A Complete Hardware Setup for Smart Lighting System

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***Abstract*—Nowadays, smart lighting systems are gaining popularity and are successful due to their ease of use through automatic control, visual comfort, low carbon footprints and low energy consumption. In the first look, these lighting systems seem to be fairly simple to develop as they employ modern communication technologies and smart sensors. But they are not easy to develop as the integration of sensors, calibration and development of sensor nodes are always challenging. In this paper, we present a complete hardware setup for the smart lighting system. The paper presents the hardware components used and their integration with communication technologies and Android App. The developed hardware platform is capable of varying the light intensities through an Android App which in turns provide a better visual comfort for users. It has been observed that there is 60-70% reduction in energy consumption as compared to the sophisticated system available in the market.**

Keywords— sensors; hardware component; smart lighting; ZigBee; IoT

I. INTRODUCTION

Today, cities are under immense pressure to remain livable due to the fast urbanization of the world's population. Smart city concept and its development are gaining popularity as it has the capability to use diverse technologies in different aspects of urban life. As a result, it can improve the sustainability and the quality of life of its inhabitants [1, 2]. With increasing demand and reduced budget, smart and intelligent solutions are needed to manage a smart city. As per the technologic map, at least 50% of the public building will be intelligent by 2020 as they will be complying the various requirements for energy efficiency and sustainability set out by European Union [3]. The Indian government has plans to build at least 100 smart cities by the year 2050. To solve future challenges and to create new services, these cities will be utilizing the advanced communication network, WSNs, and intelligent system [4, 5]. Although, the energy efficient lighting systems are installed in the official buildings of these cities, advance and low-cost IoT enabled WSN technology is the future for the coming smart cities around the world [6].

Visual comfort without compromising the energy-efficiency and set standards is a major concern in an official building. Bad lighting conditions are hampering the employee's performance and health while the companies are suffering from the high cost of energy bills. Table I shows the Lux required in various conditions of day to day working. However, in reality, there are inadequate smart lighting solutions available in the market [7]. These systems are expensive to maintain in official buildings.

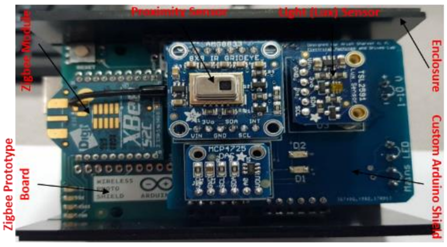

Fig. 1. Advance Hardware Platform Containing Multiple Sensors.

To mitigate this problem a smart lighting solution has been developed [8, 9]. As opposed to traditional, expensive solutions the developed lighting solution is intelligent, low-cost and uses state of the art sensors. The important issue of calibration and obtaining accurate data has been achieved through the people's participation and techniques. Fig. 1 shows the advanced hardware platform developed for the smart lighting system. It contains an array of different sensors. Important components of this platform are described in the coming sections.

TABLE I. LUX REQUIREMENTS IN VARIOUS CONDITIONS [11]

Lux Level	Area or Activity
75	Indoor Car parks (parking area, Traffic lanes)
100	Corridors, rest areas
150	Stairs and escalators
200	Lounges and canteens
300	Background lighting (e.g., IT office, classroom)
500	General lighting (e.g., conference, meeting room, kitchens)
1000	Precision lighting (e.g., quality control)

This paper presents in details the hardware setup for the smart lighting system. The system has been developed at Electrical Machines and Drives Laboratory (EMDL), National University of Singapore, Singapore. The developed system is capable of varying the light intensities through an Android App [9, 10] which in turns provide a better visual comfort for users. It has been observed that there is 60-70% reduction in energy consumption as compared to the systems already available in the market.

II. Components Of Smart Lighting System

The proposed system consists of sensors and actuators and is a design of Wireless Sensor-Actuator Network (WSAN) [8]. The local lighting agent obtains its input signals form following nodes (sensors):

- PIR (Passive Infrared Sensor) sensors
- Illumination sensors
- Personal agents

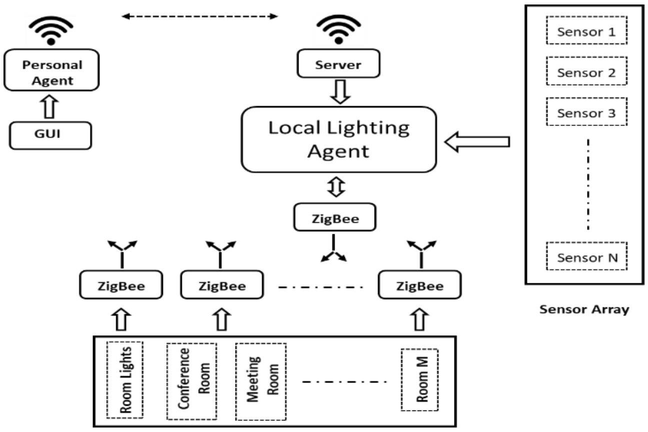

Fig. 2. The architecture of Smart Lighting System.

In the developed system, heterogeneous LED light source receives signals from the Local lighting agent (co-ordinator). In the network, each light works as a node. The nodes use XBee [12] protocol to communicate. Fig. 2 shows a simple architecture of the smart lighting system. Table II shows the different sensor used to develop the hardware and their properties.

TABLE II. Properties Of Different Components Used To Develop The Hardware.

Component	Properties or Activity
PIR Sensor	For detecting the presence of human
Illumination sensors	Feedback sensor for the control of lights lux intensities
Digital to Analog Converter	For sending analog control signal to task light LED driver
XBee ZigBee antenna	For communication between hardware and server
Microcontroller (Arduino Uno)	For handling data pack from server and sensor value to control lighting lux intensity
Pin hole cover	For limiting the illumination sensor view angle
Server PC	For coordination between the personal agent and local agent. Storing data of user preference for recommendation algorithm

A. PIR sensor

As all objects radiate at infrared wavelengths which are detected only by electronic devices. PIR sensor is used on this principle to detect the infrared radiations emitted or reflected from objects. To develop the hardware platform, in this research work, Panasonic Infrared Array Sensor Grid Eye AMG8833 [13] shown in Fig. 3, is used to detect the presence of a user/occupant. The sensor is a high precision infrared array sensor based on advanced MEMS technology.

Fig. 3. PIR sensor.

B. Illumination Sensor

Illuminance or ambient light level of a place can be measured with the help of tiny sensors. The light sensor used in this research work is Austria Micro Systems TSL2561. It is a Light to Digital converter that transforms light intensity to digital signal output. Each device combines one broadband photodiode (visible plus infrared) and one infrared-responding photodiode on a single CMOS integrated circuit [14]. Fig. 4 shows the illumination sensor used in this work.

Fig. 4. Illumination Sensor.

C. Pin Hole Cover for Illumination sensor

The illumination sensor [14] has an angular view is of 180°. This wide-angle view will also measure the lux level of the nearby workspace. This is an undesired measurement for personal space lighting control. Therefore, to restrict the illumination sensor to measure only a single workspace a pin hole cover is placed on top of the sensor to limit the angle of the view.

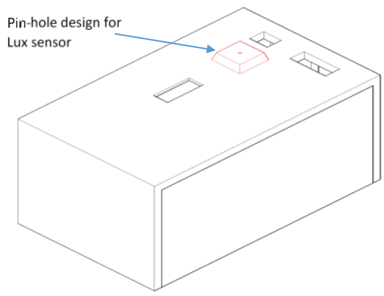

Fig. 5. Pin Hole cover.

D. Personal Agents

In the developed lighting system, the personal agents are proxies for users/occupants (mobile phone, PC, tablets etc.) in the digital domain to adjust the lighting conditions as per individualistic lighting needs. The occupant/user interacts with the WSN using Smart Android application designed.

E. Local Lighting Agent

Arduino Uno is used as a primary controller in the Local Lighting Agent. The Arduino Uno is a microcontroller board which uses ATmega328P. This can be programmed using Integrated Development Environment (IDE) called as Arduino Software. In the control system, the process variable is the parameter to be controlled; in our case, it is the working area illuminance. In a feedback control system, the sensors measure the process variable and provides the feedback to the system. On the other hand, the command value is the set point to control the process variable. Arduino Uno microcontroller is capable of communicating to sensors and converter via the I2C protocol.

F. Intelligent Algorithm

An intelligent algorithm, ReViCEE (A Recommendation based approach for personalized Visual Comfort & Energy Efficiency in buildings), is developed. This Recommender Systems (RS) based approach is to learn individual user preferences from historical data and offers recommendations. In this research work, such recommendations help to intelligently control built-environment to meet both individual comfort and energy efficiency simultaneously. The ambient conditions from various sensors are collected to form a massive data store. This data is used for learning individual's lighting preferences and their similarities using existing tools and techniques to make recommendations.

III. Hardware Setup & Calibration

This section presents the hardware setup and calibration process of the smart lighting system.

A. Simulation

To choose the lights and the illuminance setting, several simulations were performed. This section explains the simulation results and the methodology. Fig. 8. shows the arrangement of the background light (2) and task light (1) in the research room for each workspace located at EMDL.

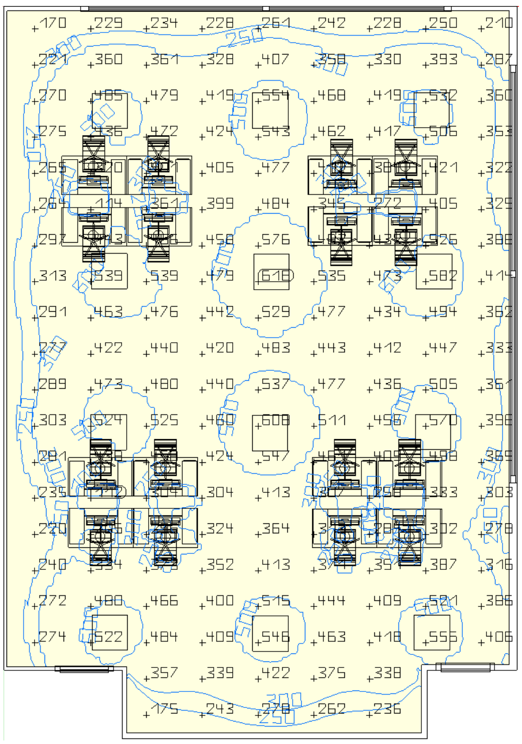

Fig. 6. Simulation of 100% Background light lux.

Simulation Procedure:

- To determine the required quantity of background light to achieve 400 to 500 Lux on each workspace. The background lights are set to 100% brightness while the Task lights have been turned OFF. From the simulation result for a room (8 x 11m), 12 sets of background lights are required to achieve the lux level. Fig. 6. Shows the simulation result for 100% brightness of background lights.
- Once the quantity of the background lights are determined, to ensure that each selected individual task light is able to achieve 300 lux on the workspace at minimum background lighting condition, the background lights are lower to 20% brightness and 2 task lights are set to 100% brightness. Fig. 7 shows the simulation results.

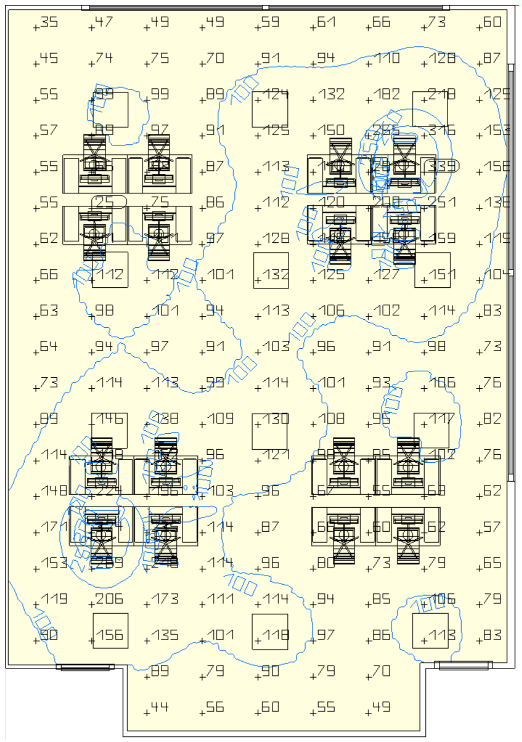

Fig. 7. Simulation of 20% Background light with 2 task light at 100% lux.

B. Test-bed Calibration

To test both hardware and software of the smart lighting system, a test-bed is set up at the Department of Electrical and Computer Engineering, EMDL, NUS, Singapore. Fig. 8. shows a Researcher Room where the lighting system is installed. The working place cubicles are fitted with personalized (task) lights, which can be accessed by the smart App installed on the user's smartphone/tablets. A researcher room has been left out which acts as a reference.

It is to be noticed that during calibration of the hardware even with the same lux level measure from a lux meter are same for each workspace, each hardware is required to be calibrated individually due to the following factors:

1. Workspace top surface colour (i.e. gray, white, black)
2. Workspace top surface finishing (i.e. smooth, rough)

Both of the above factors affect the amount of light reflected from the surface which reaches the illumination sensor located directly above the workspace.

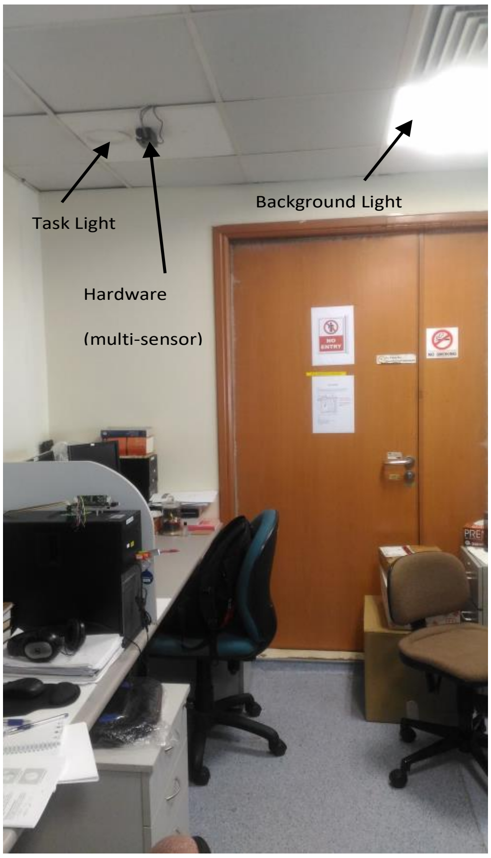

Fig. 8. A Working space (test-bed) of Smart lighting system.

In case of the rough black surface on the workspace, illumination sensor lux reading will be low which will lead to low accuracy after software calibration. Hence, it is not advisable/desired to place the hardware above the rough black surface.

IV. Discussion

The key hardware for smart lighting system are:

1) Server: This serves as the brain of the system to coordination, store and to make decisions.

2) Sensors: Sensors acts as the eyes of the system to detect the physical environmental values.

3) Controller: This acts as the hands of the system to control the output according to the setpoint received from the server via ZigBee.

4) Lights: These are the output devices to change the lux level.

5) Personal device: These devices allow human to system interface via WiFi.

The location of a sensing device in the system has a huge impact in the design of the hardware in term of physical appearance, and calibration.

In this case, with illumination sensors are located/placed on the ceiling, facing the workspace. This results in a huge disadvantage to get the accurate software calibration to determine the amount of light falling on the workspace base on the reflected light from the surface to the illumination sensor.

V. Conclusion

This paper presents a complete hardware setup for smart lighting systems. The developed smart lighting system utilizes the heterogeneous communication protocol and lighting technologies. All the components of the system has been presented in the paper. The developed hardware platform is capable of varying the light intensities through an Android App which in turns provide a better visual comfort for users. The smart lighting system has been deployed and tested in EMDL, NUS, Singapore. The system is much cheaper than the market available solution for smart lighting. Though this solution is built for official buildings, in future, we plan to push the cost of the devices further down to make it available in bulk for small industries and low household income group families. For better accuracy, in future, we also plan to add additional advance sensors to the system.

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