Development of Multi-Sensory Feedback System for Building Automation Systems

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***Abstract*— Under this research, the multi-sensory feedback system has been developed utilizing commercially available MEMS based and miniaturized sensors for building automation systems. This system consist of non-contact infrared thermal array sensor based occupancy identification / localization system and self-floor locations categorization system with an environmental monitoring system. Further, it has smart real-time energy monitoring system which capable to identify the load devices and their status while operation. The entire system is capable of obtaining quantitative values of this sensory information and applied for the development of more convenient and energy efficient automation in building premises. The implemented system was tested and validated using fuzzy logic based building automation controller via the wireless network.**

Keywords—sensors; sensor network; building automation; occupancy identification; energy measuring

I. Introduction

The Building Automation systems (BAS) can be divided into two categories based on the building infrastructures and installing facilities. At present, most of the BAS are typically installed in large scale buildings at the developing stage and rarely adopted in existing buildings such as domestic building due to flexibility issues, complexities, and barriers to infrastructure modifications in installation. The modern building automation concepts such as IoT rapidly developed after the year of 2000. By comparing the age of an existing building two-decade is not much considerable age for most of the building. It may expect up to four or five decades. Comparatively the usable lifetime of existing buildings there is a need to develop BAS to existing building [1] 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 BAS to existing buildings. Considering above facts, a multi-sensory feedback system was developed to suitable with external Building Automation Controller (BAC) for functioning on HVAC systems, Lighting systems and entire building appliance installed in the building.

The wireless sensor network based efficient BAS was proposed and tested using BACnet as a temporary installation with several sensor nodes [2]. Yuvraj Agarwal el.al developed an Occupancy driven energy management system for smart building application using PIR sensor for occupancy detection [3]. And also sensor fusion based occupancy detection model was proposed [4]. In our proposed system, non-contact infrared based thermal array sensor is used to develop efficient occupancy identification in the building. In this design, a miniaturized and low power sensors are used to implement the indoor-outdoor environment condition measuring system [5]. A Smart power meter for advanced metering infrastructure based on ZigBee communication was developed [6]. Additionally to that, a wireless energy measuring system with load device and their status identification features are incorporated in this research. Lingfeng Wang el.al was developed an intelligent multi-agent control system for smart and sustainable buildings [7] target on energy saving and comfort improvement using intelligent optimizer. In this research, a fuzzy logic based centralized controller with an advanced multi-sensory feedback system is used. The developed system includes sensors, sensor interfaces, data processing systems and communication systems which can be used for a sensory feedback system in external BAC as shown in Fig.1. And system was connected to an external BAC to test performance of the system on different control algorithms.

II. Development of Multi-Sensory Feedback System

Building automation controllers are designed for mostly

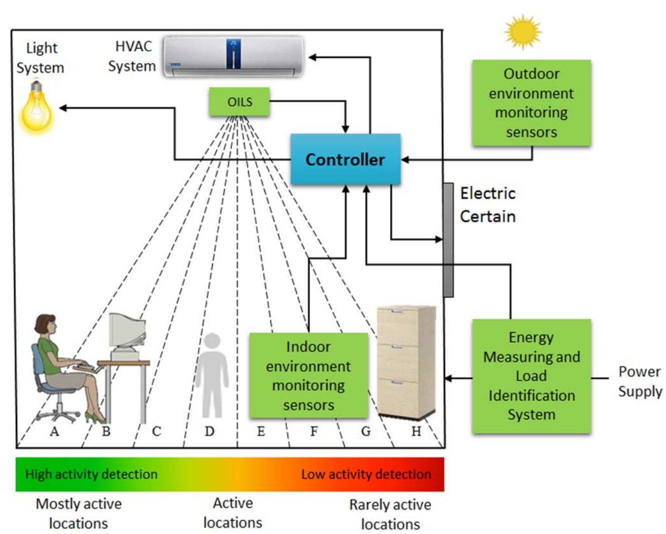

Fig. 1. Layout of Building automation application using multi-sensory feedback system

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relevant to the comfort improvement, energy utilization, and safety etc. activities in the building. In this way, the controller needs to have sufficient information relevant to these activities. Nowadays, very precise advanced sensors are developing using modern technologies. In that case, Micro-Electro-Mechanical Systems (MEMS) technology is becoming a promising solution for miniaturizing of sensing technology. The multi-sensory feedback system has four types of sensory systems which are based on miniaturized sensors associated with smart building automation systems. According to the design of multi-sensory feedback system, controller consists of occupancy identification and localization system, self-floor-location categorization system, indoor and outdoor environment monitoring system and real-time energy measuring and load identification system in a wireless sensor network.

A. Occupancy Identification And Localization System

The Real-time occupancy identification and localization is an important feature of commercial BAS. In this approach, the wireless non-contact occupancy identification system as an occupancy identification and localization system (OLIS) was developed using MEMS-based single Infrared (IR) thermal array sensor which is having 8 numbers of measuring pixels in the single array. The sensor having 4 frames per second cycle speed with the field of view (FOV) of 62.8^0, 6^0 along the x and y view angle respectively as shown in Fig.2. Measurement range of selected sensor is 5 to 50 Celsius up to 5-7 meters. The sensing algorithm is implementing on a temperature comparators. Initially, the default environment temperature values of each pixel are recorded as reference temperatures at a non-coupled condition in the selected area. Then these saved values are comparing with the present temperature values continuously. If the temperature increment is beyond the reference value of a sensing pixel, then it causes to change the output states of the related comparator. This signal is identified as a human detection in related location. The developed prototype of OILS shown in Fig.3. Developed GUI and performance test of the system shown in Fig.4.

B. Self-Floor-Location Categorization System

In a Building, the Occupancy presence and their location changes are random. But according to the floor arrangement of the specific room (E.g. walking locations, working tables, cupboards etc.), it is possible to identify the locations where the occupant living and walking frequently. And also it is an important information to predict the optimum visual and thermal comfort set points for a certain location in the building. This is a secondary application of OILS. In this

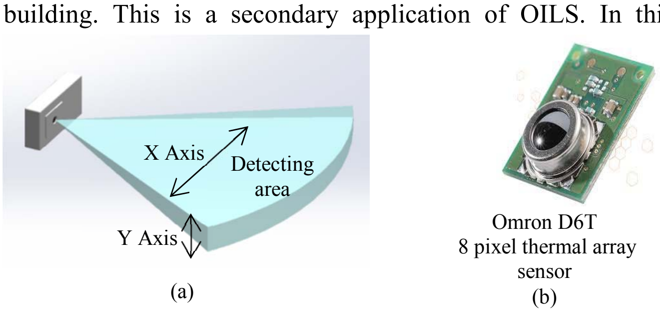


Fig. 2. Thermal sensor based OLIS (a) FOV of OLIS (b) Used thermal sensor

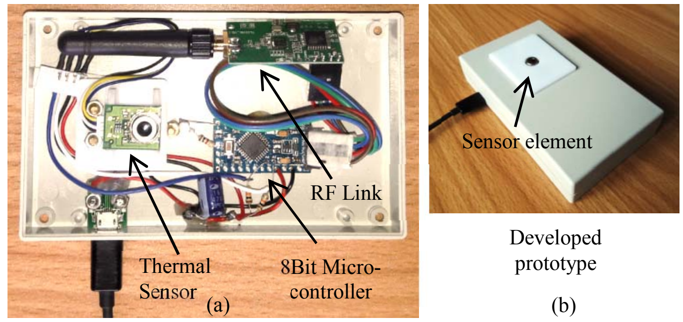


Fig. 3. Developed prototype of OILS (a) Internal view of OILS (b) Outer view of OILS

development, the classification algorithm is used to analyzing time to time occupancy presences details captured by OILS and according to the results of the algorithm, it categorizes the specific floor locations as most active, active and rarely active locations by itself as shown in Fig.1.

C. Indoor and Outdoor Environment Monitoring System

The visual and thermal comforts are the main expected improvement from the BAS. Environment monitoring system is related to providing real-time environment feedback to the BAC. It is done by sensing of environment factors such as air temperature, relative humidity, Illuminance level and solar irradiation. According to the sensory configuration, it has two wireless measuring modules for indoor environment measuring and outdoor environment measuring. Temperature and relative humidity are sensed by a digital sensor with 14bit of measurement resolution with $\pm 0.2^{O}$C of temperature measuring accuracy and ±2% of accuracy for relative humidity. Illuminance is sensed by a digital ambient light sensor which is having 16bit of measuring resolution and 1-65535 Lux of measuring range. A sub-module to measure the solar irradiation is integrated with outdoor environment measuring module. It provides the information about available

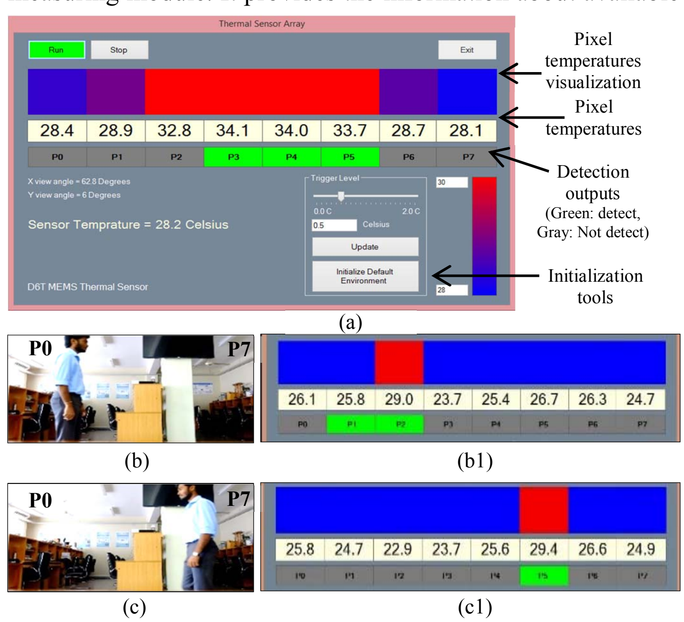
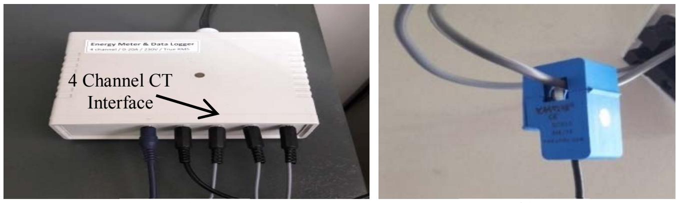


Fig. 4. (a) Developed GUI of OLIS (b) (c) System performance test in real location (b1) (c2) occupancy detection results related to the b and c status.



(a) (b)

Fig. 5. (a) Developed prototype of energy measuring system (b) Split type current transformer

solar irradiance at a specific location with directions. This information can be used to real-time thermal load prediction in the buildings. A photovoltaic cell was used as a sensory element of the measuring system and it is mounted on a servo mechanism to change orientations as required.

D. *Real-Time Energy Measuring and Load Identification System*

The energy monitoring systems are integrating with BAC to evaluate the performance of the systems. In this approach, A Real-Time Energy Measuring and Load Identification System (RTEMLI) was developed to gather overall energy consumption details by specific area as shown in Fig.5. Additionally, the developed system has the facility to identify the various loads and their status which are used in the specific building area. It was developed by implementing level recognition algorithm on real-time current measurement. As an example, if there are two different loads connected to the system through the RTEMLI, the system can identify the devices which are in activate state and deactivate state with a tolerance. Current Transformers (CT) and potential transformers used as sensing element of the system. A 16-Bit/120MHz DSP is used as the controller and integrated 12 Bit ADC is used to take a measurement of current and voltage sensors.

III. Testing and Validation of Multi-Sensory Feedback System Using A Control Platform

Developed sensory feedback system was tested and validated using a controller which is developed for existing building. The controller was implemented on a single board computer as shown in Fig.6. Further, the controller has an inbuilt teachable Universal Infrared (IR) remote controller which can be used to control most of the building appliances without any additional hardware systems. Control consists of fuzzy logic based three different controllers named as visual comfort controller, Thermal comfort controller and a Multimedia controller implemented on single board computer. The developed multi-sensory feedback system was connected to the controller through the wireless radio link as input devices. An air conditioner machine which is having a capacity of 24,000 Btu/h was operated by occupancy detection based thermal comfort algorithm using the controller trough the IR remote signals. Energy consumption by air conditioner machine was measured and collected by RTEMLI system. Comparative results collected in two days at same time period with the controller and without controller shown in Fig.7. According to the experiment results 8.25kW/h of energy

Fig. 6. External Building automation controller

usage has been minimized to 5.53kW/h using the developed system.

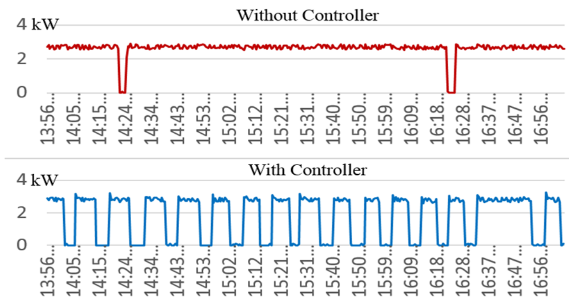


Fig. 7. Compression of energy consumption

IV. Conclusion

In this work, the multi-sensory feedback system was successfully developed using commercially available miniaturized sensors, wireless communication systems and microcontroller and DSP based data processing controllers. Using this system we get the accurate identification of real-time environment conditions, occupancy, and category of floor locations and real-time energy consumption with load devices status in a specific building. In Future work of this research includes expansion of application areas and sensory network compatible with the real environment.

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