in Fig. 10. This optimizes the thermal comfort of the environment according to the user preference by avoiding unnecessary comfort levels and energy usage.

Considering the illumination control system, controller was able to select the illuminance requirement for the control premise by the predefined situations and corresponding illuminance levels entered by user. Using this, controller optimized the natural light usage for the desired illuminance settings by changing the position of electrically operated curtain. In the situations where natural lighting is not sufficient, controller was able to operate artificial lighting source to acquire additional illumination. This features facilitates to maintain more comfort illumination in the living premises. Due to the maximum utilization of natural lighting by this system, redundant energy usage by the corresponding environment can be omitted.

C. Development of prototype

The prototype of the proposed design of AIBSBAC is developed as shown in Fig. 11 and Fig. 12. In future work of this research includes testing calibration and verification of the developed system in real environment.

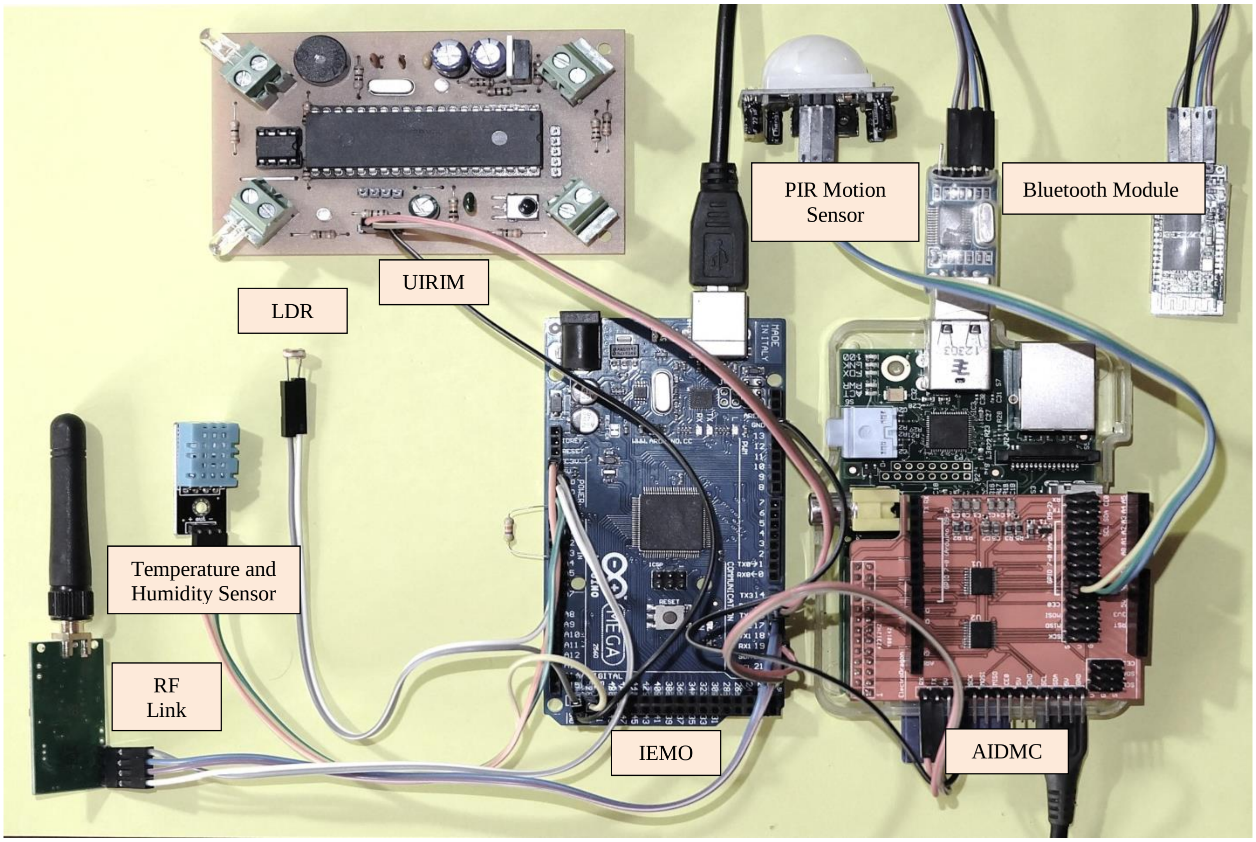

Figure 11. Hardware Implementation of AIBSBAC (AIDMC & IEOM)

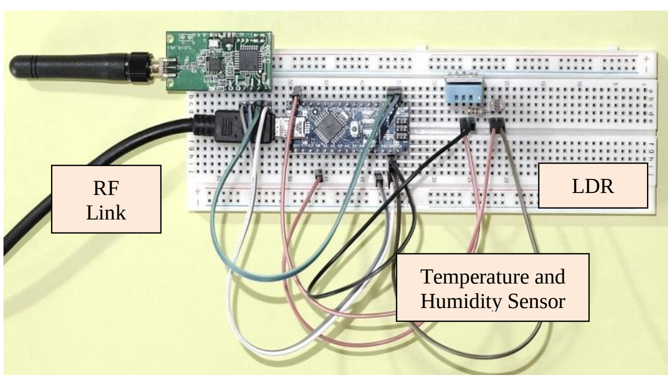

Figure 12. Hardware Implementation of AIBSBAC (EEOM)

V. Conclusion

There are many researches in building automation systems as reviewed in introduction. They are mostly based on remote monitoring and controlling of home appliances, rather than focusing on efficient energy utilization aspects.

In this research AIBSBAC is designed as a plug and play device to automate commercial buildings and residential buildings. The automation of AIBSBAC is based on multi user preferences with smart user identifications and observations of environment conditions as inputs to achieve improvement of user comfort and maximum of energy saving. In development of AIBSBAC introduced UIRIM creates wireless communication links between the AIBSBAC and electrical appliances without manual intervention.

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