Streetlight Monitoring System
Based on Wireless Sensor Networks

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Abstract

Streetlights are necessary for an urban area. However, there is no an effective monitoring system to maintain their functions for normal operating. Power outages occur frequently in the mountain area whenever a typhoon or earthquake strikes. For the purpose of energy saving, emergency lighting and monitoring, we proposes an LED-light monitoring system, which combines an MSP430 microcontroller, solar cells and various sensing elements with a Zigbee radio transmission. We hope to enhance the performance efficiently in the management and maintenance of streetlights. This can be done by changing the luminance intelligently and providing emergency lighting in times of power outages. A software VB is used to integrate with AJAX; and Google Map API is used in the display screen to monitor the status of various streetlights through computer networks.

Keyword：LED, Luminance, Zigbee, MSP430, AJAX, Google Map

1. Introduction

In the early days, streetlights were lit in the evening manually, they were then replaced by intelligent detection whether or not to switch them on by the control center in sunrise and sunset. Although that was able to control the streetlights intelligently, the sensitivity of sensors tend to drop due to long period of application, or they would maintain the streetlights in ON status if the sensors were covered with dust to cause unnecessary power wastage [1]. In addition, in order to maintain normal operation of streetlights, it is necessary to dispatch somebody at a certain time interval, so as to patrol along the streets and to check whether there are any malfunctioned streetlights. Therefore, these would cause a great deal of resource wastage on maintenance perspective.

Power consumption for traditional streetlights is about 400W/hr, and that for LED streetlights, about 120W/hr. A power consumption survey conducted in the U.S. indicates that nearly 33% of power in the U.S. is consumed during nighttime [2,3,4]. Thus, if we can change the current streetlights to LED versions, we are able to save a considerable amount of power, and achieve energy saving and carbon reduction indirectly.

In this study, a CdS photoconductor is used in the lighting source, LED, to detect the environmental brightness; and the system uses current-to-voltage switch mode to detect the actual output. By means of comparing the luminance of LED with the environmental brightness, this system can adjust their power automatically and know whether the LED has been damaged or not.

To avoid unnecessary wastage of streetlight power in mountain region where there are few vehicles, the LED luminance is set at 75% at nighttime. A PIR motion detector is used to detect the infrared come from humans or vehicles. Whenever people or vehicle passes by, apart from switching on that streetlight to 100% luminance, and then the 5-10 streetlights at the front and rear of the street will also be changed to 100% luminance. Once the people or vehicle has gone, the streetlights will resume their 75% luminance to save power.

For remote monitoring, Zigbee 2.4G transmission protocol is used in this paper. Such protocol is set up by Zigbee Alliance, adopting the media access layer and physical layer of IEEE 802.15.4 as the standard underlying norm. The main features are low speed, low power consumption, and able to support large volume of network nodes and multiple network topology.

In addition, as Taiwan is located in an Earthquake Belt, the lampposts fixed in mountain areas often collapse, but the streetlights are unable to provide emergency lighting when power outrage occurs. Therefore, the system uses solar panel and lithium battery to provide emergency lighting.

An MSP430 microcontroller made by Texas Instruments is used as the controller to perform data exchanging through Zigbee and the computer terminal. MSP430 is a 16-bit RISC mixed-signal processor that has been priority designed in low power consumption from the design stage to posses five power-saving mode. The power consumption at full speed is 220μA, and a considerable low power consumption is only of 0.5μA at sleep mode. It is built in with ADC, DAC, OPA, USART/I2C/SPI, LCD drivers, timers, DMA and other functions to allow users to design multiple integration functions using least peripheral components.

2. System Architecture

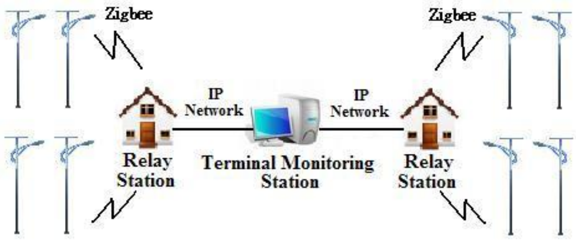


Figure 1. System Architecture

Figure 1 shows the architecture of streetlight monitoring system. The terminal monitoring station collects the streetlight information transmitted back from various relay stations through computer network and gives relevant control commands. The relay stations collect various streetlights information through Zigbee, and transmit the commands from terminal monitoring station to streetlights or give orders to streetlights directly.

The solar panels will convert sunray collected in daytime into electricity and store it in lithium batteries. Under normal condition regardless of day or night, the lighting requirement is provided by electricity, but in the accident of power outage, it is supplied by the power supply controller of lithium batteries instead.

The streetlight system is able to judge the luminous intensity intelligently according to the signals of pyroelectric infrared (PIR) sensor or IR detector. The luminous is set 75% at area without the presence of people; when the human detector or vehicle sensor is being triggered, the intensity of five streetlights at the front and rear of the street will change to 100%, i.e., the luminous of streetlights will change comply with the location of people or vehicle. The operation duration of people/vehicle detection system can be adjusted by the monitoring station as this system is not required at the densely populated urban district with heavy traffic flow, but such function will only start when people/vehicle flow has changed light at midnight or at the mountain area. In addition, the system will transmit the measured environment information, such as temperature, humidity, lighting intensity, etc. to the monitoring station.

3. Hardware Design

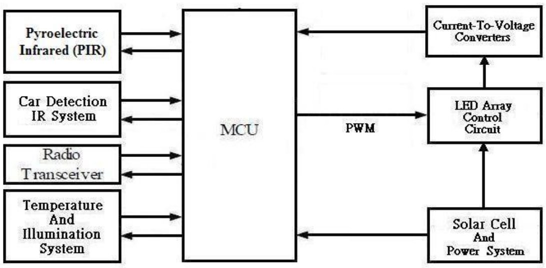


Figure 2. Hardware Architecture

Figure 2 shows the internal architecture of streetlight controller. The system will intelligently change the intensity of LED array depend on two factors: one is the environment brightness and the other is of whether people or car passes by. Besides, the system will transmit the related information, such as temperature, humidity, luminance, PMW and the information that people/vehicle has passed by, to the monitoring station through Zigbee. The Zigbee transmission with mesh mode link is adopted by this paper. Figure 3 shows the installation locations of various hardware devices.

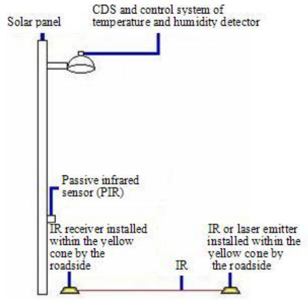


Figure 3. Diagram of device installation

The analog voltage signal measured from sensor is converted by the MSP430 into digital signal with 12-bit code. The conversion formula is shown as follows:

$$N_{ADC} = 4095 \times \frac{V_{in} - V_{R-}}{V_{R+} - V_{R-}} \quad (1)$$

N_{ADC} : the digital value after conversion

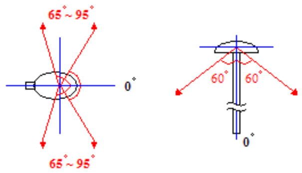
V_{in} : the input voltage value

V_{R+} and V_{R-} : the reference voltages value

3.1 LED Illumination

As mentioned in "Public Streetlights Management" to avoid energy wastage, the installation of streetlights must not be too intensive, and so one streetlight is installed at an interval of 35~50 meters depending on different road widths.

According to the regulation of "LED Streetlight Standard Protocol," the emitting angle of a LED streetlight is shown in Fig. 4, and the total luminous efficiency should be greater than 450 lm/W. While measuring the brightness, the measuring distance should be greater than 10 times the face size of LED light, and the background illumination of sample test bench should not be greater than 0.05Lux.



(a) (b)

Figure 4. Irradiation Angle Diagram
(a) Top View (b) Front View

The 5m wide-angle type LED is used by this study, its emitting angle is 100~130 degrees and the input voltage is 3.0V~3.6V, the forward current is 20mA~40mA, and the LED plate diameter is 13cm. While testing, the installation height was higher than 130cm.

3.2 Sensing Devices

The CdS is connected in series with variable resistor voltage divider to detect the environmental illumination.

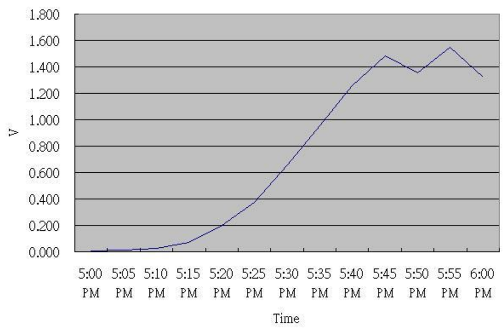


Figure 5. The correlation of CdS voltage and sunset illumination

Humidity sensor: the study adopted RHU-500M humidity module as show in Fig.6(a). The output voltage relative to humidity is linear correlation. The curve is shown as Fig.6(b). From the curve, we can figure out the formula for the correlation between voltage and relative humidity

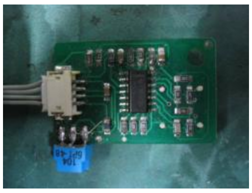


Figure 6. (a) RHU-500M model

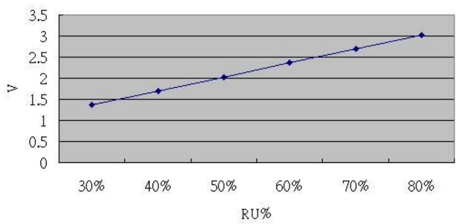
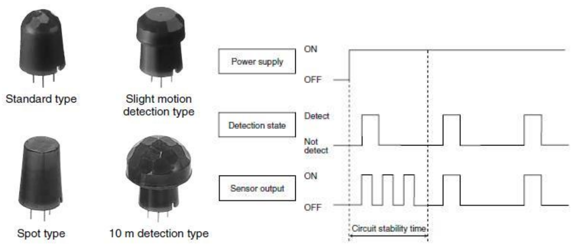


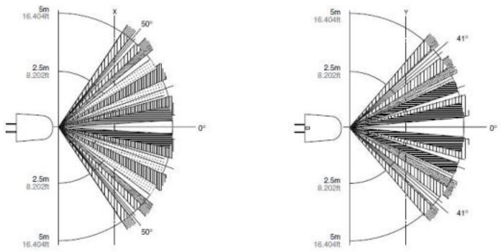
Figure 6. (b) The voltage curve relative to humidity

A PIR device, AMN11112, which includes a pyroelectric detector, has a good performance for sensing far-infrared, and is shape-formed to a digital output. Its detectable range depends on the lenses as shown in Fig. 7. The maximum detection distance is of up to 5 meters, and the horizontal and vertical detection range is 100° and 82°, respectively, and the output is in digital mode.



(a) (b)

Figure 7. (a) Package type of AMN11112
(b) Digital output



(a) (b)

Figure 8. Detection Performance
(a) Top View
(b) Side View

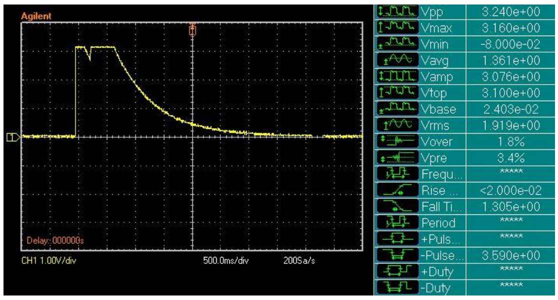


Figure 9. Actual output when the sensor has detected the presence of people

An RC circuit is used for delayed output to get correct sensor signal as shown in Fig.9. To detect the vehicles, IR method is used with a red laser acting as the transmitter and an IR photodiode as the receiver. It would block twice in a short interval to determine whether any vehicle has passed through.

3.3 Solar Cell

A low-voltage/high-current solar panel is adopted during the experiment to coordinate with boost converter made exclusively for solar panels from Texas Instruments with an input voltage as low as 0.3V. It can be operated in a single solar cell manner to avoid using several solar cells and unnecessary circuit-related protection.

A DC/DC converter circuit as shown in Fig.10, we must ensure that the electric section is of in a saturation state to perform an efficient conversion. Therefore, the circuit inductance can be calculated in the following formula:

$$L_{\min} = V_{in} \times 0.5 \frac{\mu s}{A} \qquad (2)$$

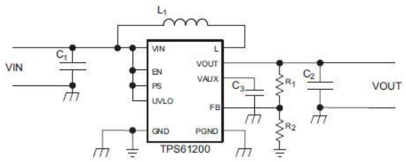


Figure 10. Application Circuit

With the chosen inductance value, the peak current for the inductor in steady state operation can be calculated. Equation 3 shows how to calculate the peak current *I*.

$$I_{L\max} = \frac{V_{out} \times I_{out}}{0.8 \times V_{in}} + \frac{V_{in} \times (V_{out} - I_{out})}{2 \times V_{out} \times f \times L} \qquad (3)$$

3.4 Illumination and Pulse Width Modulation

The timer B of MSP430 is used to control the PWM and adjust the LED luminance. TAR register will start to increase from zero and compare continuously with CCR0 and CCR1, and initiate PWM output with a high output level. When TAR count value is greater than CCR1, PWM output will be transferred with a low level output, and TAR will continue to increase. When TAR value is equal to CCR0, TAR will reset automatically and recount. The PWM signal output is shown in Fig. 11. So, CCRO will decide the PWM cycle, and CCRI will decide the duty cycle of PWM.

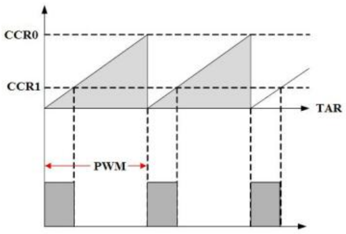


Figure 11. PWM Output Signal

As moonlight, residential lights and other lights are able to affect CdS in nighttime, the output voltage of CdS is then adjusted around 1.5V during the night, and the system will preset the PWM output at 75% at nighttime. The equation 1 can be rewritten as follow:

$$N_{ADC} / PWM = (4095 \times \frac{V_{in} - V_{R-}}{V_{R+} - V_{R-}}) / 75 \qquad (4)$$

From equation 4, we know that PWM will increase by 1% for every conversion increment in 24.2 of ADC value. The relationship of CdS voltage value and PWM output is shown in Fig. 12. Figure 13 shows that when the actual measurement of CdS voltage was 0.165V, the PWM (+D) output is 31.5%.

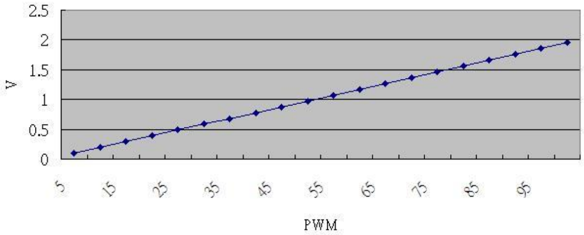


Figure 12. The correlation of PWM output and CdS voltage

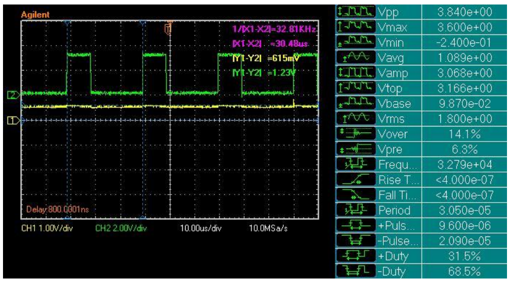


Figure 13. a PWM output state

3.5 Hardware Experimental Results

Figure 14 shows a simulated hardware construction diagram. An LED light consumed 2.88W is set at 150cm high above the ground. When surroundings are getting dark, the controller will adjust the luminance of LED light depending on the measured value of CdS. As shown in Fig. 15, when PWM output is 73.8%, the illumination is 61Lux. And while some people or car passes by, PWM output will change to 100% to give a illumination of about 86 Lux as shown in Fig. 16. Even if AC power outage, the system will shift using lithium battery to continue the operation as shown in Fig. 17.

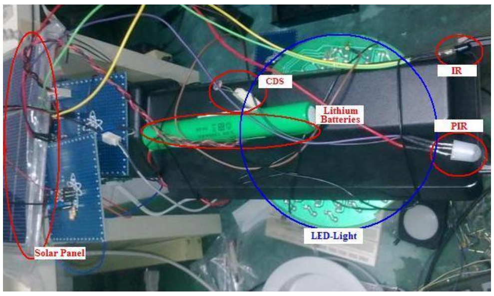


Figure 14. Hardware Setup Diagram

Figure 15. (a) The LED operation status with the absence of people

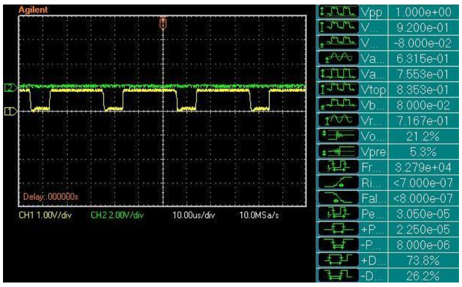
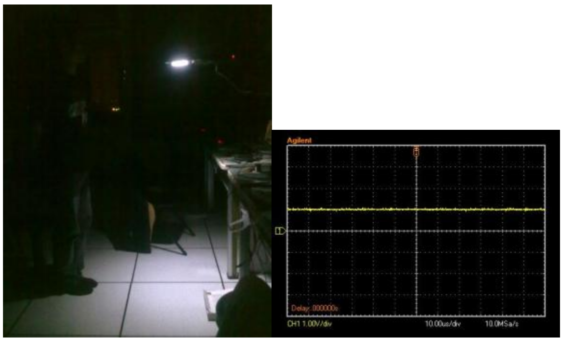


Figure 15. (b) PWM Output State



(a) (b)

Figure 16. (a) LED Light operation status upon detection the presence of people
(b) PWM Output State

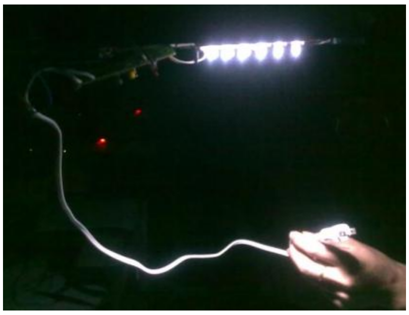


Figure 17. Normal operation of LED light during a power outrage

4. Software Design

The monitoring software is developed by using VB in the computer terminal to communicate with streetlight microcontroller, while the currently most popular Google Map is chosen as the display interface.

The earlier maps used on Internet was extremely inconvenience, and most of the network GIS system are based on Microsoft ActiveX and Sun Java Apple technologies with great inconveniences as they still required to install with auxiliary tools for loading. The brand new map service launched by Google is similar to GMail that entirely uses AJAX (Asynchronous JavaScript and XML) technology. AJAX is network development technology that uses creative interactive-based network application proposed by Jesse James Garrett. AJAX is composed with a bunch of currently existing technologies. Among its major component technologies are:

1. XHTML (or HTML) and CSS for presenting the information.
2. Uses DOM and Javascript to access and save information (mostly XML).
3. Uses XMLHttpRequest object and remote web server to perform non-synchronous data exchanging.

The advantage of using AJAX is its capabilities to perform data maintenance without having to renew the entire web page. AJAX does not require any browser plug-in but it needs user to permit JavaScript to be executed on the browser.

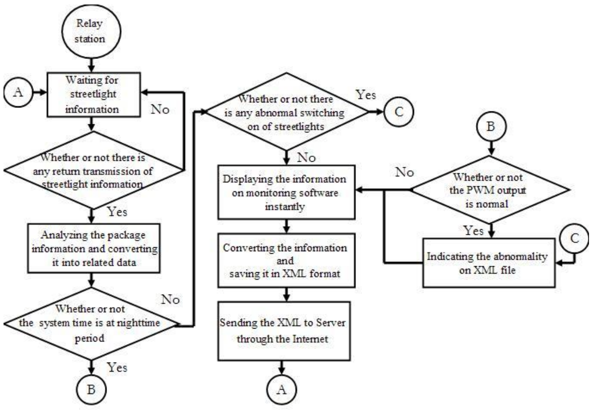


Figure 18. Software Flowchart

Figure 18 shows the software flowchart. The streetlight information received by relay station will display on GUI and send to specific server using XML format, i.e. terminal monitoring station. If the connection and operation are normal in daytime, the streetlight icons are displayed in green. The road monitoring section is displayed on the left upper corner. Chin-Yi Avenue of National Chin-Yi University of Technology for example, when a streetlight icon is clicked on, the streetlight-related information will be displayed on the left lower corner of the screen as shown in Fig. 19. If the online operation at nighttime is normal, the icons are displayed in yellow, and if the operation is abnormal, it will be displayed in red as shown in Fig. 20-21. Fig. 22 shows the basic function setup of streetlights.

Figure 19. Normal Operation of Streetlight in Daytime

Figure 20. Normal Operation of Streetlight in Nighttime

Figure 21. Abnormal operation of streetlight in nighttime

Figure 22. Streetlight Setup Interface

5. Discussion

It is a future trend to use LED for illumination. As compared with streetlights using traditional light bulbs for illumination, it not only can save energy but also reduce power consumption and carbon. In addition, the power consumed by LED is less than of traditional light bulbs, since the temperature of LED is lower than of the traditional light bulbs, it means that it is also able to lower the city temperature at the some time.

As LED lights used in this simulated system are not high-wattage LEDs, so they cannot be installed on street officially for actual testing. It is high expected in the future that the cooperation with LED factories to implement this system can be practiced earlier in the city.

6. References

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