Color Detection in Autonomous Robot-Camera

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Abstract. This is a research about color detection in which the researchers propose and implement an algorithm to distinguish the location of any desired color in any kind of scene. The algorithm is implemented in a robot that is capable to move toward the desired color. The robot system operates real-time since the algorithm works on frames of an on-time video captured by a simple camera of the robot. The algorithm uses partitioning for finding the location of the desired color, and then considers all pixels at each partition. The robot system functions rapidly since there is no transformation or other time-consuming technique related to digital image processing in the algorithm. At the end of this study, the accuracy of the system is separately presented regarding the right movement and the left movement.

1. Introduction

Colors are essentially important in our life. When we are going to buy a shirt, we look for a particular color. Or we compare different colors of that shirt, then select the best one. In soccer (or any sport match) when two teams make a match, the teams are asked to wear two different colors to be recognized clearly. In driving, the green signal means to go, and red signal means to stop. From birth some color codes are used regarding genders; girls wear pink while boys wear blue.

Colors are not just matters of how things look, they are also not purely cosmetic. We do not have any object without any color. In physics we study the truth; there is nowhere that colors do not exist [1]. In fact, colors are the first parameters that are registered in assessing objects and things. For example, when we see a small object that is flying in our home and its color is dark (somehow black), then we think of a fly. While if the small flying object has yellow stripes, then we do not think of a fly any more, instead we think of a bee. We are intimately familiar with the structure of colors in country flags. In fact, we distinguish a particular flag based on the colors. For example the flag of my country – Iran – has three colors of green, white and red such that the green color is on top, the red color is in the bottom and white is between them. If the colors are not in this arrangement, then the flag is not for Iran any more.

Since colors are important, several researches and works have been done in the field of colors. These studies were done in different views then found the relation between colors and other scopes and areas from interior design, business and marketing to psychology, biology and medicine. In the field of interior design, a research shows that in medical environment, color yellow is equivalent to happiness, while colors white, blue and red are equivalent to cleanness, rest and hunger respectively [2].

In business and marketing, some studies bold the impact of colors. These studies based on findings suggest to pay attention on colors when brand packages are designed [3] [4].
There are some studies that show the relation between colors and human appetite [5][6]. For example; serving foods in red plates has negative impact in food consumption. In other words, red color decreases appetite of human. Some other researches same as [7] show that colors have important roles in selecting food and beverage. Some researches prove that color of shopping area affects the buyer. For example red color has negative effect while blue color has positive effect [8].

Some studies were done in the field of psychology regarding colors. Studies show that there is a relation between colors and performance attainment. For example, red color decreases the performance achievement [9][10], although some other studies show that red color enhances performance achievement at some situations [11].

There are some researches and studies in biology and medicine that use colors to detect different parts and particles [12][13]. For example; green color is symbol of SYTO 9, while red color means membrane [12]. In [13] red color particles are considered as dead cells while green color parts are considered as active bacteria that can affect cells.

In the field of criminology, interestingly some studies show that pink color can affect or change the emotions of prisoners [14][15]. These studies proved if the color of cells are pink, then prisoners becomes happier.

There are other studies and researches that show the key roles of colors in our life. This is why, the researchers decided to develop a computerized system to distinguish the location of a particular color.

2. Related studies
There is a study in which the researchers propose an algorithm to detect particular color in an image [16]. To find the particular color in a colored image, the grayscale version of the image and particular color-band are subtracted. The result image shows the areas having particular color. In this research, the particular color can be pure blue (that is 0, 0, 255), pure red (that is 255, 0, 0) and pure green (that is 0, 255, 0).

In [17] researchers offer a system for people who suffer from color blindness. The system uses an algorithm in which edge detection plays the main role. The user selects desired point on the image, then system detects the color of the point. After that the system searches in its database and returns the closest color to the detected color (the color of the desired point). The database of the system contains the traditional seven colors of rainbow; red, orange, yellow, green, blue, indigo and violet. In other words, the system returns one of these seven colors.

Some researchers proposed an algorithm that recognizes the shape and the color of objects in an image [18]. Regarding color detection, the system first finds boundary of all objects, and then detects the color of each object based on region inside the boundary. The colors that can be detected by the algorithm contain pure blue, pure red and pure green.

The systems in [16] and [18] are perfect having high accuracy, but they can detect only pure red, pure green and pure blue, while reality we are dealing with many other colors caused by combining these three colors. In fact these studies are incapable regarding detection of countless colors that are not pure red, green or blue. Besides, study [18] is not able to find the location of a particular color, although it shows colors of the objects. The system in [18] also fails when the background is cluttered.

The system in [17] is really helpful and functional, but it can detect only the seven traditional colors; red, orange, yellow, green, blue, indigo and violet. Moreover, this system cannot find the location of a particular color. The system in [17] same as the system in [18] fails in dealing with cluttered background.

3. Statement of the problem
As mentioned earlier, because of importance of colors, it is suitable to have a system to find the location of a particular color. On the other hand, although there are some worthy studies and systems regarding color detection, they cannot distinguish the location of any desired color in any type of scene. In fact, the existed systems may have two problems;
1) They cannot work on any desired color. In other words, they function only on limited number of colors.

2) They cannot work on any type of scene. In other words, they function only on a neat scene in which background is not cluttered and not interfused.

4. Proposed system
To solve the problems mentioned, we propose a robot system that distinguishes the location of any desired color in any type of scene. Moreover, the robot system moves toward the location.

5. Hardware and software
The proposed system is implemented in a robot containing a Raspberry Pi 3 Model B, an original camera – 5 MP, two pieces of SG-5010 Towerpro servo motors; each of which connected to a wheel, and a free wheel in the front (see Figure 1). The distance between two wheels (the right wheel and the left wheel) is 27 cm while the radius of each wheel is 3.5 cm.

The robot uses Raspbian Jessie as operating system, Python as programming language and OpenCV as library for digital image processing.

6. Algorithm and implementation
The system works on frames of the video captured by the camera. Each frame is partitioned into two parts; the right part and the left part as shown in Figure 2.

Based on the algorithm; when the system runs, the user enters the desired color in RGB format in which the redness (R), greenness (G) and blueness (B) are entered separately. Then the user enters the tolerance for redness (RT), greenness (GT) and blueness (BT). The tolerance increases the scope of the user regarding the desired color, since the user might look for a range of colors – not an exact color.

After entering all input, the system works on frames and read the pixels of each frame. If the pixel belongs to the right part (RP) and redness of the pixel (red), greenness of the pixel (green) and blueness of the pixel (blue) are in the desired range, then the number of pixels having desired color in the right part (PixR) increases. If the pixel does not belong to the right part, then the pixel is located in the left part. In this case, if the colors of the pixel are in the desired ranges, then number of pixels having desired color in the left side (PixL) increases.

After reading all pixels of the frame, system decides for movement based on majority of desired color in the scene. If the number of pixels having desired color in the left side and the right side are equal (PixL=PixR) and the number is greater than 50% of number of all pixels in the frame (Total), then the system does not move. In this situation, the system has already found the desired color, otherwise the system moves forward. If the number of pixels having desired color in the right part is greater than the number of pixels having desired color in the left part, then the system moves to the
right and then moves forward. Else, the system moves to the left and then moves forward. After each forward movement the system works on the next frame. The system continuously works on the frames until reaches to the frame in which the number of pixels having desired color in the left side and the right side are equal and the number is greater than 50% of number of all pixels in the frame.

![Figure 2. The right part and the left part of the scene (frame)](image)

### 7. Movement

The robot moves toward the part (right part or left part) that has greater number of pixels having the desired color and then moves forward. For the movement the robot uses two servo motors. For going right, the right servo motor is at rest while the left servo motor rotates counterclockwise. For going left, the left servo motor is at rest while the right servo motor rotates clockwise. For going forward, the left servo motor rotates counterclockwise while the right servo motor rotates clockwise.

The robot moves only horizontally (not vertically), this is why; we need to know how much in degree the angle for going right or left is. The horizontal angle of view of the camera is 53.5° [19] [20]. It means the right part has 26.75° and the left part as well. Hence, for going to the center of the right part or to the center of the left part the robot needs to move 13.375°. We call this value as unit angle (UA).

The robot uses Raspberry Pi that is connected to two servo motors that are responsible for all movements of the robot. In fact, Raspberry Pi sends some signal called Duty Cycle to trigger the servo motors. That is why we focus on computations regarding Duty Cycle.

#### 7.1. Move right

Regarding going to right; if the left wheel continues its movement while the right wheel has no movement, then the path of left wheel makes a circle in which the center of the circle is the right wheel while the radius of the circle is the distance between two wheels (right and left wheels) is equal to 27 cm based on manual measurement. The circumference of this circle can be computed using formula 1 in which “C” stands for circumference of the circle, “π” is the constant ratio of the circumference of a circle to its diameter- that is equal to 3.14159, and “r” represents the radius of the circle (the distance between the right wheel and the left wheel) that is equal to 27 cm.

\[
C = 2 \times \pi \times r
\]

\[
C = 54\pi \text{ cm}
\]

It means if the robot tries to make a complete circle - that is equal to 360 degrees, while right wheel is at rest, the left wheel has to move 54π cm. We use equation (2) for computation of PU (path-unit) that is the amount of movement of the left wheel when the robot needs to move a UA (13.375°). In equation (2); PU stands for path-unit, UA is the unit angle of view, and “C” is the circumference of the circle.

\[
PU = \frac{UA \times C}{360}
\]

\[
PU = 2.00625\pi \text{ cm}
\]

It means that 2.00625π cm passing of the circumference of the circle is equivalent to 13.375° movement. In other words, for moving a UA (13.375°) to right, the robot moves the left wheel such that it passes 2.00625π cm while the right wheel is at rest.
For going to the right, the rotate direction of the left wheel is counterclockwise that is positive direction in trigonometry. To compute the quantity of left wheel rotation, the radius of the left wheel is manually measured that is equal to 3.25 cm. Now, we can compute the circumference of the left wheel using formula 3 in which $C_{\text{wheel}}$ is circumference of the left wheel, $r_{\text{wheel}}$ is the radius of the left wheel that is equal to 3.25 cm, and “π” is the constant ratio of the circumference of a circle to its diameter that is equal to 3.14159.

$$C_{\text{wheel}} = 2 \times \pi \times r_{\text{wheel}} \tag{3}$$

It means that if the left wheel rotates one round that is 360 degrees, then the left wheel moves $6.5\pi$ cm. On the other hand, for having one UA (13.375°) to the right, the left wheel needs to move one PU that is 2.00625π cm. Here, we use formula 4 to find the quantity of left wheel rotation for having 2.00625π cm where MU stands for movement unit, PU stands for path-unit that is equal to 2.00625π cm and $C_{\text{wheel}}$ is the circumference of the left wheel that is equal to 6.5π cm.

$$MU = \frac{360 \times PU}{C_{\text{wheel}}} \tag{4}$$

$$MU = 111.11538^\circ$$

It means that if the right wheel is at rest and the left wheel rotates counterclockwise as much as 111.11538°, then the robot moves to right as much as one UA that is 13.375°. Based on trigonometry concepts, MU is positive since the rotation of the left wheel is counterclockwise.

Servo motors work based on PWM (pulse width modulation). The range of PWM is varying in different servo motors. In TowerPro SG5010 servo motor, PWM is between 0.6 to 2.4 ms (millisecond) in which 0.6 ms makes rotation as much as $-90^\circ$ and 2.4 ms makes $90^\circ$. The values between 0.6 ms and 2.4 ms make different angles for rotation based on formula 5 in which PWM stands for pulse width modulation (in millisecond), and $\theta$ is desired angle (in degree) of rotation [19][20].

$$PWM = \frac{\theta + 150}{100} \tag{5}$$

In fact, $\theta$ in formula 5 is MU that we talked about it earlier. Now we use formula 5 and find PWM for right movement. $PWM_{\text{right}} = (111.11538 + 150)/100 = 2.61115$ ms.

The last step is to find the Duty Cycle (in percent) that makes proper PWM. Formula 6 shows the relation between PWM and Duty Cycle where “f” is the frequency of the servo motor that is 50 Hz [19][20], and PWM is the desired pulse width modulation;

$$\text{Duty Cycle} = PWM \times f \tag{6}$$

$$\text{Duty Cycle}_{\text{right}} = 2.61115 \times 50 = 130.5577\%$$

7.2. Move left
The story for going left is the same as going right with the difference of direction of the rotation. Here the value of MU is $-111.11538^\circ$ because the right wheel needs to rotate clockwise that is negative in trigonometry. Then based on formula 5, $PWM_{\text{left}} = (-111.11538 + 150)/100 = 0.38885$ ms. Then, based on formula 6; Duty Cycle$_{\text{left}} = 0.38885 \times 50 = 1.94423\%$.

7.3. Move forward
For moving forward, both of the left and the right wheel need to move. In this case we need to make both Duty Cycle$_{\text{right}}$ that is equal to 13.05577% and Duty Cycle$_{\text{left}}$ that is equal to 1.94423% together.

8. Result and discussion
Table 1 presents the accuracy of the robot system regarding the right movement and the left movement.

| Movement     | Value in Theory | Value in Practice | Error (%) | Accuracy (%) |
|--------------|-----------------|-------------------|-----------|--------------|
| Right Movement | 13.375° (35 cm) | 27 cm             | 22.9      | 77.1          |
Left Movement 13.375° (35 cm) 23 cm 34.3 65.7

Based on the results in Table 1, since the accuracy of the right movement and the left movement of the system are not equal, the robot cannot move forward properly.

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