Development of Smart LED Lighting System Using Multi–Sensor Module and Bluetooth Low Energy Technology

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***Abstract*—A smart LED lighting system is designed and implemented using a multi–sensor module and Bluetooth Low Energy (LE) technology. In order to monitor the environmental information such as ambient light intensity, temperature, and/or activity of human or other objects, a multi–sensor module including an ambient light sensor, temperature sensor, and motion sensor is combined to a microcontroller. By collecting environmental information, the LED lighting system can be controlled automatically. Through the Bluetooth LE technology, a user can monitor the environmental information on a smartphone and/or control the LED lighting system manually. Two features, multi–sensor module and Bluetooth LE, let the LED lighting system be more intelligent, energy efficient, and convenient lighting system.**

I. Introduction

Conventional light sources such as incandescent light bulbs and florescent lights have being replaced by the light emitting diode (LED) to save energy cost. In order to develop LED as a new light source, researches have been focused on the design of LED light fixtures [1] for efficient light emission or enhancement of the lifetime of LED light by designing an optimal heat sink [2] [3] It is widely known that LED is an energy efficient light source as well as easily combinable with other electronics such as microcontrollers, various sensors, and wired and/or wireless communication interfaces.

Due to the potentials in digitally controllable LED lighting, many intelligent lighting systems have been proposed [4] [5] [6]. In much prior research wireless capability was added to a sensor module in which one System–on–Chip (SoC) is dedicated to process wireless capability and the sensor package has its own SoC. But in many cases a small and low cost SoC in the wireless module can be utilized to process data from multiple sensors.

In this work, we propose a smart LED lighting system using a multi–sensor module and Bluetooth Low Energy (LE) technology. A low cost SoC, CC2541 is being used to not only to enable Bluetooth LE capability but also to process data from multiple sensors. It requires, as shown in Fig. 1, a microcontroller, a Bluetooth LE transceiver, a multi–sensor module, an LED driver, an LED light source, an AC-DC power supply, and a smartphone supporting Bluetooth LE technology.

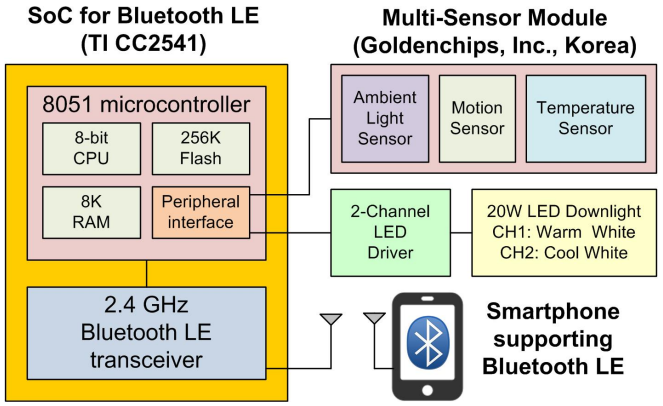


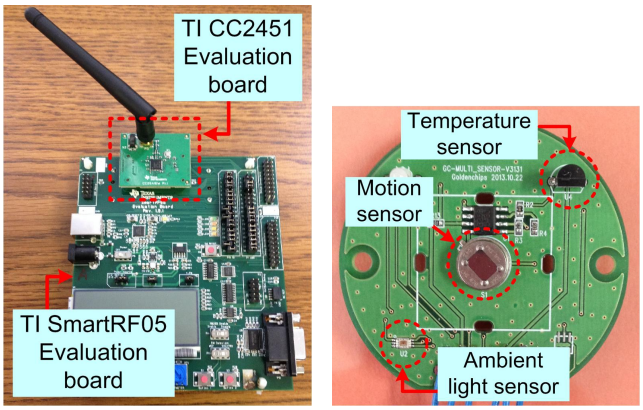
Fig. 1: High level block diagram of the proposed LED lighting system.

II. Design of Smart LED Lighting System

A. Hardware Design

As shown in Fig. 1, the hardware for the proposed smart LED lighting system consists of five different functional blocks. At first, the microcontroller and Bluetooth LE communication interface are realized by using a System–on–Chip (SoC) CC2541, manufactured by Texas Instruments (TI), in which Intel 8051 microcontroller and Bluetooth LE transceiver are integrated. A multi–sensor module including an ambient light sensor, a motion sensor, and a temperature sensor is designed by a Korean company named Goldenchips, Inc.. The multi–sensor module interfaces with the microcontroller through two analog ports for the motion and temperature sensor and a digital serial interface, I^2C for the ambient light sensor. The SoC and the multi–sensor module constitute a wireless sensor node in the WSN for the smart LED lighting system.

Secondly, the LED lighting system is established by using



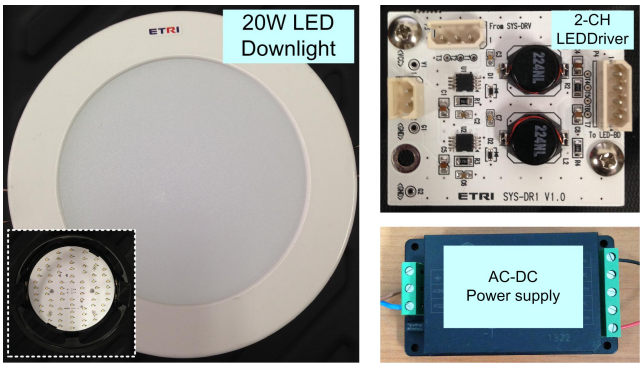


Fig. 2: Pictures of the major components: (a) TI SoC for microcontroller and Bluetooth LE, (b) multi–sensor module, (c) 20 W LED downlight (inset: inside of the LED downlight), and (d) 2-channel LED driver (top) and AC–DC power supply (bottom).

an LED driver, an LED light source, and an AC–DC power supply (omitted in Fig. 1 for briefness). In this work, a 2-channel LED driver is designed to dim the brightness of two different LED light sources, warm white and cool white LED, by adjusting the duty cycle of pulse width modulation (PWM) signal generated by the microcontroller. A 20 W LED downlight is implemented by layout of 72 warm white LED chips and 69 cool LED chips on a round shape printed circuit board (PCB) as the LED light source. A commercially available AC–DC power supply is utilized for design simplicity in this work.

Thirdly, an Android based smartphone supporting Bluetooth LE technology is used as another wireless sensor node in the WSN for the smart LED lighting system. A user can adjust the brightness of the LED downlight through the smartphone. The sensing data collected by the multi–sensor module can be monitored on the smartphone as well.

The pictures of the 5 different functional blocks are shown in Fig. 2. As shown in Fig. 2 (a), the TI CC2541 evaluation board and development kit is used to reduce the PCB design time for the SoC. The PCB design is in progress. The multi–sensor module, designed by Goldenchips, Inc. is shown in Fig. 2 (b). The 20 W LED downlight is shown in Fig. 2 (c). An inset in Fig. 2 (c) show the layout of the LED chip string on the LED downlight PCB.

B. *Software Design and Implementation*

Two different software implementation are required to control the smart LED lighting system. The one is hardware driver and the other is a mobile application on a smartphone for a user.

1) Software on SoC: The software system on the SoC for the smart LED lighting system consists two major parts: Bluetooth LE peripheral and interfaces for sensors. The system runs as a Bluetooth LE peripheral device that advertises its properties and characteristics wirelessly so that Bluetooth LE central devices in the vicinity can connect to it. We used Bluetooth LE 1.4 stack from TI to implement the Bluetooth LE peripheral. Three Bluetooth LE services were developed to send sensor readings to a connected Bluetooth LE central device. Sensor readings are being sent to the connected Bluetooth LE central device from the smart LED lighting system in every second after the connection between the peripheral and the central is made. Two Analog–to–Digital Converters (ADC) were used to process sensor readings from the temperature and the motion sensor. A digital serial interface, I^2C, was implemented to process the ambient light sensor.

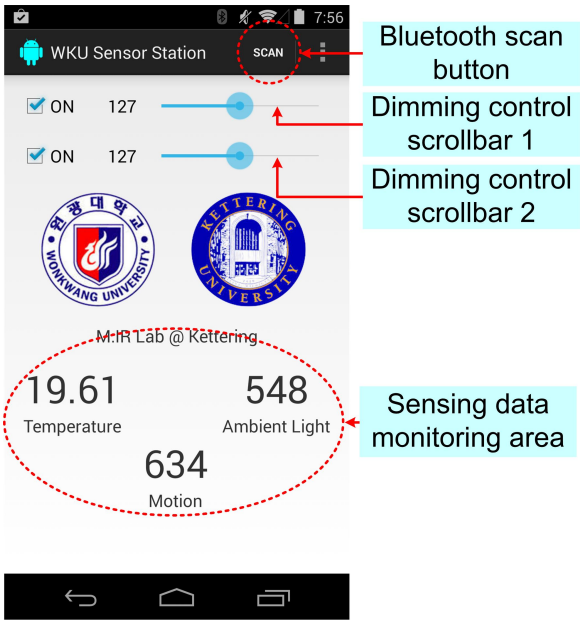


Fig. 3: Screenshot of the smartphone application for the control of the smart LED lighting system and monitoring the sensing data.

2) Mobile App on Smartphone: A mobile application (app), called WKU Sensor Station, is developed to demonstrate a simple control scenario for the smart LED lighting system. With the app, the smartphone can be a Bluetooth LE central device that can initiate connections to Bluetooth LE peripheral devices. WKU Sensor Station can both send control commands to the smart LED lighting system and receive sensor readings from the system to remotely monitor environmental changes around the lighting source.

The first function is to establish a connection to a Bluetooth LE peripheral device. The connection can be achieved by pressing "SCAN" button on top of the app.

When the app makes Bluetooth LE connection to the smart LED lighting system, the second function, transmitting the sensing data from the three sensors, begins immediately from the sensor node to the app through the Bluetooth LE interface. The sensor readings are displayed on the sensing data monitoring area at the bottom of the app as shown in Fig. 3. The unit of the temperature and ambient light intensity is degree Celsius and lux, respectively. The motion sensor value is 3–digit number converted from the analog voltage sensed at the analog port.

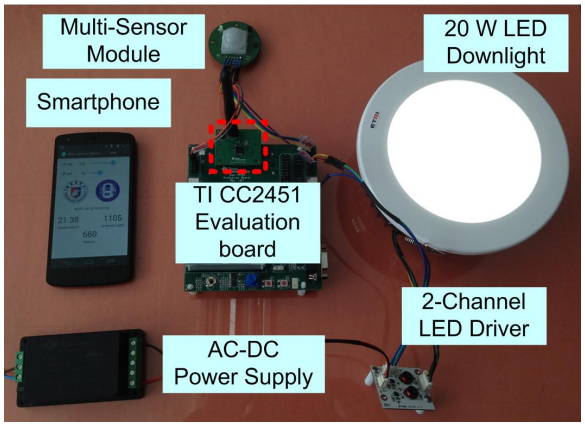


Fig. 4: A picture of the smart LED lighting system implemented.

Fig. 4 shows the smart LED lighting system implemented in this work. At the conference, a demonstration of the smart LED lighting system will be given.

III. Conclusion

A smart LED lighting system has been demonstrated to show how it is designed and implemented in terms of hardware and software design aspects. In the design of hardware for the smart LED lighting system, the five different functional blocks including a microcontroller, wireless communication interface (Bluetooth LE technology in this work), LED driver, LED light source, and power supply are required. A simple but efficient SoC, TI CC2541, is adopted for the microcontroller and Bluetooth LE function. In order to monitor the environmental information, a multi–sensor module including an ambient light sensor, temperature sensor, and motion sensor is combined to a microcontroller. By collecting environmental information, the LED lighting system can be controlled automatically. The environmental information can be monitored on a smartphone supporting Bluetooth LE technology and the LED lighting system can be controlled manually through the smartphone. Two features, multi–sensor module and Bluetooth LE, enable the LED lighting system to be more intelligent, energy efficient, and convenient lighting system.

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