논문 17-42-05-13 The Journal of Korean Institute of Communications and Information Sciences '17-05 Vol.42 No.05
https://doi.org/10.7840/kics.2017.42.5.1038

기상 모니터링과 색 온도 제어 시스템을 지원하는 무선 LED 가로등 플랫폼 설계 및 구현

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Wireless LED Streetlight Platform with Weather Monitoring and Color Temperature Control System

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요 약

본 논문에서는 기상 모니터링과 색 온도 제어 기능을 갖춘 LED 가로등 플랫폼의 설계와 구현을 제안한다. 이전 연구에서는 가로등 시스템의 에너지 효율이나 데이터 관리에 중점을 두었으나 조명 성능에 대한 연구는 이루어지지 않았다. 특히 안개나 연무와 같은 기상현상은 운전자와 보행자의 시야를 방해하기도 한다. 이러한 문제를 해결하기 위해 서로 다른 색온도를 가지는 두 개의 LED 램프를 사용하는 것을 제안한다. 이 램프는 거리의 조건에 따라 서로 전환이 가능하다. 또한 우리는 시스템 내 각 장치들 간의 통신 체계 설계한다. 더 나아가 실험결과를 통해 이 제안된 LED 가로등 플랫폼이 잘 수행되고 데이터가 웹 사이트에 제대로 표시될 수 있음을 보여준다.

Key Words : LED Streetlight, Wireless Sensor Network, ZigBee, Color Temperature

ABSTRACT

In this paper, we propose the design of LED Streetlight Platform with capabilities of weather monitoring and color temperature control. Several previous works are focused on the energy efficiency or data management of streetlight system, but no work has been done on the lighting performance, especially when natural phenomenon such as fog or haze appears on the street and obstructs the visibility of drivers and pedestrians. To solve such issue, we propose the use of two LED lamps with different correlated color temperature, which will be activated interchangeably according to the condition on the street. We also present the design of communication scheme between each devices in the system. Moreover, our experimental results show the LED Streetlight Platform can perform well and the data can be displayed properly at the website.

※ This Research was supported by a grant (#S0144-15-1007) from Gyungbuk Software Convergence Cluster Project funded by MSIP(Ministry of Science, ICT and Future Planning) and NIPA(National IT Industry Promotion Agency)
※ This research was supported by The Leading Human Resource Training Program of Regional Neo industry through the National Research Foundation of Korea(NRF) funded by the Ministry of Science, ICT and future Planning(2016H1D5A1910776)
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논문번호 : KICS2016-12-384, Received December 14, 2016; Revised April 24, 2017; Accepted April 24, 2017

Ⅰ. Introduction

Nowadays, the pace of global urbanization induces advances in digital technologies, intelligent design of cities, and also smart streetlights. According to United Nations on Housing and Sustainable Urban Development, in the 21st century, the design of urban planning should focus, among other things, on well-planned and quality streetlight system to benefit local economy, culture, connectivity, creativity, and future progresses.[1] For these reasons, many cities capitalize in different smart city applications, including the smart streetlight system. Streetlight is a crucial part of an urban infrastructure, with main function is to provide smooth traffic flow, promotion of business and availability of public facilities during night time, mitigation of night accidents, and enhanced sense of personal security.[2]

The prime concern of streetlight system should be able to illuminate the target area of roadways. Light-emitting diode (LED) based streetlight technology has substantial benefits as compared to incumbent streetlight technologies such as high and low pressure sodium lamp in terms of energy efficiency and optical luminaire.[3] Besides, LED streetlight provides numerous advantages over the conventional technologies, namely, uniformity of illumination levels via arrays of many LED chips, visibility of the streetlight through Correlated Color Temperature (CCT), visual performance improvement by virtue of high color rendering index.[2] For this reason, LED technology has shown incredible promise both in indoor and outdoor lighting systems. Moreover, the advancement in an integrated LED streetlight technology has paved a way of transforming the conventional streetlight system into LED based streetlight system.

As LED based streetlight application is relatively new, it is still an open area research including in the LED electronics part, remote monitoring of streetlight through different Wireless Sensor Networks (WSNs), and CCT of LED streetlight. Although much has been said in many literatures about LED streetlight monitoring as well as LED's lumens energy efficiency, only few papers describe about CCT and weather monitoring based design of streetlight system. Until now, most of streetlights use only fixed CCT, for example, around 5000 K, which has white color and high brightness. According to the theory of electromagnetic radiation, if the CCT is lowered, the wavelength of light will be changed from short to long wavelength. This will make the penetration rate of light and visibility improved. A study in [4] shows improvement of visibility on foggy street around 4 % when the CCT of streetlights is changed from 5000 K to 3000 K. This method can help decrease the probability of street accident happening on a foggy day, like the 106 vehicles chain collision accident on Yeongjong Bridge, South Korea in February 2015 [5], as shown in Fig. 1

The main contributions of this paper are as follows.

1) Custom design of LED Streetlight Platform is proposed.
2) Comparative study with previous and related works is reviewed.
3) Design of network and communication protocol between devices is discussed.
4) Experimental results are presented and explained.

To sum up, the rest of the paper is organized as follows. In Section 2, we discuss related and existing works. Then in Section 3, we thoroughly discuss the design of network and communication protocol, including the network diagram and the

Fig. 1. Accident on Yeongjong Bridge in February 2015.

details of communication between Streetlight Server, Streetlight Coordinator, and Streetlight Router. Implementation of LED Streetlight Platform is described in Section 4. The experimental results and discussion are presented in Section 5. Lastly, we conclude our paper in Section 6.

Ⅱ. Literature Review

In this section, we present the existing and related works on LED based streetlight systems and associated communication protocols. WSNs are more advantageous than any other communication networks for remote LED streetlight monitoring.[6] The design of remote streetlight monitoring using WSNs is considered in.[7] In this work, central control unit is used to monitor streetlight system, display topology and location maps, and send control messages to remote units, thereby gathering information of each streetlight. The sensor node in this work is used to turn the streetlight on and off, and also for dimming functionality according to the received messages from the remote unit.

Although different WSNs have been used for remote LED streetlight control applications, ZigBee is one of the potential candidates. ZigBee network has been used for LED streetlight control system, including different frameworks and network node deploying ability. Authors in [8] and [9] proposed smart streetlight system which is based on turning the streetlights on or off whenever motion is detected or not under specific area. They considered power adjustable LED lamps, motion and brightness sensors as well as ZigBee based wireless communication modules. In [10] and [11], the authors proposed LED streetlight remote control system which is implemented through a network of sensors to gather information relevant to the management, and transmit the information via ZigBee network. Other works in [12] and [13] show that the use of ZigBee network for communication can mitigate energy consumption of streetlight.

Other works such as [14] proposes a platform design with CCT control based on weather condition. The design is similar with our proposed design, but there is no explanation about remote interface for administrator to control the streetlight. In [15] and [16], the authors show how to control the CCT of streetlight by reading the weather condition from weather application programming interface, but the streetlights do not give any local weather data to server. More thorough work is shown in [17], where the request and reply communication is implemented. The use of website and smartphone application are used to display the status of the streetlights.

Ⅲ. Design of Network and Communication Protocol

3.1. Network Diagram

The proposed network diagram is shown in Fig. 2. It consists of Streetlight Server, Streetlight Coordinator, and Streetlight Router. Streetlight Server is built to acquire and log the data from sensors that attached to every streetlight for monitoring purpose and to provide control interface to each streetlight. In one street or area, several streetlights will be installed, with one streetlight assigned as a Streetlight Coordinator and the others as Streetlight Routers. Streetlight Coordinator acts as a streetlight, a coordinator of streetlight network and a gateway to Streetlight Server. Streetlight Router is the other type of streetlight that can forward data to and from other streetlights.

Streetlight Server and Streetlight Coordinator are connected through Wideband Code Division Multiple Access (WCDMA) based Third Generation (3G) network. The data are transmitted using Transmission Control Protocol/Internet Protocol

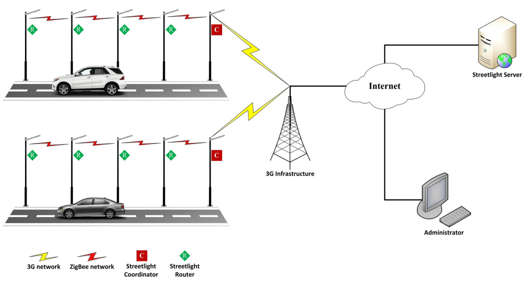

Fig. 2. Network diagram of proposed streetlight system.

(TCP/IP). Streetlight Server can transmit data to any streetlight, with the Streetlight Coordinator acting as a gateway to other streetlights. The communication between every streetlight happens over ZigBee network. All streetlights are connected in tree topology. When one streetlight wants to send data to Streetlight Server, it needs to send to Streetlight Coordinator, so that the Streetlight Coordinator can relay it to Streetlight Server.

3.2 Communication Protocol

When the streetlight system is running, every streetlight will send a periodic packet to Streetlight Server at fixed time intervals. The structure of the periodic packet is shown in Fig. 3. Streetlight Server will then receive, log, and display it on web interface for administrator.

The administrator can issue a data request or control request at any time to any streetlight from the web interface that connected to Streetlight Server. Data request is a request for specific sensor data. There are three types of sensor data that can be requested: 1) temperature and relative humidity data, 2) voltage and current data, and 3) particle concentration data. The structures of each data request packet are shown in Fig. 4. Control request is a request to control an LED lamp. There are also three types of control that can be requested: 1) turning LED lamp on, 2) turning LED lamp off, and 3) dimming LED lamp. The structures of each control request packet are shown in Fig. 5

When the request packet from Streetlight Server reaches Streetlight Coordinator, the Streetlight Coordinator will check the streetlight identity inside the packet. If the packet contains the identity of Streetlight Coordinator, Streetlight Coordinator will process the request and directly reply to Streetlight Server. If not, Streetlight Coordinator will forward request packet to the targeted Streetlight Router. The targeted Streetlight Router will receive, process, and reply the request. The reply will be sent to Streetlight Coordinator, and Streetlight Coordinator will forward it to Streetlight Server. The structures of reply packet for each data request are shown in Fig. 6.

1 byte	2 bytes	6 bytes	5 bytes	5 bytes	4 bytes	5 bytes	4 bytes	4 bytes	1 byte	2 bytes
SB	SID	T	RH	3V	3I	5V	5I	PC	EB	EOL

SB Start Byte
SID Streetlight Identity
T Temperature (°C)
RH Relative Humidity (%)
3V 3000 K LED Voltage (V)
3I 3000 K LED Current (A)
5V 5000 K LED Voltage (V)
5I 5000 K LED Current (A)
PC Particle Concentration (μg/m^3)
EB End Byte
EOL End of Line

Fig. 3. Structure of periodic data from each streetlight.

(a)

1 byte	2 bytes	1 byte	1 byte	1 byte	1 byte
SB	SID	':'	'T'	'H'	EB

(b)

1 byte	2 bytes	1 byte	1 byte	1 byte	1 byte
SB	SID	':'	'V'	'I'	EB

(c)

1 byte	2 bytes	1 byte	1 byte	1 byte
SB	SID	':'	'D'	EB

* ' ' → ASCII character

Fig. 4. Structure of data request packet for (a) temperature and relative humidity data, (b) voltage and current data, and (c) particle concentration data.

(a)

1 byte	2 bytes	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte
SB	SID	':'	'O'	'N'	LO	'K'	EB

(b)

1 byte	2 bytes	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte
SB	SID	':'	'O'	'F'	'F'	LO	'K'	EB

(c)

1 byte	2 bytes	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte	1 byte
SB	SID	':'	'D'	'I'	'M'	LO	'K'	EB

LO LED Option ('3' for 3000 K or '5' for 5000 K)

Fig. 5. Structure of control request packet for (a) turning LED lamp on, (b) turning LED lamp off, and (c) dimming LED lamp.

(a)

1 byte	2 bytes	6 byte	5 byte	1 byte	2 bytes
SB	SID	T	RH	EB	EOL

(b)

1 byte	2 bytes	5 bytes	4 bytes	5 bytes	4 bytes	1 byte	2 bytes
SB	SID	3V	3I	5V	5I	EB	EOL

(c)

1 byte	2 bytes	4 bytes	1 byte	2 bytes
SB	SID	PC	EB	EOL

* ' ' → ASCII character

Fig. 6. Structure of reply packet for (a) temperature and relative humidity data request, (b) voltage and current data request, and (c) particle concentration data request.

Ⅳ. Design of LED Streetlight Platform

We set several features that will be equipped to each LED streetlight. We use two kinds of LED lamps with different correlated color temperature (CCT), 3000 K LED lamp and 5000 K LED lamp, that will be used interchangeably according to the condition of the street. It is also able to sense the temperature, relative humidity, and particle concentration in the air around the streetlight. The voltage and current of each LED lamp can also be monitored. Each streetlight is also equipped with a ZigBee module to communicate with each other. Lastly, a 3G module is connected only to the Streetlight Coordinator to communicate with the Streetlight Server. The hardware block diagram of LED Streetlight Platform and the printed circuit board is shown in Fig. 7

The platform is driven by ATMega2560, a low power 8-bit microcontroller (MCU) with reduced instruction set computing (RISC) architecture with speed of 16 MHz at voltage range of 4.5 V to 5.5 V.[18] This MCU supports high endurance non-volatile memory segments which consist of 256 KB flash memory, 4 KB electrically erasable programmable read-only memory (EEPROM), and 8 KB static random-access memory (SRAM). It is capable of working in industrial temperature range (-40°C to 85°C), making it durable to operate in all seasons. Other utilized peripheral features from this MCU are 86 programmable I/O lines, two 8-bit timers/counters, 16-channel 10-bit analog-to-digital converter (ADC), four programmable serial universal synchronous/asynchronous receiver/transmitter (USART) interfaces, and 2-wire interface (TWI).

The LED Streetlight will be powered by 12 V of direct current. It will be first converted to 5 V and then again to 3 V. The schematic diagram of power supply module is shown in Fig. 8. The first conversion is done by a 500 kHz synchronous step-down converter RT7272A. The second conversion is done by LM1117-3.3 to convert 5 V to 3.3 V. The supporting components value are suggested in [19] and [20].

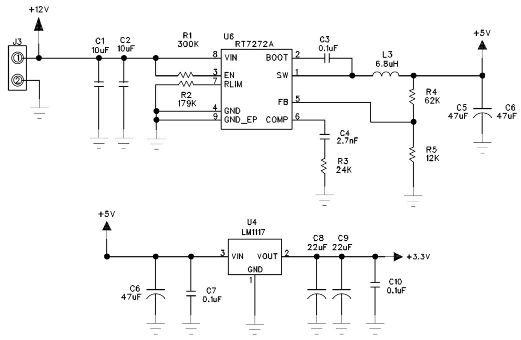

Fig. 8. Schematic diagram of power supply module.

Three sensor modules are installed on LED Streetlight Platform. The first sensor module is SHT71, a temperature and relative humidity sensor with temperature measurement accuracy of ±0.4 °C and relative humidity measurement accuracy of ±3.0 %.[21] Both measurements can be read from the Sensirion proprietary 2-wire interface pins. The second sensor module is for voltage and current measurement of LED lamps. It measures the voltage and current consumption of LED lamps when they are activated. The measurement results are outputted in analog form. The schematic diagram of voltage and current sensor module is shown in Fig. 9. The third sensor module is PM1001, a dust sensor

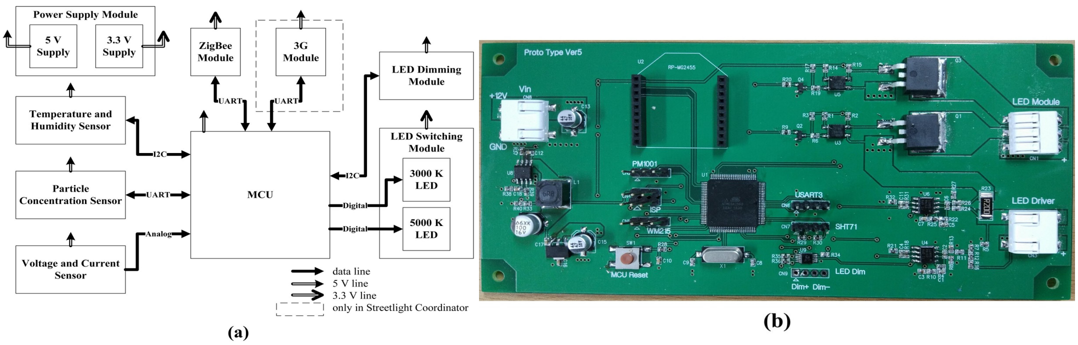

Fig. 7. Block diagram of LED Streetlight Platform.

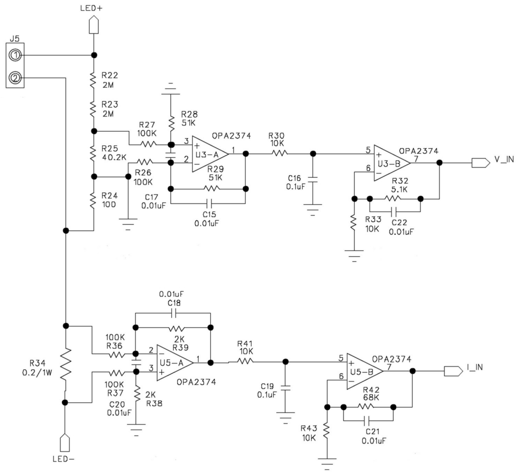

Fig. 9. Schematic diagram of voltage and current sensor module.

module that can detects particles less than or equal to 10 μm in diameter (PM10). The measurement output can be read from its universal asynchronous receiver/ transmitter (UART) interface, which is compatible with USART interface of ATMega2560.

The LED switching module consists of three main components: bipolar transistor 2N2222, optocoupler FOD817, and switch-mode power supply (SMPS) metal-oxide-semiconductor field-effect transistor (MOSFET) IRFS31N20, as shown in Fig. 10. The switching module is designed as active-low module. The bipolar transistor acts as a switch for the LED

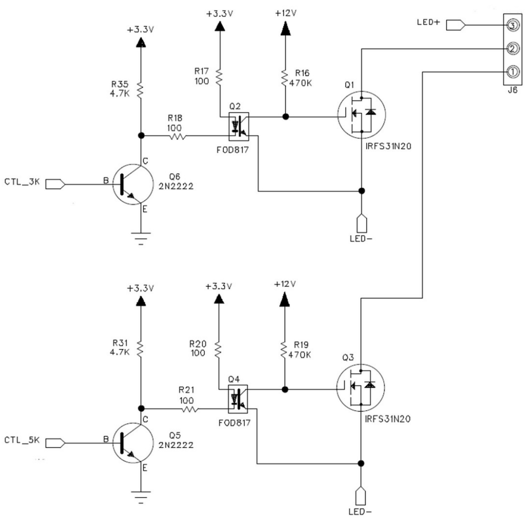

Fig. 10. Schematic diagram of LED switching module.

inside the optocoupler. The optocoupler acts as a switch for the SMPS MOSFET and also as an insulator between high-voltage circuit and low-voltage circuit. The SMPS MOSFET acts as a switch between LED lamps and power source.

The LED dimming module is controlled by a 64-position digital potentiometer AD5258. It has inter-integrated circuit (I2C) interface, which is compatible with Atmel TWI. The schematic diagram is shown in Fig. 11. The dimming can be done automatically by the streetlight or controlled by administrator.

For all streetlights, a ZigBee module XBee S2 is equipped to communicate between each streetlight. For Streetlight Coordinator, a 3G module is equipped to communicate with Streetlight Server. Both ZigBee and 3G module communicate with MCU over UART interface. These necessities are supported by the MCU that has multiple USART interface integrated in one chip.

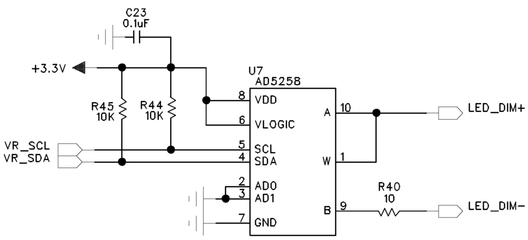

Fig. 11. Schematic diagram of LED dimming module.

V. Experimental Results and Discussion

To assess the quality of communication between streetlights, we perform several experimental measurements. Firstly, we do range test between two ZigBee devices. According to [22], the communication range can reach up to 60 m. This specification fits our implementation because the streetlights will be installed along the street with distance interval of 30 m or less. The result of range test is shown in Fig. 12. In this experiment we use XTU configuration and test utility software to measure the effective distance between two consecutive ZigBee devices. Accordingly, the test

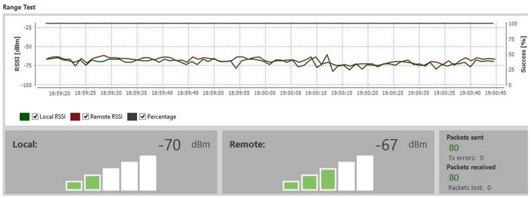

Fig. 12. Outdoor range test result between two ZigBee devices with 50 m distance.

result shows all packets are successfully transmitted between the transmitter and receiver devices. Therefore, it shows that ZigBee devices still can communicate well with distance of 50 m with the received signal strength indicator (RSSI) between the transmitter and receiver being -70 dBm and -60 dBm respectively.

We also measure the throughput between two ZigBee devices when they are sending data back and forward. According to [22], the throughput can reach up to 35 kbps. The result of measurement is shown in Fig. 13. It shows that the instantaneous throughput equals to 6.6 kbps and the average throughput equals to 6.48 kbps, which are less than the specification, but still can provide a good quality communication, because the streetlights will not transmit continuously, and also the biggest payload of transmission is relatively small (39 total bytes for periodic data as shown in Fig. 3).

The measurement data of sensors on each streetlight are sent to Streetlight Server and the results can be seen by accessing the website as administrator. We install six streetlights along Daehak Street, in front of Kumoh National Institute

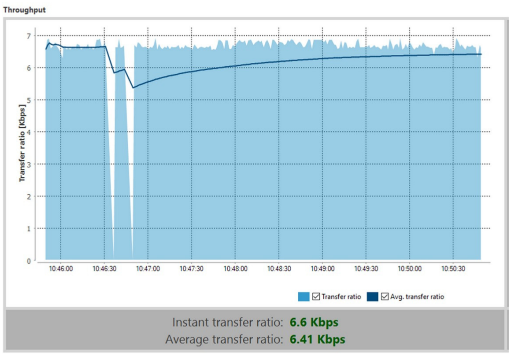

Fig. 13. Throughput measurement result between two ZigBee devices.

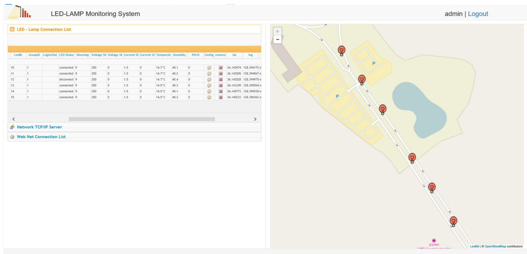

Fig. 14. Display of streetlight properties using website interface.

of Technology, as shown in Fig. 14. The Streetlight Server can receive the data without problem and the website can provide interactive and clear display to administrator.

Ⅵ. Conclusion

Several streetlight implementation has been done to tackle issues such as energy usage and data management, but only few discuss about the lighting performance. This paper has proposed an LED Streetlight Platform to provide good visibility by road illumination in clear weather and in fog or haze situation. We present and explain in detail about the communication protocol and the hardware design of the platform. The experimental results show that our proposed platform can work properly and the Streetlight Server can display the streetlight status with our proposed network design. As a future recommendation, much work can still be done on the efficacy of LEDs to allow dynamic adjustment of CCT based on weather and other physical parameters.

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