The Impact of Light Intensity on Color Perception

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***Abstract*—Proper lighting is a crucial factor for the performance of robot systems, especially in competitions such as the Botball. Color recognition plays a central role here, as it is often used to sort objects or examine tasks. Different lighting conditions, measured in Candela and Kelvin, can strongly influence the accuracy of cameras and sensors. The purpose of these studies is to determine the best light conditions where the effects of light intensity and color on the robots color perception are most consistent. The knowledge gained should help to define standardized lighting conditions for the ECER and thus create the same conditions for all participants.**

***Index Terms*—Color recognition, lighting conditions, Candela, color contrast, computer vision, robotics, light intensity, color calibration, sensor accuracy, environmental lighting, object sorting**

I. Introduction

Some tasks performed by the robot require a more sophisticated approach than simple programming. We have reflected on a solution that uses a camera to determine the optimal light intensity and color temperature for achieving the best conversion of analog light signals into digital color values. This paper presents our proposed solution. Our peers have talked about a problem that has already caused several malfunctions of the robots at the ECER, resulting from the fact that the lighting there was worse or just different from that of our own working environment. Color recognition is crucial in robotics. It enhances object detection, sorting, and interaction between robots. By identifying and processing colors, we can maximize the accuracy of the robots color recognition. However, the challenge of color recognition lies in the fact that various external factors, such as whether the light source is natural or artificial, can alter the way colors appear in the light sensors of the camera. The intensity of light, which is the brightness of the light source, significantly affects the clarity of colors, whereas the temperature of the light, which refers to the warmth or coolness of the light source, may alter the way the colors are perceived. These inconsistencies negatively affect the robot's decision-making process. To study the best way to work with these varying light conditions, we use a camera mounted on our robot while constantly changing the light source to systematically study how changes in Candela and Kelvin impact the contrast and recognition of colors in images. By examining the result, we aim to determine all-time best light conditions via which the bot can function the most consistently.

II. Background and Theory

This background and theory explain how light measurement impacts sensor performance, functionality and perception of the camera and therefore also that of the robot.

A. Candela and Kelvin

The characteristics of light are measured in terms of Candela(cd) and Kelvin(K). Candela is employed to measure the luminosity of a light source in a single direction, while Kelvin is used to measure color temperature [1]. Lower values such as 2700K produce warm, yellowish light, while higher values like 6500K emit cooler, more bluish light.

B. Impact of light temperature on color perception

Warm light reaching from 2700 – 3500K enhances reds and yellows but may distort other colors. Cool light reaching from 5000 – 6500K mainly enhances blues and whites but can make warmer colors look washed out. [2] Color temperature not only influences the way in which we humans perceive colors, but also that of a camera-based system, impacting accuracy for color-critical operations.

C. Camera Sensor and Light Capture

Cameras use CMOS or CCD sensors to convert light into electrical signals. CMOS sensors are faster and overall, more energy efficient, but they can generate noise, while CCD sensors are more light-sensitive at the expense of higher energy consumption. [3]

1) CCD: CCD (Charge-Coupled Device) sensors are considered to be analogue devices. Beneath the CCD layer is the serial shift register, which is connected to an amplifier on one side and an analogue-to-digital converter on the other. The charge in the CCD layer is amplified and subsequently transferred to the ADC. This charge is then read from pixel to pixel to recreate an image.

2) CMOS: CMOS (Complementary Metal Oxide Semiconductor) is distinct from CCD (Charge-Coupled Device) in that CMOS incorporates an amplifier within each pixel. While this is true for some CCD sensors, it is true for most CMOS sensors. This results in higher noise compared to a CCD Sensor. However, this trade-off enables the simultaneous reading of multiple pixels, a feature that is crucial for certain applications.

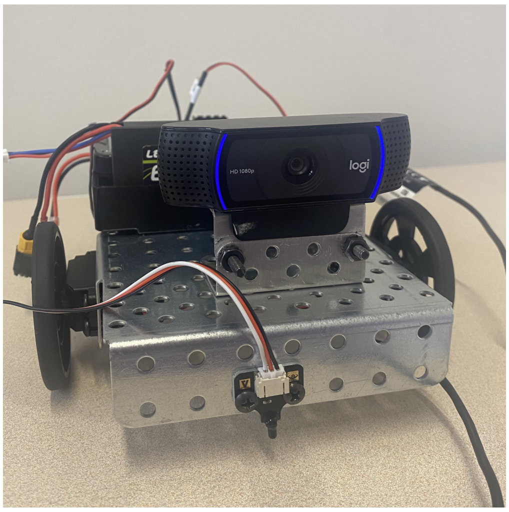

Figure 1: A picture of the camera used.

D. How Sensors Process Light

Light is detected by sensors through RGB filters that differentiate color and help construct images through contrasting levels of light. Exposure, white balance, and sensor sensitivity decide accuracy and the light conditions, as mentioned here a couple of times before, become crucial for machine vision and automation. [4]

III. Experiment Setup

Tests will be carried out using the robot shown in Figure 1. Each test will be explained in detail when relevant, but generally, they will follow this approach: The robot will be placed in a specific location, and its surroundings will be described. The difference between the highest and lowest recorded values will be analyzed for comparison. The Light values will be measured at different positions, usually around the corners of a given shape. This method is both time-efficient and easy to explain to the user. Botball light-start usually involves a stationary robot, so for this experiment we plan to induce the same strategy, even though testing in different locations would provide a more accurate representation of how incoming light varies.

A. Equipment and Setup:

For the experiment we will be using the following equipment:

- ECER Robot
- Laptop for editing and analysis
- Logitech C920 PRO HD webcam for taking pictures and color recognition
- Gimp for cutting out any background
- Lepro AI Smart lightbulb B2 for changing the light conditions
- Online website for obtaining the average color value of every pixel combined in an image.

Figure 2: A picture of the light bulb used.

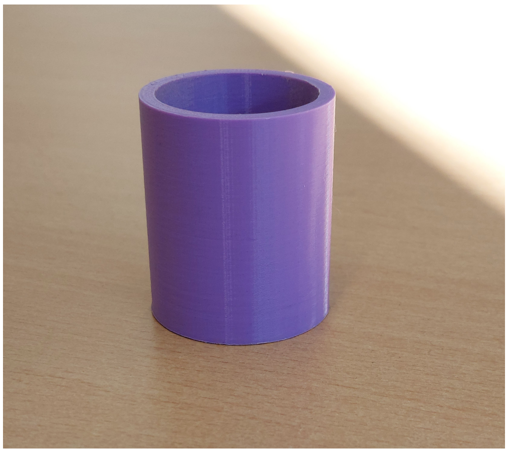

Figure 3: An example of an object used.

Before the experiment can be carried out, it is important that the camera is calibrated. For our camera, this was done manually, without the need of our intervention. It is also important to ensure that the camera's white balance is correct, as this can also lead to incorrect recognition. [5]. This can be done either manually or automatically. We tested it manually using the v4l2-ctl command on Linux, but decided that the automatic approach was better for us in the end.

IV. Methodology

This study will address how light intensity and light warmth influences color perception. The methodology will consist of two main experiments which at the end will be combined, to find out the perfect lighting conditions:

1) Measuring light intensity to determine the optimal conditions.
2) Measuring light temperature to determine the optimal conditions.

3) Combining both factors to determine how they work together to create optimal conditions.

To create the perfect testing environment, we will darken up the room, to the point of complete darkness, to ensure no external factors affect our light measurements. While normally, there are other objects visible for the camera, for the sake of accessing the exact values used for the experiment, we will use a white base and background, to not be disturbed by any other inconsistencies that might occur.

V. 1st Experiment

The experiment will be conducted by measuring the light intensity and concluding, which value will result in the perfect outcome for the cameras color recognition.

A. Procedure:

The procedure will be initiated by placing the bot on the white base exactly 30 cm away from the wall. Hovering over it by 55 cm the light source will be positioned. Both the light source, as well as the camera on the bot will be facing the object in a straight line to eliminate unnecessary shadows. [6] As soon as those items are positioned correctly and optimized by exact measurements, the next step of our experiment can be carried out. For the next step, we will be changing the intensity of the light to three different values:

- 29,2 Candela
- 16,8 Candela
- 4,4 Candela

This we will achieve by using the Lepro AI Smart light bulb B2 with the companion app. Objects will be placed 10 cm away from the wall, corresponding to that, 20 cm away from the camera. Once the light intensity has been adjusted and the object placed in its designated location, the pictures can be taken. For this, we will connect the robots camera to our laptop, and use the standard camera app of a Lenovo Laptop to successfully take three pictures of each object, while changing the light to all the different light luminosities. The pictures will be imported into Gimp, where we cut out each object along it's outline, while keeping the extracted area the same for every light variation. All the cut-out images will then be exported into .png to ensure a transparent background. We will then use software to determine the average color of each pixel in every object. The measurements will then be analyzed and compared, and the perfect condition will be determined.

B. Expected outcome:

At the end of the experiment, we hope to be able to identify the best light intensity for the cameras' color recognition.

VI. 2nd Experiment

In this experiment, we will measure the best light temperature to determine the optimal conditions for color recognition, and use the result to calculate the best value for the most accurate results.

A. Procedure:

The equipment and procedure for this experiment will be exactly the same as the first. We'll use the same robot and camera to take the pictures, the only difference being that we'll be changing the color of the light source rather than its intensity. The objects will again be placed in a straight line towards the camera and the light source, exactly 30 cm away. 55 cm horizontally we will position the light source to ensure that the entire object is illuminated. This will again be done with three different values:

- 5700 Kelvin
- 4200 Kelvin
- 2700 Kelvin

As before, we will use the Lepro AI Smart Light bulb B2 with the companion app. Once the object has been placed according to the measurements taken earlier and the temperature has been changed accordingly, we can take the pictures in exactly the same way as before and use Gimp again to crop the images accordingly. By retracing each step taken in the first experiment, we can determine the perfect state by analyzing the values accordingly.

B. Expected outcome:

At the end of this experiment, we hope to be able to identify the best light temperature for the cameras' color recognition.

VII. 3rd Experiment

For the last experiment, or rather the last step, we want to determine the best light intensity and temperature for the camera's color perception. This is done by taking all the previous calculations and adding them up to make sure we are actually getting the results we desire.

This last step is the combination and result of the previous two experiments.

VIII. Results and Analysis

This section presents the results of the three experiments mentioned above, together with the analysis of the data. To show you the results better, we will show you the exact spreadsheet we used for the calculations.

A. Calculations

For the calculations, our approach may not be the most effective, but we have taken the following approach. We eliminated color differences by calculating their average RGB values. The exact same approach was used to eliminate color differences due to light temperature. This allowed us to normalize the colors to a single RGB value. [7]The result was then used to compare each individual Kelvin and Candela variation with the average normalized color to see which was closest, and to determine the perfect light temperature and luminance. For the purpose of finding this out we wrote a short python algorithm.

B. Data table

The table below shows the RGB values we calculated. The first column explains the values in Candela, while the second column explains the values in Kelvin, and the columns after that show the color of the objects used for the experiment. Each row then shows a different combination of Kelvin and Candela along with the corresponding average RGB value.

Table I: Data Table

Candela	Kelvin	red	purple
4,4 Candela	2700 Kelvin	RGB(108, 6, 3)	RGB(75, 66, 101)
4,4 Candela	4200 Kelvin	RGB(111, 3, 3)	RGB(74, 61, 114)
4,4 Candela	5700 Kelvin	RGB(132, 4, 4)	RGB(86, 77, 126)
16,8 Candela	2700 Kelvin	RGB(105, 4, 2)	RGB(85, 75, 105)
16,8 Candela	4200 Kelvin	RGB(113, 2, 2)	RGB(87, 77, 132)
16,8 Candela	5700 Kelvin	RGB(131, 2, 3)	RGB(95, 86, 132)
29,2 Candela	2700 Kelvin	RGB(125, 3, 2)	RGB(85, 75, 106)
29,2 Candela	4200 Kelvin	RGB(146, 2, 2)	RGB(87, 76, 132)
29,2 Candela	5700 Kelvin	RGB(147, 5, 6)	RGB(90, 78, 124)

Candela	Kelvin	yellow	green
4,4 Candela	2700 Kelvin	RGB(150, 131, 22)	RGB(11, 38, 16)
4,4 Candela	4200 Kelvin	RGB(130,101, 12)	RGB(10, 39, 18)
4,4 Candela	5700 Kelvin	RGB(143, 111, 27)	RGB(13, 48, 20)
16,8 Candela	2700 Kelvin	RGB(131, 110, 15)	RGB(11, 45, 23)
16,8 Candela	4200 Kelvin	RGB(135, 110, 11)	RGB(14, 54, 28)
16,8 Candela	5700 Kelvin	RGB(141, 113, 27)	RGB(17, 55, 24)
29,2 Candela	2700 Kelvin	RGB(150, 130, 21)	RGB(14, 62, 37)
29,2 Candela	4200 Kelvin	RGB(165, 134, 45)	RGB(10, 72, 46)
29,2 Candela	5700 Kelvin	RGB(160, 134, 33)	RGB(22, 73, 35)

C. Calculation results

Finding the values closest to the calculated average color took some time and careful observation, but in the end we came up with a result. The optimal lighting conditions for object recognition varied according to color. The red object was best recognized at 29.2 Candela and 2700 Kelvin, while the purple object performed best at 4.4 Candela and 5700 Kelvin. For the green object, the ideal conditions were 16.8 Candela and 2700 Kelvin, while the yellow object was best recognized at 4.4 Candela and 5700 Kelvin. These findings suggest that different colors require specific light intensities and color temperatures for optimal recognition. The average value we believe would help recognize each color as accurately as possible would be 16,8 Candela and 5700 Kelvin.

IX. Conclusion

Determining the perfect lighting conditions for a camera's color perception requires proper calculations and the consideration that external factors, such as natural light, could alter them. Color perception remains crucial to solving tasks with a robot, and mastering it by ensuring that lighting conditions are as they should be, will help to avoid unnecessary errors, both for competitions and for application in other aspects of robotics. With the help of this study and all the things we have learned from it, we hope to use all the new information we have gained to improve our robot's performance at the ECER.

X. acknowledgment

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