Intelligent LED Lighting System with Route Prediction Algorithm for Parking Garage

Insung Hong, Jisung Byun, and Sehyun Park
School of Electrical and Electronics Engineering, Chung-Ang University
Seoul, South Korea
axlrose11421@wm.cau.ac.kr, jinsung@wm.cau.ac.kr, shpark@cau.ac.kr

***Abstract*—Various LED applications have been developed and implemented in diverse spots because of LED's characteristic. However, some specific places such as a parking lot are required to be studied to increase energy efficiency. In this paper, the proposed LED lighting systems for a parking lot provides energy efficient management by turning on and off LED lights according to vehicle's movement through a route prediction algorithm.**

Keywords-LED, ZigBee, Route prediction, Energy efficiency, Parking lot

I. INTRODUCTION

In recent years, usage of LED lights has been increasing. As interest of energy saving broadens, light power consumption, which are one of the highest power consumption, becomes a big issue. At this point, LED lights will be the most practical answer to decrease power consumption in a home or building. Moreover, LED technology has been researched by many companies and research centers with advanced countries as the center, and now it can be substituted for the existing lights. There are various types from low power to power LED, and it is expected that it will influence lighting markets seriously.

LED has a variety of advantages compared with the existing lights. First of all, it is easy to interwork with other electronic modules such as sensors and communication module to provide new services, and can be controlled more elaborately because LED is a kind of electronic components. For example, fluorescent lights are difficult to control their brightness. Even though it is available to control, an additional control module is needed. However, LED can be handled by PWM (Pulse Width Modulation) or current control to change its brightness easily. Furthermore, it has a low power characteristic, whose power consumption is much lower than the existing lights, and a heating problem has been improved compared to the past.

By using the characteristics of LED, various LED applications are now developed. LED lighting systems now provide a lighting function and are united with ICT (information and communications technology). The intelligent lighting control system [1] provides improved user-oriented services based on wireless sensor networks, and pattern recognition about user activities and profiles. In reference [2] and [3], it shows similar services by using location-based living patterns. These researches decrease power consumption in a lighting system and service response time.

Usage of LED lighting systems has been spread gradually from normal lights in a building to parking lot. According to the characteristics of a parking lot, although movement of people is less than other places, lighting systems are always needed in this place. A parking garage requires more lights than other places, and a certain level of brightness should be maintained. In even an outdoor parking lot, lights are needed at night. Although lights are required for most of the day, frequency of the light usage is very low so this causes inefficient power consumption. By replacing the existing light with LED light, it is assumed to save power consumption as described before. Therefore, we use the route prediction algorithm to save power consumption. There are various route prediction algorithms [4] – [6] but we design the route prediction algorithm by using motion detection sensors which are included in the light controller.

In this paper, we design an intelligent LED lighting system which is suitable for a parking lot and implement it to verify its energy efficiency compared with the existing lights. Moreover, this system includes two types of sensors, illumination and motion detection, and ZigBee communication, and analyzes vehicle movement to turn on and off the minimum number of LED lights.

In Section II, we describe the hardware structure and middleware of this system are described. Section III presents the energy efficiency of this system, and it is compared with other light systems. Section IV describes the analysis of the experimental result and concludes this paper.

II. DESIGN OF INTELLIGENT LED LIGHTING SYSTEM

For the intelligent LED lighting system, the proposed system in this paper is composed as follows. Each light in a parking lot has a lighting controller in ZigBee-based sensor network. Each lighting node includes an illumination sensor and motion detection sensors. Based on the two sensor information, the lighting system decides to turn on or off the lights in the expected route where a car will enter to save needless power consumption.

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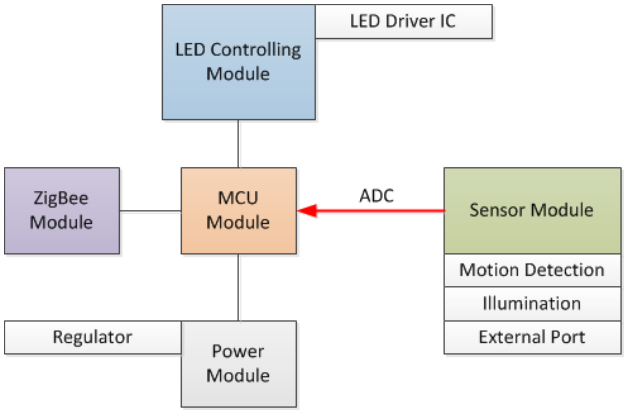
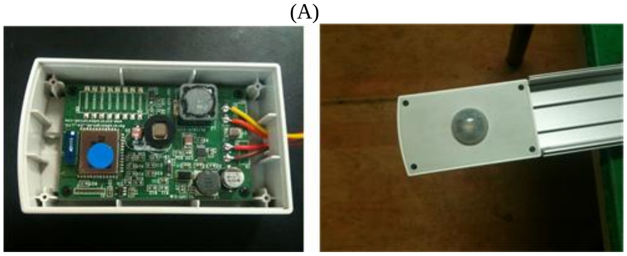
A. Overrall of the LED Lighting Controller

The overall structure of this controller is similar to the Light Enabler [2]. Basically, the controller consists of five parts, MCU module, LED control module, power module, sensor module, and ZigBee module.





(B)

Figure 1. (A) Hardware Composition of Lighting Controller (B) LED Lighting Controller and Motion Detection Sensor

The basic hardware structure of this controller consists of the five parts, and each part is controlled by the MCU module. In particular, the sensor module is designed to change the types of the sensors in this system, and the system performs its function according to the values of the two sensors, the illumination and motion detection sensor.

B. ZigBee-based Sensor Network Structure

Based on the ZigBee network, each node sends and receives data. The basic idea is that sensed data in the sensor module, illumination and motion detection, are transmitted to the neighbor or entire nodes. Each node decides to process the sensed data after analyzing the packets based on an allocated address. Each node is included in the assigned group, and this group can be changed according to the structure of a parking lot like figure 2. There is the Group Router node in the group including the certain number of nodes like figure 2, and the only two types of nodes, the Group Router and Coordinator node, are able to communicate with each other to minimize collision in the ZigBee network. The normal nodes can communicate with the Group Router node in the same group, not in different groups or the coordinator node.

In a network initialization time, the Coordinator node checks status of every node in each group by receiving initialization packets from each Group Router node. The most important role of the Coordinator node is to collect sensed data and the status of nodes and control each group based on the data.

The Group Router node performs similar functions like the Coordinator node but the functions are limited in the single group. For example, if a normal node in the same group detects a motion, the Router Node receives this data from that node, and transmits control packets to other nodes in the same group. That is, the Router Node collects the sensed data in the same group, and decides to send the data to the Coordinator Node based on the internal policy.

Types of controls by the Coordinator and Router Node are as in the following. There are the two controls, the in-group-control and group-unit-control, and the Coordinator decides one between the controls according to kinds of sensed information and internal policy in the middleware.

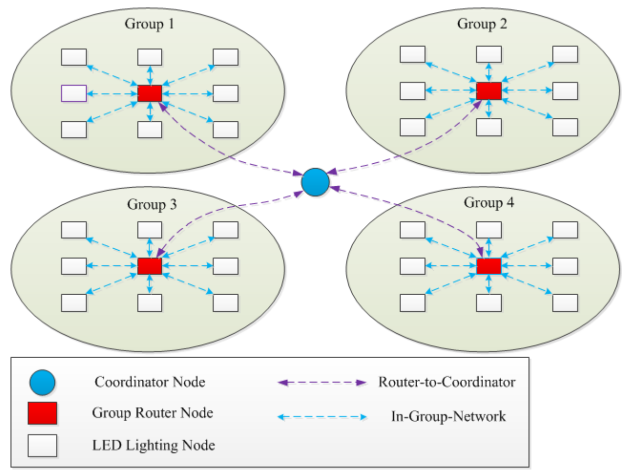


Figure 2. ZigBee Network of the proposed system

C. Middleware Structure

As described above, there are the two control types of the LED lighting node by the Coordinator and Router nodes.

- In-group-control: the control which is performed in a group based on the collected sensed data
- Group-unit-control: the control which can affect multiple groups by the Coordinator node

The most difference between the two types of the controls is the scope to affect group units. For example, if there are nine LED lighting nodes including one Group Router node, the eight nodes can communicate with only the Group Router Node. Therefore, if one node detects a motion, it sends motion detection data to the Router node, and the Router node determines to process the data and send this event to the Coordinator node. The algorithm of the in-group-control is relatively simple. Based on the critical value which can be set initially or changed by the Coordinator node, if the sensor value of motion detection

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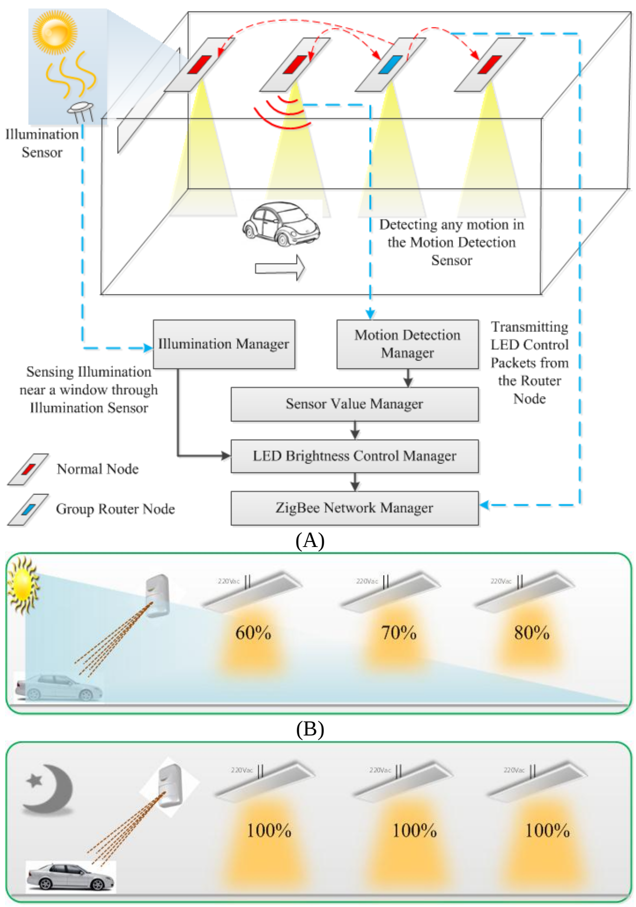
exceeds the critical value, the Router node performs the in-group-control to turn on or change brightness of lights in the same group. The designed sensor modules are an illumination sensor and motion detection sensor, but the critical value affects only the motion detection sensor. A PIR (Passive Infrared) sensor is used to detect movement, and the MCU module reads an analog value changed by the sensor module. The illumination sensor influences a brightness of the LED light. This sensor cannot turn on or off the light but the maximum or minimum brightness of the light is changed according to the illumination sensor.

Figure 3 (A) shows the essential structure of the middleware. The illumination manager and motion detection manager collect sensed data from the sensor module, and the two types of data are sent to the sensor value manager and the LED brightness control manager respectively. The LED brightness control manager changes the minimum and maximum brightness of the light based on the illumination sensor, and the sensor value manager determines to control the light by comparing the critical value with the sensed data. Through this process, the Router node decides to perform the in-group-control.



(C)

Figure 3. (A) Middleware of the LED Lighting System (B) Brightness Control in day time (C) Brightness Control in night time

D. Route Prediction

We described the middleware structure about the simple operation based on collected data. However, in an actual environment such as a parking lot, this simple operation could decrease energy efficiency and make functional problems. Therefore, we design the LED lighting system with the LED controller in consideration of the floor plan of a test bed, interworking with each LED light group, and a pattern recognition by a motion detection to maximize system efficiency.

Figure 4 (A) shows the test bed floor plan of this system. We implement the total 48 LED light nodes in the test bed, and a red line box in figure 4 (A) means one group. Moreover, each group is assigned according to drive routes. If the LED lighting node cannot detect any motion, it controls its brightness at the minimum level considering the illumination sensor, and changes to the maximum level if detecting a motion. The red circle points are motion sensing modules including the sensor module and ZigBee module so that the system can notice going in and out of vehicles by using the sensing modules. The green circle points are the Coordinator nodes which manage 24 nodes respectively.

As described above, the in-group-control is used when the light node detects unexpected motion mostly but the group-unit-control is used to control the brightness of a drive route according to the vehicle's movement when a vehicle enters a parking lot. For example, if a vehicle enters a parking lot, the Coordinator node notices the movement of the vehicle and turns on lights near the vehicle. This passive LED light operation is widely used in commercialized systems. In this paper, we propose the more advanced system with better energy efficiency based on pattern recognition.

In figure 4 (B), a vehicle is in the route A, and it could choose the router B or C after passing the route A. The normal lighting operation generally turns on both route B and C while the vehicle is in the route A, or turns on one of them after it enters the route. The former causes inefficient energy consumption because one path is not used, and in the latter a driver is difficult to secure a clear view. In this paper, we develop the algorithm with the LED lighting node to improve energy efficiency. Comparing figure 4 (A) with (B), the route A has the total six LED lighting nodes with a motion detection sensor. Each node sends a motion detection data to the Router node when it senses movement. By collecting this data, the Router node can infer a velocity of a vehicle.

$$Inst\_Velocity = \frac{Distance}{(Time\_Node_n - Time\_Node_{n-1})} \quad (1)$$

$$Avg\_Velocity = \sum_n Inst\_Velocity_n / n \quad (2)$$

Equation (1) and (2) describe the instantaneous and average velocity, and the first one is the instantaneous velocity between two nodes. The Router node checks the time when receiving a motion detection data and figures out the velocity if having two successive motion detection data like equation (1). The distance factor in equation (1) is set 5 meters in this test bed but it can be changed according to different environment. The instantaneous velocity is sent to the Coordinator node, and equation (2) is generated in the Coordinator node by using the collected data.

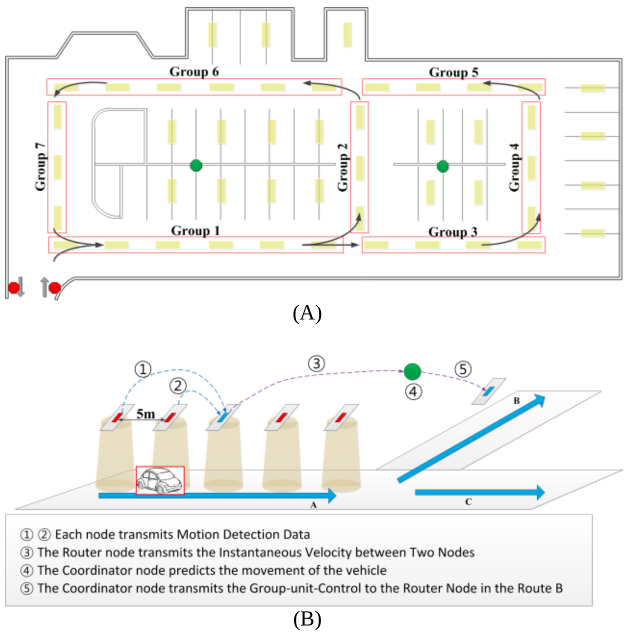


Figure 4. (A) The floor plan of the tes bed (B) Description of the route prediction

Through the two velocity information, the Coordinator node predicts whether the vehicle enters route B or C. If the velocity of the vehicle is constant and over the certain value which is set in the route A, the Coordinator node turns on the LED lights in the route C. However, if the velocity is constant under the value, it turns on the lights in the route B. Because it is difficult to drive at a high speed in a parking lot, this system can save inefficient energy consumption.

To improve this algorithm to predict drive path, the system uses the two velocity information as follows. For example, the Coordinator node uses the three velocity information, the initial, final instantaneous and average velocity. Therefore, if the final instantaneous value is larger than the initial one, the Coordinator node regards this movement as a direct drive. As described above, in case of maintaining constant velocity, it is considered as a direct one. On the other hands, if the initial velocity is larger than the final one, it is regarded as a turning drive. However, according to driving habits of drivers, some vehicles would maintain constant and slow velocity under the certain value, and it is hard to predict which route a driver chooses. In the case, the Coordinator node turns on both routes' lights which the driver can choose to handle the exception case.

Furthermore, there are the two motion sensing modules in the entrance so the system can recognize the situation a vehicle enters or gets out a parking lot. If the vehicle enters and no movement is detected during 30 seconds, the system recognizes it as a completion of parking and turns on all the lights at the half brightness to help a driver to find and move to an entrance. However, in case of getting out, the system does not turn on the lights.

III. IMPLEMENTATION

We implement the proposed system in the test bed like figure 4 (A) and figure 6, and verify the energy efficiency and accuracy of the drive route prediction. The following table shows the conditions of the test bed.
In this test bed, the average number of vehicles using the parking lot is approximately thirty, and we limit the number of driving vehicles to only one at the same time.

TABLE I. EXPERIMENTAL CONDITION

Unit	*Specification*
Number of Used LED lights	48
Area of the test bed	1800 m²
Number of available parking rooms	40
Cars per day	25~30

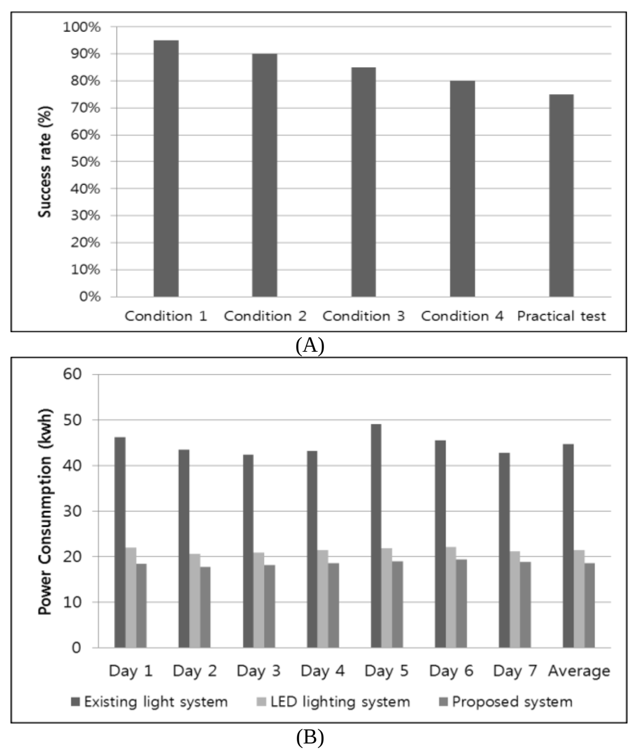


Figure 5. (A) Accuracy of route prediction (B) Comparison of energy efficiency in the three types of the lighting system

The first experiment is about the accuracy of the prediction. We choose four types of driving patterns, and each driving way is repeated 20 times.

1) *Drive to stay constant 20km/h*

2) Drive to accelerate velocity from 20 to 25km/h

3) Drive to stay constant 20km/h and slow down speed near a corner

4) Drive to stay constant 15km/h

5) Practical test for a day

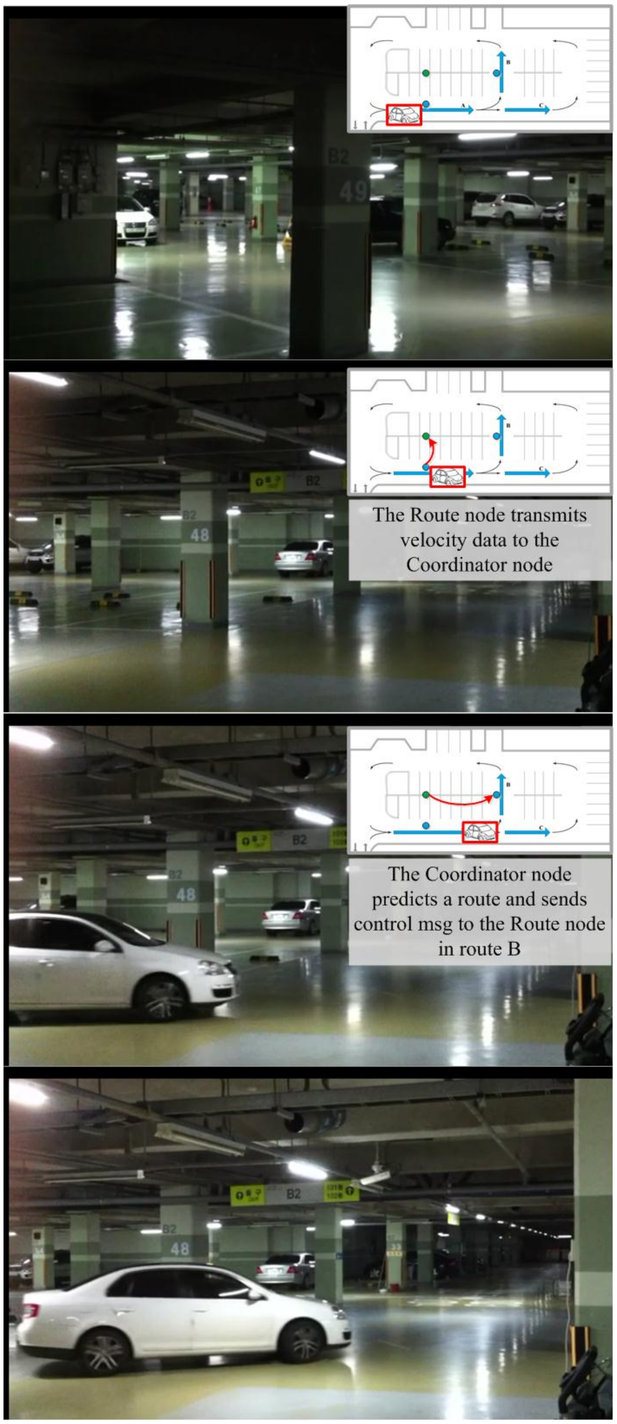


Figure 6. Implementation in the test bed

Each driving way is repeated 20 times, and, in addition, we test the proposed system for practical users. As a result of this, the practical test shows higher rates of exceptional events than the other tests.

In the second experiment, we compare the energy efficiency of this system with others. To do this, we measure three types of power consumption by using a wattmeter in the test bed for a week, the fluorescent lights, LED lights with simple operation, and the proposed system. The figure 5 (B) shows that the proposed system saves 10 percent power consumption beside the simple operation.

IV. CONCLUSION

In this paper, we design and implement the intelligent LED lighting system for a basement garage having specific characteristics different to other places. By implementing the system, the LED lighting system with the route prediction saves approximately 60 percent power consumption compared to the existing fluorescent lights and 13 percent consumption beside the LED lighting system with the simple operation.

However, in the first experiment for the practical users, the system could not predict a driver's route and considers it as an exceptional event at higher rates than the others. It is assumed that this is caused by various drivers’ patterns and size of vehicles. To complement this error, the algorithm should be improved to include driving patterns and complement response and processing time of the ZigBee network.

We plan to expand this system in a larger parking lot. This new test bed has more intersections and vehicles so the improved sensor management to handle more sensors is required. We also plan to design a management application for administrator to manage the whole lighting system.

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