Light Sensor for Automatic Street Light Control

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Abstract
Street lights in Singapore are currently switched on for the entire duration of sunset to sunrise, regardless of the amount of vehicular traffic. This results in energy wastage, which can be mitigated through the use of light sensors to determine the need for street lights to be switched on. This project aims to develop a sensor tailored to control street lights according to oncoming vehicular light intensity.

1. Introduction

Street lights in Singapore are currently switched on at full intensity for the entire duration of darkness [1], which is between 7pm to 7am daily. This is done without regard for the amount of traffic on the roads, which can be extremely low during the early hours of the mornings.

There are approximately 95,000 (4,000 in residential roads, 91,000 in arterial roads and expressways) sodium vapor street lights scattered all around Singapore's residential, arterial roads and expressways, which are all due for replacement with LED lights by 2022 [2]. Sodium vapor street lights of 70 and 150W (with LED replacement wattages of 55 and 130W) are being used for residential roads, and 250 and 400W (with LED replacement wattages of 200 and 300W) are being used for arterial roads and expressways currently [3], [4]. Though the LED lights are expected to be about 25% more energy efficient when compared to the sodium vapor street lights, more energy can be saved with the appropriate switching on and off of the street lights depending on vehicular traffic.

This project will hence develop a sensor system to detect the approach of vehicles towards the street lights, automatically switching the street lights on to illuminate the roads. The sensor system shall also automatically switch the street lights off when the vehicles have passed, enabling energy savings from the switching off of street lights during periods of low vehicular traffic on the roads. The sensor system shall make use of photodiodes to detect light intensity of the headlights of the oncoming vehicles, triggering the street lights through the use of relays when the detected light intensity is greater than a pre-set threshold.

2. Description of Sensor

The sensor system will consist of photodiodes, operational amplifiers, transistors, resistors and relays connected in an electrical network. The photodiodes will detect the light intensity from the oncoming vehicles, converting incident photons into electrical current. Photodiodes were chosen over light-dependent resistors due to the directionality provided by photodiodes that would be more specific for the application. The small signal from the photodiodes would be used to trigger the relay, in turn switching the larger load (street lights) to illuminate the roads ahead of the vehicles. This system would be positioned such that the street lights would be switched on in advance, allowing for safe usage of the roads.

After the vehicles have passed safely, the photodiodes would then detect a drop in light intensity. This decrease in light intensity would then cause the street lights to switch off, until other vehicles approach again. Energy savings would be determined based on the number of hours that the street lights are automatically switched off during the standard hours of operation of the street lights.

A light-dependent resistor circuit could be incorporated to trigger this sensor system based on the detection of surrounding light intensity. The light-dependent resistor would detect a high intensity of surrounding light during the daytime, and a low intensity during the nighttime. This would then be used to determine whether the sensor system would have to be triggered.

3. Electronic Circuit for Sensor System

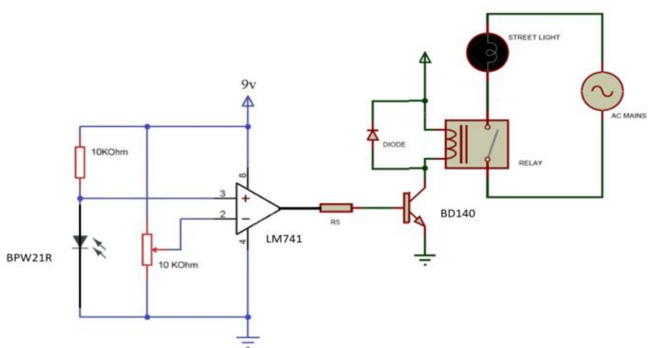

Fig. 1. Electronic circuit for system

At night, the resistance of the photodiode is high so pin 3 gets higher voltage than pin 2 and makes the output of the op-amp high as this high output keeps the NPN transistor off since its base is positive. Thus, the street lamp remains off. When the photodiode detects the light from the car headlights, the resistance of photodiode decreases and the voltage at pin 3 decreases. As a result, output of the op-amp becomes low to switch on the transistor. This will in turn trigger the relay system and switch the street light on. Finally, a diode is added to the relay system to reduce excess voltage once the transistor switches off. This will therefore disconnect the relay system and switch the street lamp off.

In addition, the photodiode will be reversed biased so that it can respond faster. The models used for the various components are, BPW21R (photodiode), LM741 (op-amp), BD140 (NPN transistor).

4. Main area of application

This sensor system would be mainly used for street lights in Singapore, due to the threshold set for the incident light intensity on the photodiodes to trigger the switching on of the street lights. Street lights were chosen to be the main area of application over walkway lights and other types of lights due to the larger number of street lights present in Singapore, and the higher energy usage of the street lights compared to other forms of lighting used in other areas. This project aims to look into the area of application where the energy savings arising from the sensor system being added into a current system would be significant enough to cause the sensor system to be a worthy investment. The payback period for the investment should not be too long in order for the sensor system to be taken with serious consideration.

5. Feasibility

The main concern regarding the feasibility of the sensor system was whether or not the photodiode would be unable to differentiate between light picked up from the surroundings and other street lights, from the light emitted by the headlights of the vehicles. This was because we did not want the sensor system to mistake the light from the surroundings and other street lights to be indicators that there was a vehicle approaching, and that the street light had to be turned on.

In order to test whether this problem would be present, we measured the light intensity of the LED street lights, as well as the light intensity of the car headlights. This was done by placing a lux meter directly underneath a street light to mimic the placement of the sensor, and expanding outwards at 1m intervals to obtain a radial variation of the light intensity of the street light, as shown in Fig. 2.

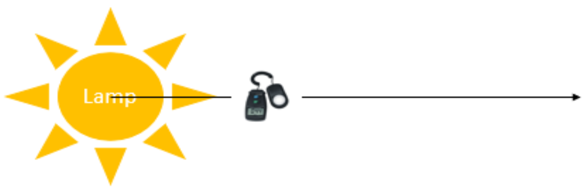

Fig. 2. Set-up for measurement of street light intensity

Results obtained are displayed in Fig. 3.

Distance from middle of light (m)	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Lux	13.6	13.2	12.7	12.5	11.8	10.3	9.7	8.3	7.9	6.6	6.3	6.5	7	7.2

Fig. 3. Results for street light intensity

From the measurements, it could be deduced that the maximum intensity of light emitted from the street lights was 13.6 Lux, and that the light emitted by two consecutive street lights started to overlap at about 11m away from the first lamp.

For the measurement of the car headlight intensity, the lux meter was held 70cm above the ground, perpendicular to the car headlights. This was done to simulate the height at which the light would be incident on the sensor. The measurement was done in 1m intervals, starting from 3m, from the front of the car, and at 45 and 65 degree angles.

The results were plotted in two graphs: distance from middle of car against lux level (Fig. 4), and angle against lux level (Fig. 5).

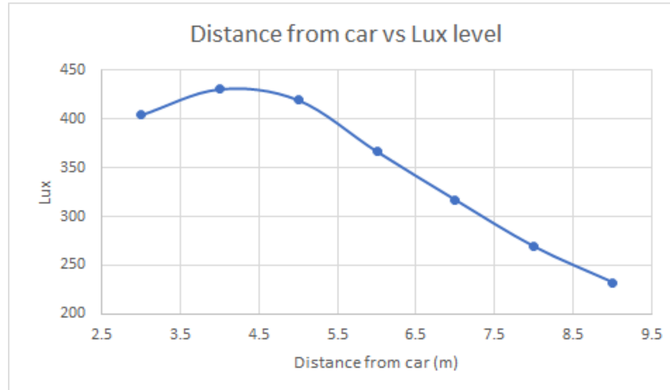

Fig. 4. Graph for distance vs lux level

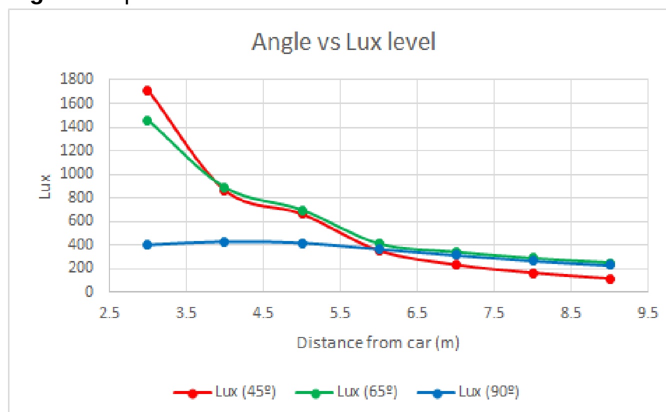

Fig. 5. Graph for angle vs lux level

The measurements were taken from 3m to 9m as it was discovered that the lux level was extremely low before the 3m mark, and that the lux level started to fall too close to the lux level obtained from the street light after the 9m mark. 9m is also approximately the length of two cars, which is a relatively safe distance to switch the street lights on before the vehicle approaches.

The results show that the maximum intensity is located at around 3m from the car, with the intensity dropping rapidly beyond the 3m mark. This means that the car headlights were designed to illuminate the roads 3m ahead of the car most brightly. The lux level at 9m falls to about 118 lux at 45 degrees, and about 200 lux for 90 and 65 degrees. Also, it can be seen that the light intensity measured directly in front of the car (at 90 degrees) was much lower than measured at other angles, until at about 6m, where the light intensities became similar in magnitude. From this, the rough pattern for the car's headlights could be inferred, as shown in Fig. 6.

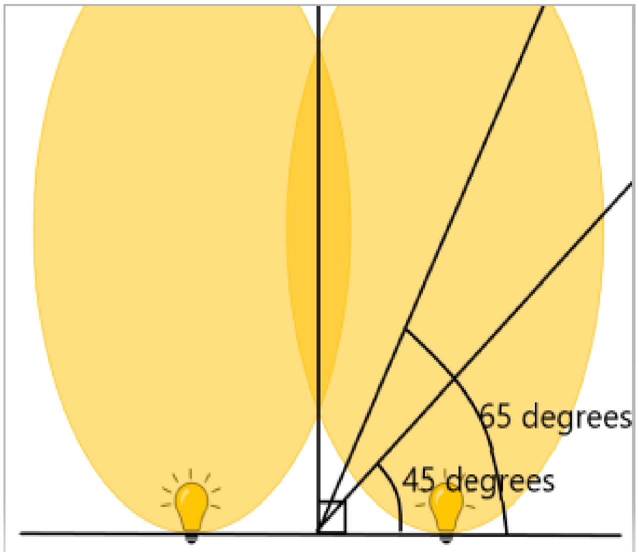

Fig. 6. Car headlight pattern

From the results, it could be deduced that we had to design the sensor such that the street lights would not be switched on for an incident light intensity of below 100 lux, as that would be the light from the surroundings and street lights. We would set the street lights to be switched on when an incident light intensity of 100-200 lux was detected, in order to illuminate the road 9m ahead. This is to ensure a safe distance by illuminating the roads further ahead of the vehicles. After the vehicles have passed the sensor, the lux level would then drop below 100 lux as the surroundings and street light intensity would contribute less than 100 lux of light intensity incident to the sensor. This would then switch off the street lights to save energy.

6. Improvements to Project

To improve on the project, we believe that we could firstly utilize better tools to measure the light intensity of the headlight and street lights. This is in a bid to improve accuracy of the measurements, as the measurements directly affect the switching of the street lights. We could use tools that would allow for more consistent and accurate measurements if given the time and budget to further improve on our project.

We could also add in other sensors to investigate whether there are other vehicles or commuters passing by. Simply using the LDR and photodiode might not be reliable as there is a possibility of other sources of light affecting the current set-up, switching the lights on unnecessarily. For further improvements, we may consider using specific infrared or thermal sensors to verify that there are cars passing by, based on the amount of heat emitted from the cars or other factors. This further increases the correctness of sensor control.

7. Conclusion

Concerns about increasing energy usage have been steadily increasing over the years, and while a sustainable source of energy can be created, it is also advantageous that we try to reduce redundant energy consumption wherever possible. We hope that the energy-saving feature of our project can help to reduce this unwanted energy consumption, allowing for a 'smart controller' to gauge the nature of the roads and the traffic and expending energy to illuminate the surroundings only when needed.

References

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