Journal of Electrical Engineering and Computer (JEECOM)
Vol. xx, No. xx (20xx), DOI: 10.33650/jeecom.v4i2
p-ISSN: 2715-0410; e-ISSN: 2715-6427

Lighting System Control for Cataract Maturity Imaging Device

Katon Bagus Setiawan [1], I Komang Somawirata [1], Irmalia Suryani Faradisa [1]
[1] Electrical Engineering, National Institute of Technology Malang, Malang, Indonesia

Article Info

Article history:

Received February 28, 2025
Revised March 2, 2025
Accepted April 11, 2025

Keywords:

Cataract Eye
LED Lighting
PWM
OpenCV
Image Processing

ABSTRACT

As technology advances, various innovations have been made to assist in diagnosing and treating cataracts. In cataract detection, artificial intelligence-based methods such as Convolutional Neural Networks (CNN) have proven very effective in detecting cataracts. CNN can classify eyes with an accuracy of up to 87%. In addition to image processing techniques such as CNN, the quality of the resulting images highly depends on the lighting system used during the eye image capture. This research expects the lighting system to be designed to adjust light intensity flexibly. This feature allows for adjusting brightness as needed, ensuring high-quality image results without compromising eye health. From this research, the image quality test results show good quality in the duty cycle range of 23.53% to 62.75% with light intensity of 30-84 lux. This indicates that the light intensity at the medium level produces images with good indicators. However, the light intensity conditions at the medium level begin to vary in terms of visual comfort and are still tolerable by most users. In the final test, an experiment involving respondents and image analysis using image processing was conducted. From the experiment, the respondents felt comfortable with the light intensity emitted by the LED. In the image processing section, the average number of images taken to obtain a good indicator was 3 times. A structured lighting system can ensure that good image results are obtained and patients feel comfortable with the light intensity used.

Corresponding Author:
I Komang Somawirata,
National Institute of Technology Malang, Jalan Raya Karanglo km 2 Malang, Malang and 65145, Indonesia
Email: kmgsomawirata@lecturer.itn.ac.id

1. INTRODUCTION

The eye is an organ that plays an important role in human life. It helps people understand their surroundings, communicate, and perform various daily activities[1]. Unfortunately, the eyes are vulnerable to various health issues affecting vision. If these disorders are not addressed promptly, they can have fatal consequences and affect a person's quality of life.

One of the most common eye diseases is cataracts. Cataracts are a disease characterized by cloudiness in the eye's crystalline lens. This condition is caused by calcification or hardening of the eye lens, preventing light from reaching the retina[2]. As a result, cataract patients will experience blurred, cloudy, or even total vision loss if they do not receive immediate treatment[3]. This disease does not only occur in the elderly but also in young people due to certain risk factors such as trauma, diabetes, and radiation exposure. Cataracts have become a serious problem in Indonesia, and according to the results of a blindness survey conducted in 15 provinces from 2014 to 2016, around 70-80% of blindness cases were caused by cataracts[4]. These figures indicate that cataracts are this country's leading cause of visual impairment.

As technology advances, various innovations have been made to assist in diagnosing and treating cataracts. The main innovation is digital image processing, which helps detect eye diseases like cataracts. This technology allows for obtaining information about eye diseases more quickly, accurately, and efficiently than traditional methods. In the context of cataract detection, artificial intelligence-based methods such as Convolutional Neural Networks (CNN) have become one of the most popular approaches.

CNN is an artificial neural network that analyses visual data such as images and videos. This technology is inspired by the human visual system's remarkable ability to recognize patterns, shapes, and objects[5]. The CNN application processes image data in various layers to extract essential features from the image. These features are used for image classification, such as detecting the presence of cataracts in eye images. The advantage of CNN compared to other methods is its ability to function automatically without much human intervention. CNN can learn from the provided training data. The more data is processed, the more accurate the classification results will be[6].

The use of CNN has proven to be very effective in detecting cataracts. Based on previous research, CNN can classify eyes with an accuracy of up to 87% [7]. According to [8], a cataract maturity identification tool based on Raspberry Pi with an Adam optimizer has been developed for the CNN model training process. The image capture utilizes a VR (Virtual Reality) box containing electronic components such as an ESP32-CAM, a power bank for power supply, a step-up, and an LED. The image processing section contains a place for the Raspberry Pi, LCD, and a 5V DC fan. The research results, starting from the design of the hardware system that has been implemented, have achieved a cataract eye classification process with an accuracy of 99% using the CNN model and the Adam optimizer with 40 epochs and a 0.0005 learning rate.

Research has developed a Convolutional Neural Network (CNN) model to detect cataracts in eye images. According to [9], 600 eye images have been used, with 300 normal eye images and 300 cataract eye images. The designed CNN model uses convolutional and pooling architecture with hyperparameter optimization, which allows for improved model performance. The results obtained from the model with the Adam optimizer, a learning rate of 0.001, a batch size of 32, and 50 epochs achieved an accuracy of up to 97% during testing. The image processing method using the 5-fold Cross-Validation technique applied during the training process helps increase data variation and ensures the model evaluation is conducted objectively. The results show a precision value of 95%, a recall of 100%, and an F1-score of 97%, reflecting the model's ability to detect cataracts with high accuracy and minimal error. This figure shows that CNN is a reliable tool to assist doctors and medical staff in diagnosing cataracts. The high accuracy of CNN speeds up the identification process and minimizes the risk of diagnostic errors commonly occurring with manual methods.

In addition to image processing techniques such as CNN, the quality of the resulting images greatly depends on the lighting system used during the eye image capture. Lighting is important in ensuring that the eye images captured contain sufficient detail for analysis. Insufficient or excessive light intensity can affect the image results and even harm the eyes. An optimal lighting system is one of the supporting factors for successfully detecting eye diseases.

A lighting system requires consideration of several important aspects, such as the type of lamp, the placement of the lamp, and the intensity of the lamp used. The position of the lighting must also be adjusted so that the light is evenly distributed on the area of the eyes that will be recorded[10]. It is necessary to adjust the light intensity to be neither too bright nor too dark. The intensity of light that is too high can cause damage to the eyes, and the intensity of light that is too low can result in blurry images [11].

This research expects the lighting system to be designed to adjust light intensity flexibly. This feature allows brightness to be adjusted as needed, ensuring high-quality image results without compromising eye health. An optimal lighting system also supports the CNN image processing, as good image quality greatly affects the accuracy of the analysis results. Research on detecting cataracts using CNN and an optimal lighting system will provide significant benefits, especially for the medical field. This technology allows cataract diagnosis to be performed more quickly and efficiently so patients receive treatment faster. In addition, because highly accurate analysis results can be provided automatically, this reduces the burden on medical professionals.

The goal of this research is to create a cataract identification tool that is not only reliable in terms of accuracy but also safe to use. A well-designed lighting system ensures that eye imaging does not pose any additional risk to the patient's eye health. On the other hand, by using CNN as an image processing method, the identification results become very accurate and effectively support medical professionals in diagnosis.

However, the success of this technology also heavily depends on the quality of the images produced. An optimal lighting system becomes a key element to support the identification process [12]. A carefully designed lighting system must not only enhance image quality but also protect the patient's eye health. This research is expected to be a first step in developing a safe, reliable, and efficient cataract diagnostic tool, thereby helping to reduce the number of blind individuals in Indonesia.

2. METHOD

This chapter on research methodology will outline the system's workflow, starting with an explanation of the block diagram and continuing with the system flow as a flowchart. This chapter also explains the stages of hardware and software design.

2.1 Design Block Diagram

The system designed in this research aims to create hardware integration that supports automatic control and monitoring functions. The block diagram below explains the system workflow, starting from power, light intensity control, and data processing, and provides an overview of the relationships between the components.

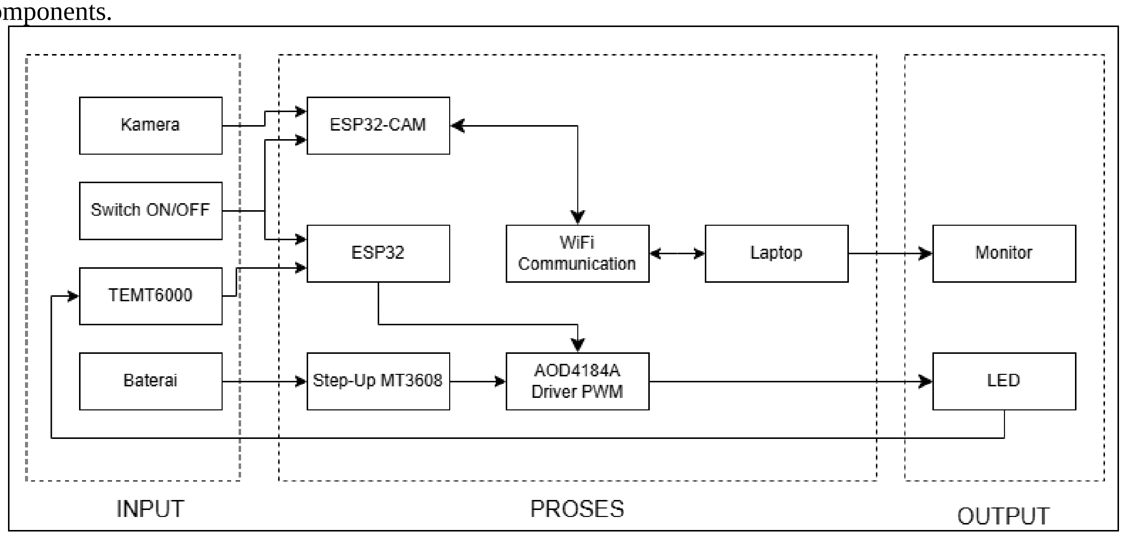


Figure 1. Design Block Diagram

The block diagram shown in Figure 1 consists of several main components with their respective functions. In the first stage, an ON/OFF switch allows users to manually activate or deactivate the system. Then, the camera will be responsible for capturing images in real-time. This camera serves the primary function of capturing visual information. A TEMT6000 sensor is used to measure the intensity level of the LED light. The second stage is data processing on the ESP32 received from the TEMT6000 sensor. The ESP32 in the system is used for PWM control and reading lux value data from the TEMT6000 sensor. To control the LED light intensity through the PWM (Pulse Width Modulation) mechanism, an AOD4184A mosfet driver is needed, which serves as a bridge for PWM control between the ESP32 and the LED. Lighting control will use PWM settings. PWM (Pulse Width Modulation) is a method of widening a signal with pulses over time. PWM aims to obtain varying output voltage values on the microcontroller by adjusting the high pulse width (duty cycle) [13]. Changes in PWM are influenced by the resolution of the PWM itself. For example, an 8-bit digital PWM with a resolution of 8 = 256 means the PWM output value has 256 variations ranging from 0 – 255 or a duty cycle value of 0 - 100% of the PWM output. The wave frequency in the PWM signal is constant, but the duty cycle varies [14]. The LED power supply will use a battery with a stepped-up voltage to meet the LED voltage requirements. After the step-up voltage

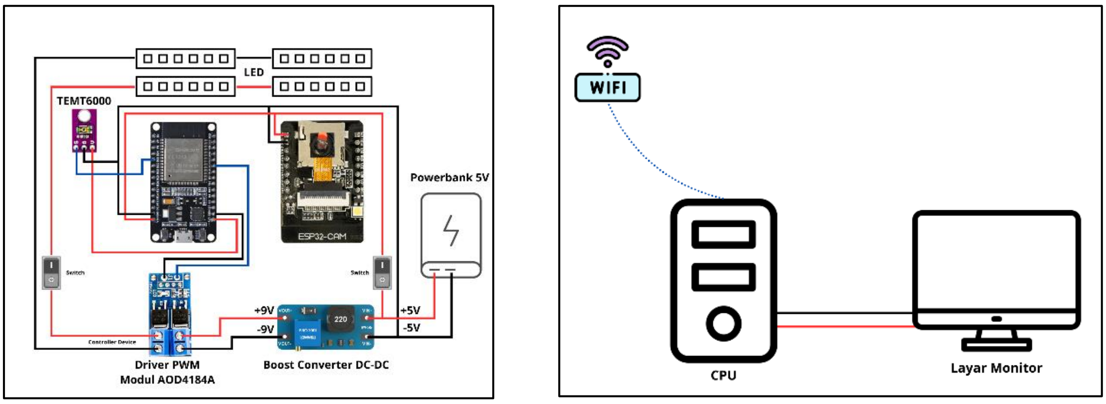
will pass through the AOD4184A mosfet driver for PWM control.

The ESP32-Cam then processes the image data into a digital format that can be transmitted over a WiFi network. The data is forwarded until it reaches the laptop for image processing. The laptop will function as data processing, image analysis, and lighting correction. After the data processing from the laptop is complete, the processed data will be displayed on the monitor screen to show the image processing results. The monitor screen functions as an output device to display information regarding image quality, such as whether the image meets the criteria or needs to be corrected.

2.2 Hardware System Design

The system design includes three main components: input, process, and output. Input functions as the signal sender, the process acts as the data processor according to the programmed instructions, and the output generates the processed data.

The overall system circuit refers to the block diagram above, which consists of various main components that are interconnected to support eye image capture with optimal lighting for the image capture circuit in Figure 2.



(a) (b)

Figure 2. (a)Schematic of Image Capture and (b) Image Processing

2.3 Software Design

The design of this software will involve developing programs that run on microcontrollers and supporting software such as computers. The software controls components, data processing, and module communication.

2.3.1 Flowchart System

The following flowchart will show the process flow of the designed software data processing.

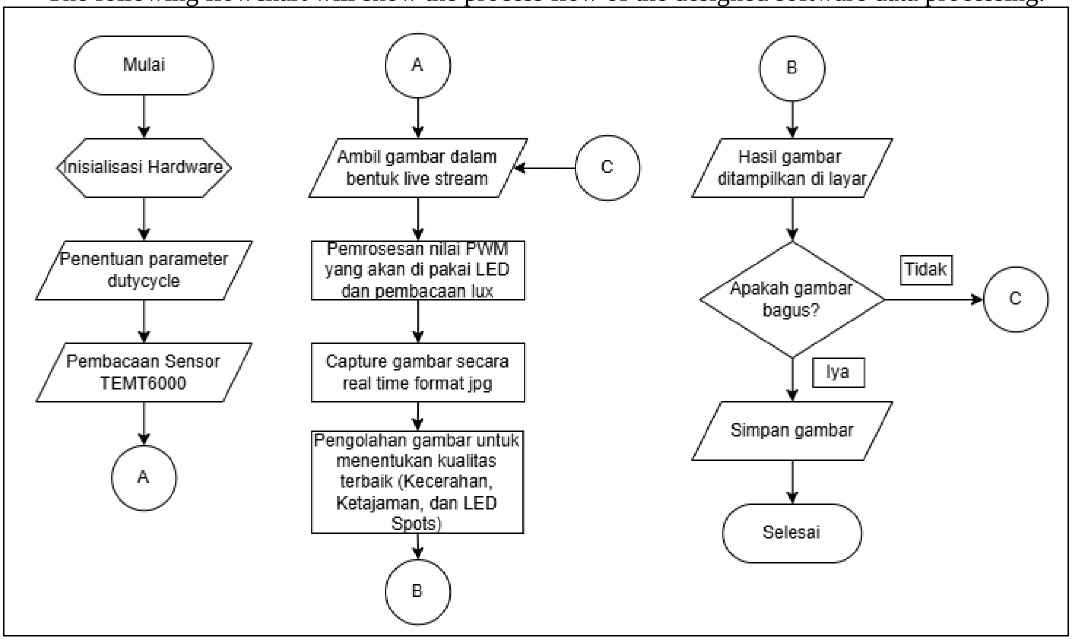


Figure 3. Data Processing System Flowchart

Figure 3 shows a flowchart of the software data processing system that optimizes lighting using the PWM mechanism. The process begins with the hardware initialization stage, such as the camera, microcontroller, and monitor screen, to ensure all components are ready for use. Determining the duty cycle parameter in the ESP32 aims to achieve the appropriate light to support optimal image capture. Duty cycle determines the percentage of time the LED is on in one cycle and will affect the intensity of the light produced. The TEMT6000 sensor starts working by reading the light level (lux), ensuring the lighting data is collected.

Then, the system will capture images using a camera in the form of a live stream. The images taken in real-time serve as input for image quality evaluation. Next, the processing of the PWM value will be used on the LED, and the lux results will be read. The system then captures images in real-time in JPG format, efficiently storing data and making image processing easier. The images that have been captured will go through the image processing stage. At this stage, the image will be analyzed to determine the best quality by considering several factors, such as sharpness, optimal lighting, and noise level.

After the image processing is complete, the resulting image will be displayed on the screen for the user's evaluation. If the image does not meet the quality criteria, the process will return to the image capture step. However, if the image is deemed good, it will be stored as the final result. This process will continue iteratively until an image that meets the desired criteria is obtained.

2.3.2 Brightness Level Process Flowchart

The flowchart for this brightness level process illustrates the evaluation of brightness levels in an image by analyzing pixel intensity values. The process begins with reading the image and converting the image to grayscale. The conversion from RGB image to grey aims to change an RGB formatted image into grayscale using a combination of the three primary colour channels: red (R), green (G), and blue (B). The grayscale value is calculated as the average of the three colours, taking into account the human eye's sensitivity to each colour. The human eye is more sensitive to the colour green compared to red and blue, so green is given greater weight. The basic formula commonly used for converting RGB to grayscale is:

$$Gray = (0.2989\ x\ R) + (0.5870\ x\ G) + (0.1140\ x\ B) \quad (1)$$

In the RGB to grayscale conversion formula, the following explanation can be provided:

- R, G, and B are the intensities of red, green, and blue colors in each pixel within the range of 0 to 255.
- The coefficients 0.2989, 0.5870, and 0.1140 come from luminance standards that reflect human perception of light intensity.

The result of the grayscale image processing where each pixel has the same intensity for the three colours (R, G, B). The values in grayscale represent the brightness level on a grey scale, with black (0) and white (255) [15]. Then, calculate the average brightness value. The calculation results will be evaluated based on a brightness range between 100 and 200. If the brightness value is less than 100, it is not categorized as good. If the brightness value is between 100 and 200, the image can be categorized as good.

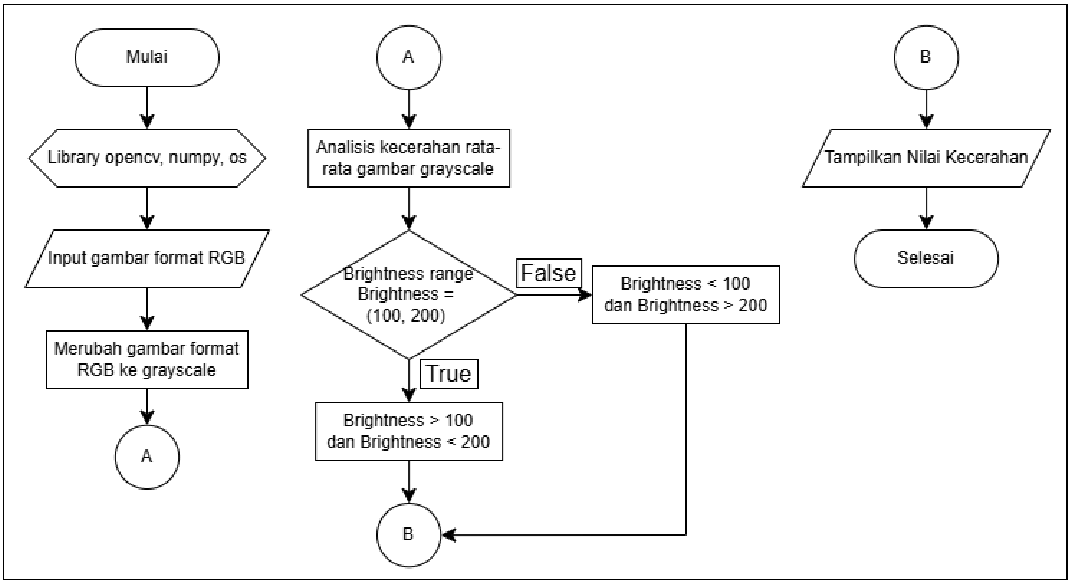


Figure 4. Flowchart of Brightness Level Process

3. RESULTS AND DISCUSSION

3.1 Implementation of Testing

In this section, testing will be conducted on the device created based on the schematic mechanism and block diagram. Data will be collected from the main parameter values.

3.2 Testing PWM and Lux Values

This research tests the changes in LED lighting based on the predetermined PWM values, which will then be read using a lux meter. This test starts from dim lighting (duty cycle 0%) to bright lighting (duty cycle 100%).

Table 1. Results of PWM and Lux Value Testing

No.	**PWM Serial Monitor (*Dutycycle*)**	**PWM Osiloskop (*Dutycycle*)**	**Lux Meter (Lux)**
1.	0.0%	0%	0
2.	3.92%	20.99%	1
3.	7.84%	26.45%	2
4.	11.76%	23.74%	14
5.	15.69%	27.66%	19
6.	19.61%	29.37%	24
7.	23.53%	34.77%	30
8.	27.45%	30.34%	35
9.	31.37%	36.65%	40
10.	35.29%	43.58%	45
11.	39.22%	43.90%	51
12.	43.14%	44.36%	57
13.	47.06%	47.23%	62
14.	50.98%	50.96%	68
15.	54.90%	55.83%	72
16.	58.82%	58.57%	77
17.	62.75%	62.94%	83
18.	66.67%	67.20%	89
19.	70.59%	68.40%	94
20.	74.51%	70.61%	99
21.	78.43%	75.20%	104
22.	82.35%	80.56%	110
23.	86.27%	82.51%	115
24.	90.20%	86.20%	121
25.	94.12%	90.00%	127
26.	98.04%	93.90%	132

In Table 1, the data tested are the PWM values from the serial monitor compared to the PWM measurements on the oscilloscope and light intensity measurements using a lux meter. The data shows that the increase in light intensity (lux) is directly proportional to the change in PWM value in Figure 5. However, there are some differences between the PWM values displayed on the serial monitor and the oscilloscope measurements.

When the duty cycle value on the PWM increases, the light intensity also increases. At the initial value (0%), the light intensity is 0 lux, indicating that the LED does not produce light. At the maximum value (98.04%), the light intensity reaches 132 lux.

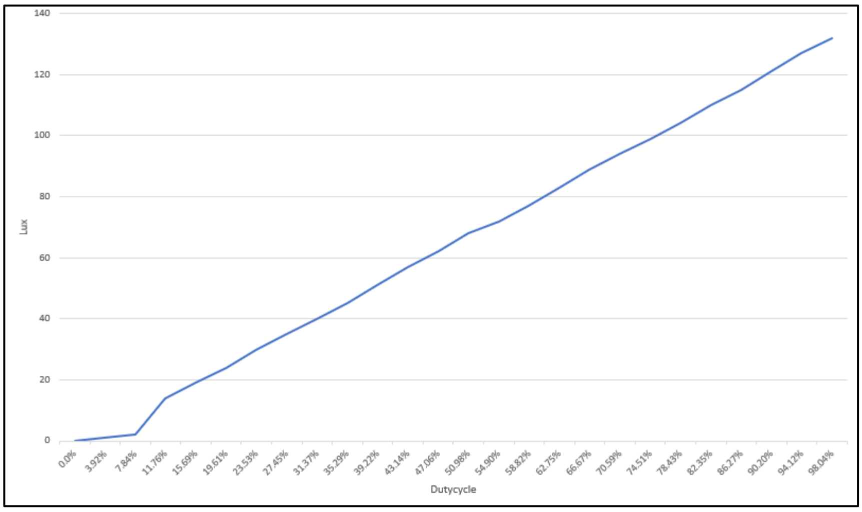


Figure 5. Graph of PWM and Lux Value Comparison

3.3 Comfort Testing Against Lighting

This test aims to ensure that the designed lighting system provides the appropriate light intensity while also being comfortable for the eyes. In this test, respondents will be involved in providing feedback based on their experience with the lighting. The LED lighting is activated gradually, starting from 0% to 100% duty cycle. Here are the results of the first respondent's comfort test regarding the lighting emitted by the LED.

Table 2. Respondent Feedback

No.	PWM Serial Monitor (Dutycycle)	Visual Comfort (Glare)	Tingkat Gangguan (Lelah)	Intensity Comfort
1	0.0%	No	No	Yes
2	3.92%	No	No	Yes
3	7.84%	No	No	Yes
4	11.76%	Yes	Yes	No
5	15.69%	No	No	Yes
6	19.61%	Yes	Yes	No
7	23.53%	Yes	No	Yes
8	27.45%	Yes	Yes	No
9	31.37%	No	No	Yes
10	35.29%	No	No	Yes
11	39.22%	No	No	Yes
12	43.14%	Yes	Yes	No
13	47.06%	Yes	Yes	No
14	50.98%	Yes	Yes	No
15	54.90%	No	No	Yes
16	58.82%	No	No	Yes
17	62.75%	No	No	Yes
18	66.67%	No	No	Yes
19	70.59%	Yes	Yes	No
20	74.51%	Yes	Yes	No
21	78.43%	Yes	Yes	No
22	82.35%	Yes	Yes	No
23	86.27%	Yes	Yes	No

24	90.20%	Yes	Yes	No
25	94.12%	Yes	Yes	No
26	98.04%	Yes	Yes	No

The testing was conducted 5 times with different respondents. Based on the results, the tests involving variations in the PWM duty cycle and their effects on visual comfort (glare), disturbance levels (fatigue), and light intensity preferences show a consistent relationship pattern. In the low-duty cycle range, 0% to 19.61%, most respondents stated that the lighting conditions did not cause glare or eye fatigue. Almost all respondents felt comfortable with the level of light intensity produced. This indicates that visual comfort is within the limits acceptable to the human eye at low light intensity without causing disturbances.

Respondents' opinions vary as the duty cycle increases, ranging from 23.53% to 62.75%. At specific values, such as 27.45% and 43.14%, some respondents reported experiencing glare and eye fatigue. However, some respondents still feel comfortable. This indicates that medium-level light intensity affects visual comfort, although this perception depends on individual sensitivity. The condition of medium light intensity can still be tolerated by most users.

At high duty cycles, namely 66.7% to 98.04%, respondents' opinions showed a significant increase in complaints of glare and eye fatigue. Most respondents reported visual discomfort as the duty cycle increased. This indicates that the higher the duty cycle, the brighter the produced light becomes, causing disturbances such as glare and accelerating eye fatigue. So, the light intensity at a high-duty cycle tends to be undesirable and has a negative effect on user comfort.

3.4 Testing Images with Good Quality

Testing high-quality images aims to evaluate several images obtained after the image capture process. Measurements are conducted to determine the image quality produced at each lighting level. The testing was conducted using a medium duty cycle value, namely 23.53% to 62.75% with a light intensity value of 30 lux to 83 lux.

Table 3. Test Image Results

No.	Gambar	PWM (Dutycycle)	Intensitas Cahaya (Lux)
1.		23.53%	30
2.		27.45%	35
3.		31.37%	40
4.		35.29%	45
5.		39.22%	51
6.		43.14%	57

7.		47.06%	62
8.		50.98%	68
9.		54.90%	72
10.		58.82%	77
11.		62.75%	83

Several images from Table 3 will be reprocessed by evaluating the quality of the best images. The image results for evaluation are in Table 3, which have been processed using image processing based on the average brightness value or quality score of Figure 6.

Figure 6. Good Image Result

The evaluation of the best image will be processed using image processing by taking the average brightness value. So that the image can be analyzed, the colored image will be converted to grayscale format. The calculation to obtain the grayscale value is performed for each pixel depending on the resolution used. The OpenCV image processing software assists the calculation here. Here is the manual calculation for converting RGB to grayscale format in Figure 7 pixel (1, 0).

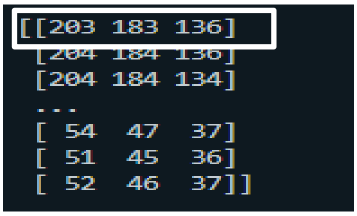


Figure 7. RGB Values for Image Analysis

Diket:

R = 203

G = 183

B = 136

Calculation:

$$Grayscale = (0.2989\ x\ R) + (0.5870\ x\ G) + (0.1140\ x\ B)$$

$$Grayscale = (0.2989\ x\ 203) + (0.5870\ x\ 183) + (0.1140\ x\ 136)$$

$$Grayscale = 183.6017$$

The result obtained from the pixel calculation (1, 0) is 183.6017. This can be proven with the results of the grayscale image processing in row 1, column 0 of Figure 8.

	0	1	2	3	4	5	6	7	...	242	243	244	245	246	247	248	249
0	182.4878	183.6726	184.4445	184.4445	183.6726	180.4988	180.6128	179.8301	...	45.0234	46.1373	45.5395	48.5993	50.3711	46.2575	43.8448	44.8447
1	183.6017	184.4876	184.2596	184.9714	183.0856	180.6128	180.7268	178.0691	...	44.2407	45.0557	44.6428	47.8875	49.3604	47.9476	45.7629	46.7628
2	183.6017	184.6016	183.4877	182.7867	181.6127	179.7269	179.8409	178.7809	...	44.3439	46.0448	45.5179	45.9909	47.1649	47.4530	46.4531	47.1541
3	184.7048	185.3026	184.6016	182.6018	182.3137	179.9549	180.3678	180.1937	...	47.5285	48.9305	47.2897	45.8769	45.7521	45.6381	45.2252	45.7521
4	185.0037	186.3025	184.6016	182.6018	183.3136	181.2537	181.6666	180.1937	...	48.0123	50.3002	49.1863	47.6595	46.2467	46.6165	44.7307	46.1435
..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
182	165.9328	165.0469	166.0468	167.7477	166.5737	166.1007	166.2147	165.2148	...	103.0604	102.0605	102.0605	99.6586	98.6587	99.6586	99.6586	99.6586
183	166.2317	164.9329	166.2317	167.4596	166.5737	166.5028	165.3288	164.5138	...	101.4627	102.0605	101.0606	99.3597	97.9469	99.3597	99.6586	99.9575
184	163.1288	162.1289	162.2429	163.6557	162.4709	162.9870	163.1010	162.8021	...	102.4087	102.5936	102.3055	101.9034	102.5012	102.9141	101.9142	100.9143
185	157.8412	157.8412	158.5530	161.6667	160.4819	161.5850	161.6882	161.5033	...	102.2947	102.4796	103.0774	103.9741	103.9849	103.5828	101.1701	98.2844
186	154.8415	154.8415	157.1402	160.6668	160.4819	161.5850	161.6882	161.5033	...	102.2947	102.4796	103.0774	103.9741	103.6860	101.2841	98.2844	96.2846

[187 rows x 250 columns]

Figure 8. Grayscale Image Processing Results

After obtaining the grayscale values, the next step is to find the average brightness value to obtain the quality score. The calculation of the average brightness value is as follows.

```
total_intensity: 5875858.975799999
total_pixels: 46750
mean_brightness: 125.68682301176469
Processed image.jpg - Quality Score: 125.68682301176469
```

Figure 9. Calculation of Average Image Brightness Value

$$Mean\ Brightness = \frac{Total\ intensity}{Total\ pixels}$$

$$Mean\ Brightness = \frac{5875858.97579}{46750}$$

$$Mean\ Brightness = 125.686823$$

The image's average brightness value is 125.686823. This average brightness value will be used as the quality score and evaluated with other images based on it. The highest quality score will be taken and stored for the next process, as shown in Figure 9.

3.5 Testing Image Results and User Response to Lighting Comfort

In this section, user responses to lighting comfort and image quality are conducted to determine the impact of lighting on the resulting image quality and the users' visual comfort. This test involves respondents providing feedback based on the comfort of the obtained lighting. If the processed image results do not yet provide good indicators and the respondents still feel uncomfortable with the obtained LED lighting, the image capture will be repeated.

The parameters used to obtain a good indicator are based on brightness, sharpness, and LED spots. Brightness will be processed using OpenCV by converting the RGB image to grayscale. Then, from the grayscale format, it will be analyzed to find the average brightness value. The sharpness value is obtained by converting the RGB image to grayscale so that it can be analyzed using the Laplacian variation. If searching for an LED point, the method is almost the same, which is converting the RGB color to grayscale. Then, a threshold value of 200 to 255 is determined. If the value is below 200, it will not be considered a light spot, whereas if the value is above 200, it will be considered an LED spot. A good indicator can be obtained if the brightness value is in the range of 100 to 200, sharpness 50 to 150, and LED spots 1 to 3 points.

Here are the image results with good indicators based on image processing in the software.

```
Analysis Results:
Gambar: D:\Document\program\Program Skripsi\Hasil gambar\cob\Photo 1.jpg
  Kecerahan: 113.40526849037488
  Ketajaman: 76.49720528185789
  LED Spots: 5
  Kualitas: Belum Bagus

Gambar: D:\Document\program\Program Skripsi\Hasil gambar\cob\Photo 2.jpg
  Kecerahan: 115.10097939885173
  Ketajaman: 99.64866884122661
  LED Spots: 1
  Kualitas: Bagus
```

Figure 10. Analysis of Good Image Results for Respondents

In Figure 10, it can be analyzed that the image with good quality is shown in file photo 2 with a recorded brightness value of 115.10, sharpness of 99.64, and 1 LED spot. This is because there are range values for these three parameters to produce a good-quality image.

The results obtained from the image analysis and the fifth respondent's statement are in Table 4.

Table 4. Comfort and Respondent Image Results

No.	Image	Image Quality	Comfort
1.		Blure	Comfort
2.		Blure	Comfort

In Table 4, it is sufficient to take 2 pictures according to image processing. The first image capture was not good, but the respondents felt comfortable. The second shoot was good, and the respondent felt comfortable.

4. CONCLUSION

This research develops an optimal lighting arrangement with a PWM mechanism as the control for LED light intensity. In the discussion results conducted, the testing of light intensity on the LED showed that the increase in PWM value is directly proportional to the light intensity (lux). At low-duty cycles such as 0% to 19.61% (0-24 lux), the lighting is still considered comfortable without causing glare and eye strain. At a medium duty cycle such as 23.53% to 62.75% (30-83 lux), some respondents began to experience glare and fatigue, but the intensity of the light was still tolerable. At high-duty cycles, such as 66.67% to 98.04% (83-132 lux), most respondents reported visual discomfort due to excessively bright light. Image testing shows good quality in the duty cycle range of 23.53% to 62.75% with a light intensity of 30-84 lux. User response to the lighting and image results provided feedback that medium-level lighting can produce better images and be more comfortable for users' eye health. Indicators of good image quality can be obtained by using image processing and focusing on brightness, sharpness, and LED spots. From several respondents, in the comfort test, several captures were obtained with an average of 2 to 3 image captures. Overall, the LED lighting control system using the ESP32 device can provide good performance with eye comfort. The images obtained using image processing also function according to the system that was created.

ACKNOWLEDGEMENTS

On behalf of the authors, we would like to thank our supervisors, Dr. Eng. I Komang Somawirata, ST., MT., and Dr. Irmalia Suryani Faradisa, ST., MT., for their guidance during this research, providing advice, opinions, and motivating us throughout this study process.

REFERENCES

[1] Muhammad Nur Ihsan Muhlashin and A. Stefanie, "Klasifikasi Penyakit Mata Berdasarkan Citra Fundus Menggunakan YOLO V8," *jati*, vol. 7, no. 2, pp. 1363–1368, Sep. 2023, doi: 10.36040/jati.v7i2.6927.
[2] Made Selly Dwilestari Putri, Moch. Iwan Kurniawan, Hikmah Hiromi Razak Datu, Sri Irmandha Kusumawardhani, and Azizah Anoez, "Gambaran Visus Pasien Katarak Post Operatif di RS. Bhayangkara Tahun September 2019 – Januari 2022," *fmj*, vol. 4, no. 1, pp. 29–37, Mar. 2024, doi: 10.33096/fmj.v4i1.319.

[3] F. Ramadhani, A. Satria, and S. Salamah, “Implementasi Algoritma Convolutional Neural Network dalam Mengidentifikasi Dini Penyakit pada Mata Katarak,” *sudo j. Teknik inform.*, vol. 2, no. 4, pp. 167–175, Dec. 2023, doi: 10.56211/sudo.v2i4.408.

[4] G. J. Bu’ulölö, A. Jacobus, and F. D. Kambey, “Identification of Cataract Eye Disease Image Using Convolutional Neural Network”.

[5] D. Marcella, Y. Yohannes, and S. Devella, “Klasifikasi Penyakit Mata Menggunakan Convolutional Neural Network Dengan Arsitektur VGG-19,” *algoritme*, vol. 3, no. 1, pp. 60–70, Oct. 2022, doi: 10.35957/algoritme.v3i1.3331.

[6] Mochammad Toyib, Tegar Decky Kurniawan Pratama, and Ibnu Aqil, “Penerapan Algoritma CNN Untuk Mendeteksi Tulisan Tangan Angka Romawi dengan Augmentasi Data,” *Algoritma*, vol. 2, no. 3, pp. 108–120, May 2024, doi: 10.62383/algoritma.v2i3.69.

[7] S. A. Maulana, S. H. Batubara, T. A. Amelia, and P. P. Pasaribu, “Penerapan Metode CNN (Convolutional Neural Network) Dalam Mengklasifikasi Jenis Ubur-Ubur”.

[8] D. R. M. Syahputra and I. S. Faradisa, “Pengembangan Alat Identifikasi Maturitas Katarak Berbasis Raspberry Pi Dengan Adam Optimizer Untuk Proses Pelatihan Model CNN”.

[9] Y. J. Krisnawan and W. Setiawan, “Implementasi Convolutional Neural Network (CNN) untuk Deteksi Katarak pada Citra Mata,” *JEMSI*, vol. 6, no. 1, pp. 443–450, Oct. 2024, doi: 10.38035/jemsi.v6i1.3066.

[10] J. Patra, “ANALISIS PENCAHAYAAN ALAMI DAN BUATAN PADA RUANG KANTOR TERHADAP KENYAMANAN VISUAL PENGGUNA”.

[11] D. Rahmayanti and A. Artha, “Analisis Bahaya Fisik: Hubungan Tingkat Pencahayaan dan Keluhan Mata Pekerja pada Area Perkantoran Health, Safety, and Environmental (HSE) PT. Pertamina RU VI Balongan,” *j.optim.sist.ind.*, vol. 14, no. 1, p. 71, Apr. 2016, doi: 10.25077/josi.v14.n1.p71-98.2015.

[12] M. S. Purba, “Perancangan Sistem Identifikasi Biometrik Iris Mata Menggunakan Metode Transformasi Hough,” vol. 7, no. 2, 2020.

[13] P. Astuti and H. Masdi, “Sistem Kendali Kecepatan Motor BLDC Menggunakan PWM Berbasis Mikrokontroler Arduino Uno,” *JTEIN*, vol. 3, no. 1, pp. 120–135, Jan. 2022, doi: 10.24036/jtein.v3i1.216.

[14] D. Dewatama, M. Fauziyah, and N. K. Jannah, “Sistem Pengaturan Pencahayaan pada Budidaya Jamur Tiram Berbasis Arduino Uno Dengan Metode Fuzzy Logic,” *protk*, vol. 9, no. 2, p. 99, Sep. 2022, doi: 10.33387/protk.v9i2.4319.

[15] S. G. Gunawan, “Pewarnaan Citra Grayscale dengan Histogram Specification”.