Proceedings of CONF-FMCE 2025 Symposium: Semantic Communication for Media Compression and Transmission
DOI: 10.54254/2755-2721/2025.GL24809

LED Constant Illumination Control System Based on Distance Measurement

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Abstract. With the development of science and technology, light-emitting diodes (LEDs) have been extensively used in the field of illumination due to their characteristics of low power consumption and high stability. According to the different usage scenarios, the demand for automatic adjustment of lighting intensity is growing rapidly. This paper designs a self-adaptive illumination system that automatically calculates LED output power with the change of measurement distance and maintains constant brightness of the irradiated object. The system uses Arduino Mega as the processor, measuring the distance between the light source and the target object by using multiple distance sensors and reducing measurement errors through the use of a fusion algorithm. The photosensitive sensor BH1750 is used to collect the luminance of the target object, and then the lighting intensity error between the actual data and the preset data is adjusted by using the Proportional Integral Derivative (PID) algorithm. Through the combination of experimental data and experience formulas, the numerical correspondence between light intensity and Pulse Width Modulation (PWM) values can be calculated. When an object at a known distance needs to reach the desired light intensity, this correspondence relationship can be used to calculate the PWM value output to the LED. With the subsequent adjustment process by PID, this correspondence relationship can be used to calculate the PWM output difference based on the light intensity difference, so that the response speed of the PID can be improved.

Keywords: self-adaptive, relational model, PID

1. Introduction

In recent years, with the continuous development of Light-emitting Diodes (LED) technology and the reduction of production costs, the size of the LED lighting market has been expanding year by year, and the application fields are constantly expanding. With the increasing awareness of energy conservation and environmental protection in society, LED intelligent lighting systems based on Proportional Integral Derivative (PID) algorithm and Pulse Width Modulation (PWM) dimming technology have become a research hotspot in different application scenarios.

There has been some research focusing on different introductions of the control algorithm. Jing summarized the research progress of indoor LED lighting control strategies and technologies [1]. Tong used a combination of sensor information fusion and fuzzy neural network to achieve intelligent dimming of tunnel LED lighting through PWM control, which provided a dynamic

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luminance adjustment method for tunnel lighting [2]. Mao designed an intelligent lighting monitoring system for university classrooms based on STM32. The system uses a single-neuron adaptive PID algorithm to detect indoor natural light intensity and personnel information. The controller can achieve automatic switching and dimming functions of the lighting fixtures based on intelligent algorithms [3]. In response to the complex and ever-changing port environment with high requirements for lighting systems, Cai introduced a PID algorithm based on real-time detection of on-site illumination to achieve smooth control of changes in illumination intensity so that the steady-state error can be controlled within 1% [4].

With the maturity and stabilization of unmanned drone technology, miniaturized drones have been widely used in various fields in recent years, especially in road tracking, field rescue, and other areas. The drone is playing an irreplaceable role. Since the battery is an important resource when drones perform a mission, it is necessary to develop a lighting system that can ensure illumination intensity as well as save power consumption so that the drone's flight durations can be extended greatly when performing a mission at night.

Through experiments, this paper builds a relational model between PWM values and light intensity on the premise that the distances are known and makes dynamic adjustments to the illumination intensity of the target object by combining PID algorithms into account. Using this method, the intelligent dimming control can maintain the luminance of the target object when the distance changes.

2. Methods

According to the formula (1), the light intensity I is inversely proportional to the square of the distance d when the value of power P is certain.

$$I = P/4\pi d^2 \tag{1}$$

However, in a practical use case, due to the impact of the precision of component design and the drive circuit, it is not easy to figure out the output voltage value of the light source exactly, as well as the power P that is needed through the theoretical formula.

Some researchers use an MCU to control voltage or use an MCU to adjust the output of PWM to control the current value of the driving circuit to control the light intensity of the LED [5-8]. The PID algorithm has been proved to be an effective method that can dynamically calculate and adjust the output PWM according to the optical feedback signal [9].

In this paper, a method is found to solve this problem. On the premise that the distance is known, by combining experimental data and theoretical formulas, the approximate corresponding relationship between the luminance of the target object and the PWM value input to the source of light is built. Using this corresponding relationship, the light intensity of the LED light source can reach the set value quickly so that the luminance of the target object can approach the set value, and then the difference between the actual illuminance value and the set value of the target object can be corrected by using the PID algorithm.

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3. Test environment diagram

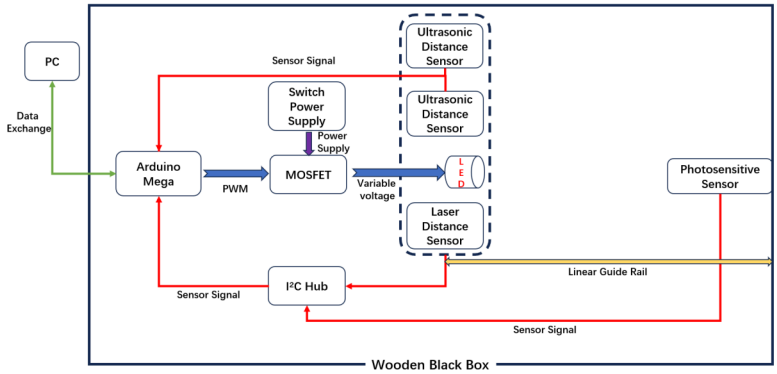


Figure 1: Test environment diagram (original)

To avoid the influence of environmental light on the test results, a black testing box, as shown in Figure 1, was made. The distance sensors are used to measure the distance between the light source and the target object, and the photosensitive sensor is used to test the actual light intensity at the position of the target object. Using Arduino, the difference between the actual illuminance value and the set value can be calculated, and then the input voltage value to the LED light source can be adjusted by changing the PWM value so that the light intensity of the LED light source can be adjusted.

Two ultrasonic sensors, HC-SR04, and one laser distance sensor, VL53L0X, are adopted in this test system to measure the distance between the LED and the target sensor. The data collected from three sensors is integrated to reduce the error so that an accurate distance value can be calculated. In this program, signal time-sharing is used to avoid the mutual interference between two ultrasonic sensors. The photosensitive sensor BH1750FVI is used to measure the light intensity of the target position. Using the I²C Hub, the signals from the laser distance sensor and the photosensitive sensor can be transferred to Arduino through the I²C interface. Using the MOSFET, the PWM signal outputted by Arduino can be transferred to a voltage signal to control the light intensity of the LED lamp. At the bottom of the test box, a linear guide rail was installed, and the distance between the LED lamp and the photosensitive sensor can be adjusted through the handle installed outside the box.

4. Test result

During the experiment, 4 sets of PWM output values were set to change the light intensity of the LED, and the photosensitive sensor measured the light intensity values at different distances. The test data is shown in Table 1.

In Table 1, 4 sets of test data at 4 PWM output values are recorded. d is for the distance between the light source and the target object, and I is for the light intensity detected by the photosensitive sensor. According to the formula (2), the value of P corresponding to I at different distances can be calculated. For every P at the same PWM value, $\bar{P}$ can be obtained by an average calculation.

$$P = 4\pi Id^2 \tag{2}$$

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Table 1: The relationship between light intensity and distance under different PWM values

	PWM=64		PWM=128		PWM=192		PWM=255	
d (cm)	I (lx)	P	I (lx)	P	I (lx)	P	I (lx)	P
10	317.00	39.84	610.00	76.66	877.00	110.21	1,037.00	130.31
15	147.00	41.56	280.00	79.17	374.00	105.75	455.00	128.65
20	77.00	38.70	152.00	76.40	215.00	108.07	254.00	127.67
25	47.50	37.31	92.00	72.26	130.00	102.10	160.00	125.66
30	33.00	37.32	66.00	74.64	95.00	107.44	115.50	130.63
35	24.00	36.95	47.50	73.12	68.00	104.68	85.00	130.85
40	19.50	39.21	39.00	78.41	55.50	111.59	67.00	134.71
$\overline{P}$		38.70		75.81		107.12		129.78

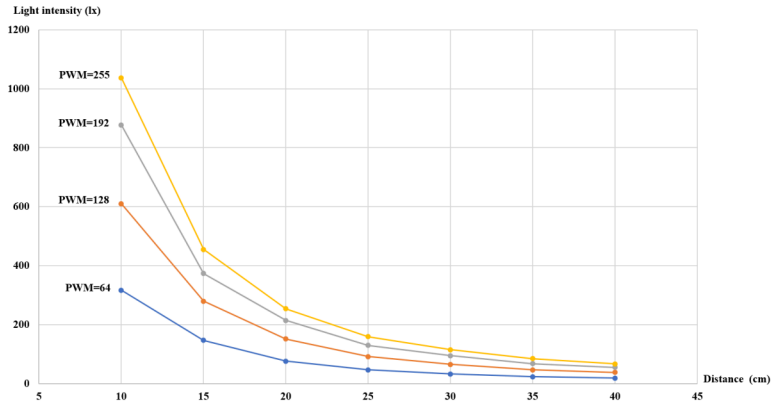


Figure 2: The relationship between light intensity and distance (original)

Figure 2 shows the corresponding relationship between the distance value d and the light intensity value I at every set of PWM values in Table 1. The abscissa shows the distance, and the ordinate shows the luminance of the target object. According to the curves in Figure 2, the light intensity of the target position I is inversely proportional to the square of the distance d at the same PWM output value. The test data detected by this system is approximately matched with the formula (1).

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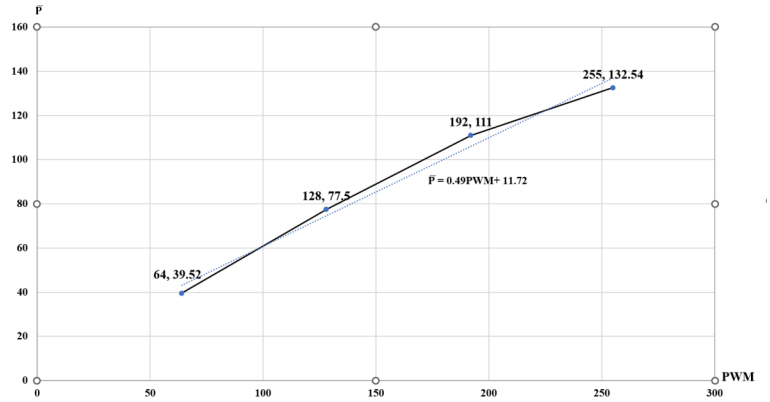


Figure 3: The relationship between PWM and $\bar{P}$ (original)

In Figure 3, the abscissa shows the output PWM value, and the ordinate shows the $\bar{P}$ value corresponding to every PWM value. Through the dotting in Figure 3, the corresponding relationship between $\bar{P}$ and PWM value can be approximately represented with a straight line. This corresponding relationship can be expressed as formula (3) below.

$$\bar{P} = 0.49PWM + 11.72 \tag{3}$$

According to formulas (2) and (3), formula (4) can be obtained, from which the initial PWM output value of Arduino can be calculated when the set light intensity I and the distance d are known.

$$PWM = \left(4\pi Id^2 - 11.45\right)/0.48 \tag{4}$$

When the LED lamp is lit up with the initial PWM value, the photosensitive sensor feeds back the detected data of light intensity to the Arduino. The difference in the light intensity ΔI that needs to be adjusted can be calculated through the PID algorithm. According to the formula (4), the ΔPWM output from Arduino can be figured out.

During the experiment, the luminance of the target object is set to 60 lx and 120 lx, respectively, in advance, then changing the distance, the output PWM value can be calculated by Arduino to keep the luminance of the target position stable. The system records a set of data every second, and every set of data includes 3 values: the distance between the light source and the target object, the PWM value output from Arduino and the light intensity tested by the sensors.

In Figures 4 and 5, the abscissa represents the time, the left ordinate represents the PWM value and the light intensity, and the right ordinate represents the distance between the light source and the target object. When the distance becomes larger, the output PWM value also becomes bigger to retain the luminance of the target object. When the distance just changes, the system calculates the PWM value according to formula (4) to control the light intensity of the source. At this moment, the luminance of the target object deviates from the set value, so the system adjusts the output PWM by the PID algorithm in a short time to keep the luminance of the target object near the set value. In the PID algorithm, Kp = 0.5, Ki = 0.05, and Kd = 0.1.

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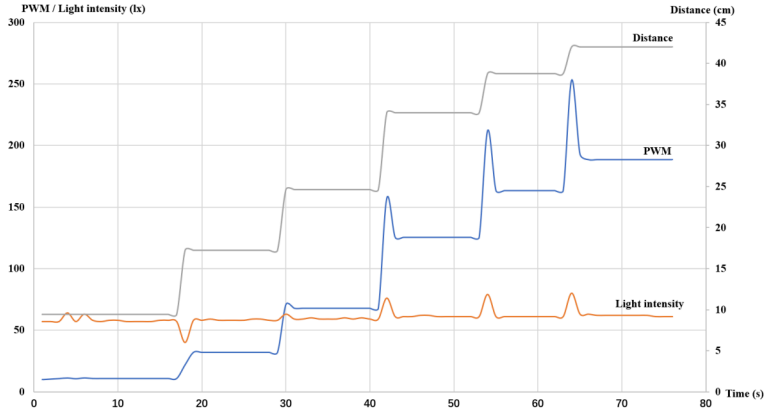


Figure 4: When light intensity = 60 lx, the PWM value varies with distance (original)

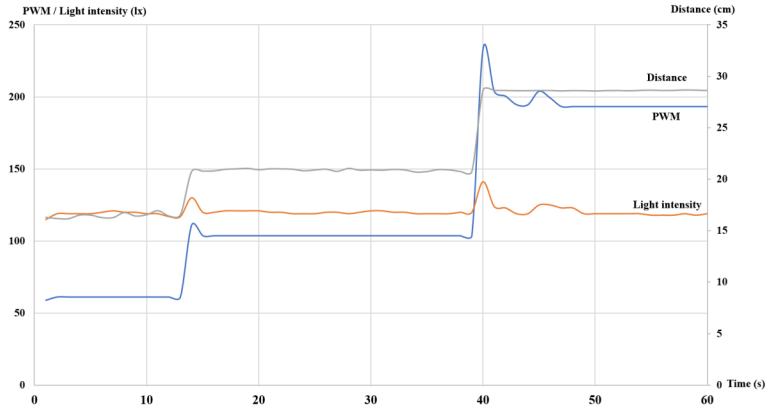


Figure 5: When light intensity = 120 lx, the PWM value varies with distance (original)

5. Discussion

According to Figures 4 and 5, when the distance changes, the system can adjust the PWM value automatically and stabilize the output value of PWM in a short time so that the light intensity of the target position can be maintained near the set value. When the distance is short, the difference between the PWM value calculated through formula (4) and the one that is outputted steadily after being adjusted by PID is small. But when the distance is long, the difference becomes bigger. In the process of further research, the parameters in formula (4) will be further adjusted based on the range of the distance. In this test, the photosensitive sensor is placed in the position of the target object. In the future, camera equipment is considered to be positioned at the light source so that the image of the target object can be processed in real-time to get the light intensity, and the output power of the light source can be adjusted at the same time [10].

6. Conclusion

This paper built a testing system by using Arduino Mega as a processor, as well as a photosensitive sensor and three distance sensors. The distance sensors are used to test the distance between the light source and the target object, and the photosensitive sensor is used to collect the luminance of the target object. The relation model between the output signal PWM and the light intensity in a non-ideal system is built by combining theoretical formulas and experimental data. This model conforms

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to the corresponding relationship that the light intensity is inversely proportional to the square of the distance. Using this model, after measuring the distance, the PWM value that is output to the light source can be calculated to control the light intensity of the LED according to the set value of the target light intensity so that the target object can achieve the set light intensity in a short time. Using the relation model between the output signal PWM and the light intensity, the value of light intensity calculated through PID can be transferred to the adjusted value of PWM so that the system can respond quickly according to the change of the luminance of the target object, which can save the dimming time to achieve a closed-loop control to the luminance of the target object. Using this testing system, when the distance changes, the testing system can adjust the output value of PWM automatically to change the light intensity of the light source so that the luminance of the target object can be maintained at the set value. If using image recognition to determine the luminance of the target object, this research can realize the continuous tracking of dynamically moving objects under constant illumination, which can be used in unmanned drone technology in the future.

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