Development of Long Distancing Control and Alarm System for Street Light Maintenance using LoRa

การพัฒนาระบบควบคุมและแจ้งเตือนระยะไกลเพื่อการซ่อมบำรุงไฟส่องสว่างถนนโดยใช้ลอร่า

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Abstract

This paper presents the study, design and development of a long distancing control and alarm system for street light maintenance using LoRa. The data of street lights were collected for street light maintenance planning. The sun path theory was used to calculate the optimal time for data collection. It was found that the optimal time for collecting street light data was the time that was closest to the officer's working hours and was the time when the street lights were still on, that was about an hour before sunrise. The performance of different maintenance systems with different sensor types were designed and evaluated, which were the systems that used only the light sensors, the system with only the current sensors and the system with both the current sensors and the light sensors. The experimental test-rig was setup with 3 different types of light bulbs: normal bulbs, flashing bulbs and defective light bulbs. Then, the experiment results in terms of costs, energy consumption and precision were analyzed and compared. It was found that the system using either light sensors or current sensors solely achieved was about 50.79 % cheaper than the system with both two sensor types, but had the drawback of being less precision in data transmission and consuming more power than the system that combined both two sensor types, which would save more than 52.38% energy.

Keywords: Street Lighting Long distance control and alarm system maintenance system LoRa

บทคัดย่อ

บทความวิจัยนี้ได้นำเสนอการศึกษา ออกแบบ และพัฒนาระบบแจ้งเตือนระยะไกลเพื่อการซ่อมบำรุงไฟส่องสว่างถนนโดยใช้ลอร่า โดยเก็บข้อมูลไฟส่องสว่างถนน เพื่อวางแผนการซ่อมบำรุงไฟส่องสว่างถนน ผู้วิจัยได้ใช้ทฤษฎีเส้นทางของดวงอาทิตย์ในการคำนวณเพื่อให้ได้เวลาการเก็บข้อมูลที่เหมาะสม พบว่าช่วงเวลาที่เหมาะสมที่จะเก็บข้อมูลของไฟส่องสว่างถนนเป็นช่วงเวลาที่ใกล้เวลาทำงานของเจ้าหน้าที่มากที่สุด และยังเป็นเวลาที่ไฟถนนยังทำงานอยู่นั่นก็คือช่วงเช้ามืดก่อนพระอาทิตย์ขึ้นประมาณ 1 ชั่วโมง และผู้วิจัยได้ออกแบบระบบเพื่อเปรียบเทียบสมรรถนะของการซ่อมบำรุงด้วยเซนเซอร์ที่แตกต่างกัน ได้แก่ ระบบที่ใช้เซนเซอร์วัดค่าความเข้มแสง ระบบที่ใช้เซนเซอร์วัดค่ากระแสไฟฟ้า และระบบที่ใช้เซนเซอร์วัดค่าความเข้มแสงร่วมกับเซนเซอร์วัดค่ากระแสไฟฟ้า โดยการทดสอบสมรรถนะการส่งข้อมูลของเซนเซอร์แต่ละระบบ จะทดลองกับหลอดไฟ 3 ประเภท ได้แก่ หลอดไฟปกติ หลอดไฟกระพริบ และหลอดไฟที่ชำรุด แล้วนำการทดลองที่ได้มาเปรียบเทียบ ราคา การใช้พลังงานและความแม่นยำ พบว่า ระบบที่ใช้เซนเซอร์วัดค่าความเข้มแสง และระบบที่ใช้เซนเซอร์วัดค่ากระแสไฟฟ้า อย่างใดอย่างนึงมีราคาถูกกว่าระบบที่ใช้เซนเซอร์สองตัวประมาณร้อยละ 50.79 แต่มีข้อเสียคือมีความแม่นยำของข้อมูลน้อยกว่าและใช้พลังงานมากกว่าระบบที่รวมทั้งสองเซนเซอร์ คือเซนเซอร์วัดค่าความเข้มแสงร่วมกับเซนเซอร์วัดค่ากระแสไฟฟ้า ซึ่งจะประหยัดพลังงานได้มากกว่าร้อยละ 52.38

คำหลัก: ไฟส่องสว่างถนน, ระบบควบคุมและแจ้งเตือนระยะไกล, ระบบซ่อมบำรุง, เทคโนโลยีลอร่า

1. Introduction

Street lights are the important electrical devices for public services; especially, for night time traffic, providing safe driving visibility for drivers, passengers and foot travelers. Lack of sufficient light at night will cause unclear visual for the driver and lead to accidents, injury and even death [1-3]. Research on [4] has shown that street lighting can increase driving safety and can reduce the number of deaths by 50%. Even if this issue has been remarked, in fact, the problem has not been solved. This is because of the fact that the street lights are usually installed covering large operation areas and thus the concerned authorities may not be able to fix them immediately when they are broken, damaged or malfunctions. The effective monitoring, control and alarm system for street light maintenance is therefore needed.

In Thailand, only the on/off street lighting control systems are available both for the safety or energy saving purposes [5-8]. There is no other data or information, such as bulb lifetime, broken/damage or malfunction, etc., available. The authorities would then have no information to make a proper plan for maintenance in a timely manner. One possible way is to employ the advancement of wireless data transmission technology such as Internet of Things (IoTs), which is a framework for networking that supports connections to a wide range of devices, from computers, mobile phones, network devices, to networks automatically. The wireless data transmission technologies available todays would be ones listed in the Table 1[9].

Table 1 Wireless Data Transmission Technologies [9]

Technology	Transmission Distance	Data Frequency range	Data Speed	Energy Consumption
Bluetooth	5-10 m	2.4 GHz	260 KB	Hight
Zigbee	300 m	2.4 GHz 915 MHz 868 MHz	250 KB 40 KB 20 KB	Low
RFID	0-10 m	433 MHz	250 KB	Low

Technolo gy	**Transmissi on Distance**	**Data Frequency range**	**Data Speed**	**Energy Consumpti on**
NB-IoT	10 Km	180 GHz	250 KB	Low
Wi-Fi	100 m	2.4 GHz 5 GHz	600 KB	Hight
LoRa	5-10 Km	868 MHz 433 MHz 915 MHz	50 KB	Low

It can be seen in Table 1 that the NB-IoT and LoRa (long range) technologies would be the most suitable for street light data transmission applications due to their long distance up to 10 km capability. However, the NB-IoT would require high frequency range for its data transmission and would lead LoRa to be the most cost effective where lower frequency can be used. As a result, this research focus on the implementation of the LoRa technology for the street light monitoring, control and alarm system for the maintenance purposes.

2. System Configurations

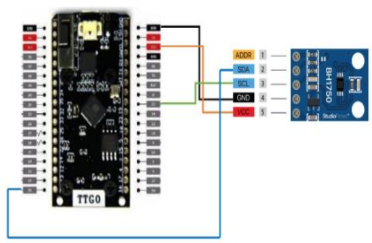
This section presents the configurations of the proposed long distance street light control and alarm system using LoRa. There were 3 systems under this investigation:

(1) System using a light intensity sensor as an on/off switch

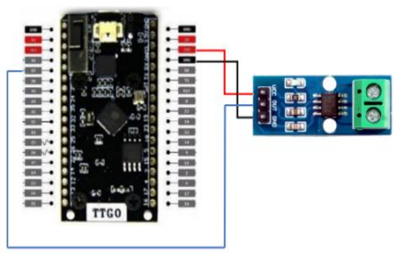
(2) System using a current sensor as an on/off switch

(3) System using both a light intensity sensor and a current sensor as an on/off switch

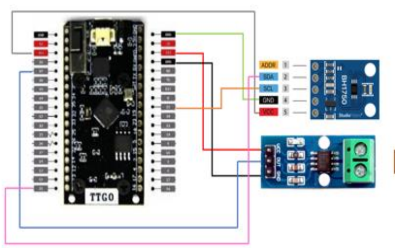
Figure 1 (a)-(c) show the wiring diagrams of the investigated system with a light sensor (module BH1750) [10-12], with a current sensor (module ACS712) [13-15] and with both light and current sensors (module BH1750 +ACS712), respectively; where the Lora module LILYGO®TTGO LORA32 V1.0 868MHz/915MHz SX1276 ESP32 LoRa [16-17] was used. The low cost and commonly used commercial devices were selected for this research for potentially massive production in the future development. The photographs of the investigated system prototypes when installed in the field side are shown in Figure 2.



(a)



(b)



(c)

Figure 1 The wiring diagram for (a) system with a light sensor, (b) system with a current sensor and (c) system with both light sensor and current sensors

Figure 2 Photographs of the investigated control and alarm system prototypes when installed in the field sides.

To evaluate the performance of the investigate systems in terms of long operation time; the power consumption made by the systems during data transmitting was therefore examined. Figure 3 shows the experimental test results for the 3 particular investigated systems.

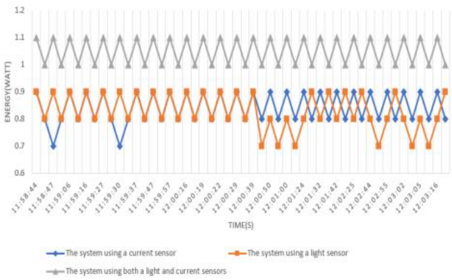


Figure 3 Power consumption in the transmission of data for each system

From Figure 3, it can be seen that the two sensor-based system that used both a light intensity sensor and a current sensor as a on/off switch spent the highest amount of the power for data transmission, approximately in the range of 1.0 - 1.1 watts; following by the system using a current sensor as a on/off switch with approximately by 0.8-0.9. The system using a light sensor as a on/off switch spent the lowest amount of power, approximately by 0.75-0.85 watts.

As the more frequent the data is transmitted, the more power is consumed by the system. Therefore, the data sending should be performed. The following factors were taken into the consideration for the design of data transmission time:

(1) Sending data once a day is sufficient due to the maintenance activity could be done only at the working hours (08.30a.m. - 04.30p.m.) to avoid excessive labor cost.

(2) The best time for sending the light bulb status is before the sunrise, so that the worker can check in the morning and operate the fixing if broken/damage or malfunctions happened.

As a result, the street light status checking and transmitting should be performed at the closest time of the officer's working time and the time when the street light bulbs are still operating, by mean of before the sunrise. To simplify the on/off programing for data transmission, the knowledge on solar path and the relationship between the earth and the sun [18-24] was used in the design.

Determining the position of the sun in the horizon coordinate system which is in terms of azimuth angle and altitude angle. declination angle (δ), hour angle (ω), time and latitude ($\emptyset$)

$$\sin\alpha = \sin\delta\sin\emptyset + \cos\delta\cos\omega\cos\emptyset \quad (1)$$

$$\cos\alpha\sin A = -\cos\delta\sin\omega \quad (2)$$

$$\cos\alpha\cos A = \sin\delta\cos\emptyset - \cos\delta\cos\omega\sin\emptyset \quad (3)$$

Equation (1) is the equation for the latitude angle in terms of Latitude angle (location), hour angle (time), and declination angle (day).

$$\alpha = \sin^{-1}(\sin\delta \sin\emptyset + \cos\delta \cos\omega \cos\phi) \quad (4)$$

The azimuth angle depends on the location, latitude, time, season, and latitude angle. Which has a value between 0-360 degrees Sines and Cosines of Angles will depend on the quadrants (Quadrants) by determining

$$A' = \sin^{-1}\left(\frac{-\cos\delta \sin\omega}{\cos\alpha}\right) \quad (5)$$

when $\cos\omega \geq \left(\frac{\tan\delta}{\tan\emptyset}\right)$ and $A = 180^0 - A'$

(6)

when $\cos\omega < \left(\frac{\tan\delta}{\tan\emptyset}\right)$ and $A = 360^0 + A'$ (7)

when considering (3) by requiring

$$A'' = \cos^{-1}\left(\frac{\sin\delta\cos\emptyset - \cos\delta\cos\omega\sin\emptyset}{\cos\alpha}\right) \quad (8)$$

when $\sin\omega > 0$ and $A = 360^0 - A''$ (9)

when $\sin\omega \leq 0$ and $A = A''$ (10)

The angle of hour of the sunrise, It can be obtained in the equation (1) of the altitude angle, since the altitude angle at sunrise and sunset is equal to 0 degrees ($\alpha = 0$).

$$\omega_s = cos^{(-1)}(-tan\delta tan\emptyset) \quad (11)$$

ω_s will have a negative value for the sunrise and a positive value when the sunset. In hours, it can be obtained from the equation (12).

$$\omega_s = \pm\frac{24}{360} \times cos^{(-1)}(-tan\delta tan\emptyset) \quad (12)$$

; where ω_s is the hour corner of sunrise and sunset

δ is a declination angle

$\emptyset$ is the altitude angle

3. Results and Discussion

3.1 Light Bulb Status Detection Performance Test

To test the performance of the light bulbs' status detection and data transmission, 3 types of 12watt LED light bulbs were used to test the investigated systems, which are:

(1) Normal light bulb

(2) Flashing light bulb

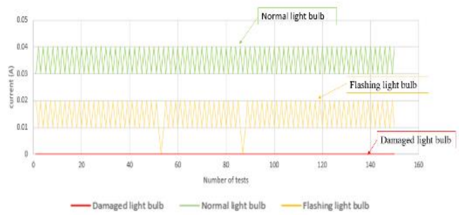
(3) Damaged light bulb

The photographs of the above light bulb types when tested in the laboratory are shown in Figure 4, while Figure 5(a)-(b) show the light bulb detection waveforms obtained from the system using a light sensor and the system using a current sensor as the on/off switch, respectively.

(a) (b) (c)

Figure 4 Three types of 12W LED light bulbs used for the status detection test: (a) normal, (b) flashing and (c) damaged bulb (low light intensity)

(a)



(b)

Figure 5 The light bulbs' status waveforms: (a) system with a light sensor, and (b) system with a current sensor

It could be summarized from the Figure 5 that The system using a light sensor solely as the on/off switch has better status classification among the normal, flashing and damaged light bulbs compared to the one using a current sensor (see Figure 5(a) and Figure 5(b)). This is because of the fact that when installing the light sensor with 5 cm away from the bulb, approximately 20,000 lux (for 0.03-0.04 A) could be measured, which is much far from almost 0 lux (for 0.0 A) under dark environment situation, 700-1,500 lux for flashing (0.01-0.02 A), and thus easy to classify the bulb's status. In turn, the system with a current sensor has very large fluctuated waveforms, which would easily encounter the wrong detection.

3.2 Estimated Cost, Power Consumption and Number of Data Set for Judgement Test

Table 2 shows the performance comparison among the 3 investigated systems in terms of estimated element cost, power consumption and number of Data sets required per one status judgement.

Table 2 Performance Comparison of the 3 investigated systems

System with	Est. Cost (Baht)	Minimum Power Consumption (Watt per 1 Status Judgement)	Number of Data Sets for 1 Status Judgment
a light sensor	100-160	2.1 – 2.7	At least 3
a current sensor	120-185	2.3 – 2.9	At least 3
both light and current sensors	220-345	1.0 – 1.1	1-2

It could be summarized from Table 2 that:

(1) The systems using either a light sensor or a current sensor has similar cost (100-185 Baht), while the system using both sensors has a double cost (220 – 345 Baht).

(2) The minimum power consumption for one status judgement for the system using both light and current sensors is the lowest (1.0-1.1 watts), while one of the systems using either a light sensor or a current sensor is approximately triple.

There are only 1-2 datasets required for the system using both light and current sensors, while at least 3 datasets are required for the systems using either a light or a current sensor. Therefore, the system using both light and current sensors would have more advantage in terms of minimum data storage and transmission for a large street light system

3.3 Control and Alert Performance Test

In this research, the collected data from the proposed system using LoRa was used for evaluating the control and alert for the maintenance via the open source Home Assistant application. The status of the registered light bulbs could be easily monitored through the computer or the mobile phone screen as some examples shown in Figure 6 and Figure 7 for the case of normal light bulb operation and the case of damaged light bulb operation when the light bulbs (number 11 and number 16) of the street light control and alert system, respectively. This information will be useful for the maintenance workers to monitor and diagnose the initial symptom, to perform the instant control for special turned off cases (as shown in Figure 8), and to make a cost effective maintenance plan regarding the proper maintenance routs, manpower required and etc.

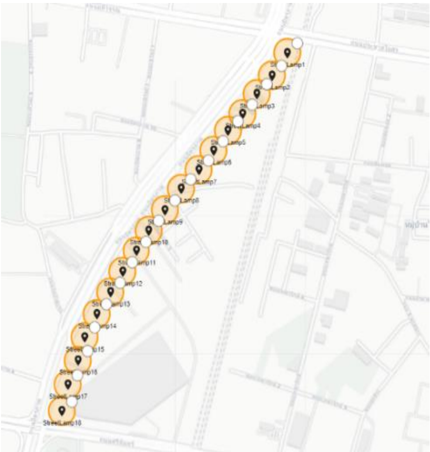


Figure 6 Example of the light bulb status on the Home Assistant display screen for the case of normal light bulb operation

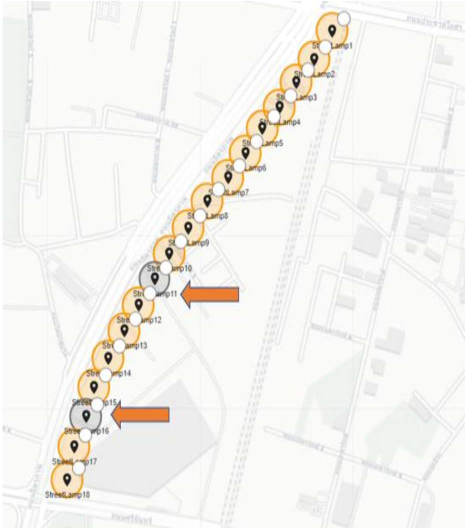


Figure 7 Example of the light bulb status on the Home Assistant display screen for the case of damaged light bulbs happened (no. 11 and 15)

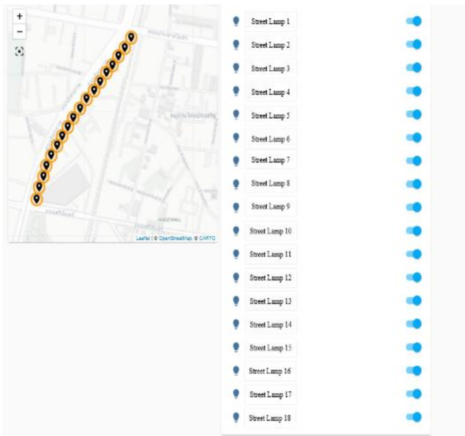


Figure 8 Control panel for the street light bulbs using Home Assistant application

4. Conclusions and Discussion

This paper presents design and development of a long distance street light control and alert system using the most common commercial LoRa (module LILYGO®TTGO LORA32 V1.0 868MHz/915MHz SX1276 ESP32) with capability of wireless data collection. The collected data could be used to effective maintenance plan regarding the minimum maintenance time, manpower and related cost. The solar path theory was used to calculate the suitable time for regular data collection for the street light bulbs. There were 3 control and alert systems under this research investigation: using a light intensity sensor (module BH1750), using a current sensor (module ACS712), and using both a light intensity sensor and a current sensor (module BH1750 +ACS712). The experimental prototypes were developed and tested. The test results related to the performance of light bulb status detection, estimated cost, power consumption, number of datasets required for the light bulb status judgement, and control and alert capability have been considered. The results showed that the system using a light sensor as an on/off switch achieved the best bulb status judgement accuracy. The systems using either a light sensor or a current sensor has similar cost (100-185 Baht), while the system using both sensors has a double cost (220 – 345 Baht). The minimum power consumption for one status judgement for the system using both light and current sensors was the lowest (1.0-1.1 watts), while one of the systems using either a light sensor or a current sensor was approximately triple. There were only 1-2 datasets required for the system using both light and current sensors, while at least 3 datasets were required for the systems using either a light or a current sensor. Therefore, the system using both light and current sensors would achieve a more advantage in terms of minimum data storage and transmission for a large street light system. These research findings could be useful for further study on the cost effective street light system maintenance plan and operation.

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