Abstract— Color detection methods are generally discarded in introductory robotic system because of the complexity of the detection procedure and the lack of reliable and economical color detection methods. This paper examines how to develop an easily implementable and cost effective color detection scheme. Method used for color detection is based on the visible properties of light. A pair of techniques based on the experimental data has been developed and discussed. The sensor is built with very low cost materials such as colored cellophane paper as an alternative of color filter & simple light dependent resistors etc.

Index Terms—color detection, robotics

I. INTRODUCTION

There are three primary colors; Red, Green and Blue. These colors are known as the light primaries. Lights of red, green, and blue wavelengths may be mixed to produce all colors e.g. the secondary colors cyan, magenta and yellow are the combinations of the pair of these three colors. Yellow is the combination of Red and Green color [1]-[2]. Cyan is the combination of blue and green and Magenta is the combination of red and blue. Red, Green and Blue are known as primary additive colors and Cyan, Magenta and yellow are known as the primary subtractive colors [2].

Color is produced by the absorption of selected wavelengths of light by an object. A blue colored object reflects all the lights other than blue when illuminated by white light and thus we see it blue.

A blue surface when exposed to Green, Blue and Red lights (light primaries), the surface shines brightly for the blue light while appearing dark for the other two lights because of the absorption of lights in the surface. Similarly, when a red surface is exposed to RGB lights, it shines brightly for red light while appearing dark for the other two lights (green and blue) and similar result can be found for a green surface exposed to the primary colored lights. So for a color which is the mixture of all three colors, a fraction of these primary colors will be reflected. For example, when a yellow surface is subjected to the RGB lights, the surface shines brightly for red and green while appears dark for the blue light.

So if the reflected light from any object can be separated to the primaries and the output can be processed in a suitable form then the processed values can be used to represent the colors of that object.

To separate the reflected lights from the object red, green, and blue color filters can be used. A red filter will only pass the wavelength of lights in the red region and similarly green and blue filters will permit only lights in their respective regions [3].

So, the method consists of illuminating the object with three light sources; red, green, and blue and then separating the light reflected from the object into these three colors and then conditioning the signal to get the information of the color of the object. Simple light dependent resistors are used to sense the reflected and filtered light from the object.

Since the process is related with the reflected light from the object, it is very important to notice the reflective properties of the surface whose color is to be detected. If the surface is glossy then the reflected light intensity will be higher than the surface which is not glossy even though the surfaces are of same colors. So it always becomes difficult to detect colors from the object even with the use of very good technology.

In practice the color of an object is very difficult to

Figure 1: White light composed of all wavelengths of visible light incident on a pure blue object. Only blue light is reflected from the surface.
recognize because it may be seen at first look that an object is green but in reality it may consist of other colors too but not visible due to the dominance of the green light.

II. SENSOR ARRANGEMENT AND MATERIALS

The sensor which is similar to a rectangular box consists of six different chambers [Fig.2]. The upper three chambers are used for light sources and the lower chambers are used to place the LDRs. In front of the LDRs color filters (cellophane papers) are placed. One light source and the immediate lower section can be thought of as a single sensing unit. Color filters placed in a unit is of same color as the light source. As from the Fig.2, the red color filter is placed just below the red light source. We used LEDs as the light sources but other light sources may also be used.

Fig.2: Front view of the sensor used in the process.

Low cost cellophane papers are used as an alternative of the color filters in the experiment. The sensor arrangement is connected to a control circuit. Outputs from the LDRs are sent to a microcontroller chip for detection and controlling purpose. A general list of the materials can be listed easily as following,
- LDRs
- Microcontroller chip
- LEDs
- Resistors
- Cellophane papers (Red, green, and blue)

III. EXPERIMENTAL SETUP AND SPECIFICATIONS

A. Circuit Arrangement

The circuit used in this experiment is based on simple voltage divider rule [Fig.3]. The LED’s are controlled from one of the output pins of a microcontroller. We used Atmega8 in this experiment. The output signal is taken from each LDR voltage output and sent to the ADC channels of the microcontroller for a digital conversion.

Three voltage outputs from three LDRs are sent to the ADC channel one, two, and three of the microcontroller chip (Atmega8). From Fig.3, resistance $R_2$ is the LDR. The output signal is taken from the LDR.

Fig.3: Circuit arrangement for a single unit (one light source and corresponding LDR)

The reflected light from the object passes through each filter to reach LDRs. The value of resistance $R_3$ should be chosen such, which will generate a maximum voltage range in the LDR.

B. Evaluation of value of $R_3$

To find the value of $R_3$ for which the voltage range in LDR will be maximum can be evaluated as in [4] or as following,

Since, we need the maximum voltage range for the LDR output; this can be expressed as,

$$V_{\text{range}} = V_{\text{MAX,LDR}} - V_{\text{MIN,LDR}}$$

or,

$$V_{\text{range}} = I_{\text{MIN}} R_{\text{LDR,MAX}} - I_{\text{MAX}} R_{\text{LDR,MIN}}$$

Where,
- $V_{\text{range}} = $ Voltage range developed across the LDR
- $V_{\text{MAX,LDR}} = $ Maximum voltage across the LDR
- $V_{\text{MIN,LDR}} = $ Minimum voltage across the LDR
- $I_{\text{MIN}} = $ Minimum current
- $I_{\text{MAX}} = $ Maximum current

But, $I_{\text{MIN}} = \frac{V}{R_3 + R_{\text{LDR,MAX}}}$

And $I_{\text{MAX}} = \frac{V}{R_3 + R_{\text{LDR,MIN}}}$

Where,
- $V=$Supply voltage [Fig.3]
- $R_3=$Resistor [Fig.3]
Putting these values in equation (2),

\[ V_{\text{range}} = V \left( \frac{R_{\text{LDR,MAX}}}{R_3 + R_{\text{LDR,MAX}}} - \frac{R_{\text{LDR,MIN}}}{R_3 + R_{\text{LDR,MIN}}} \right) \]  

(3)

Where,

- \( R_{\text{LDR,MAX}} \) = Maximum resistance of LDR
- \( R_{\text{LDR,MIN}} \) = Minimum Resistance of the LDR

For a fixed \( V \) (supply voltage), the value of the \( V_{\text{range}} \) will be maximum if the term in between parenthesis in (3) becomes maximum.

So differentiating the term with respect to \( R_3 \),

\[
\frac{d}{dR_3} \left( \frac{R_{\text{LDR,MAX}}}{R_3 + R_{\text{LDR,MAX}}} - \frac{R_{\text{LDR,MIN}}}{R_3 + R_{\text{LDR,MIN}}} \right) = \frac{R_{\text{LDR,MIN}}}{(R_{\text{LDR,MIN}} + R_3)^2} - \frac{R_{\text{LDR,MAX}}}{(R_{\text{LDR,MAX}} + R_3)^2}
\]

Putting the result equal to zero gives,

\[ R_3 = \frac{R_{\text{LDR,MAX}} \times (R_{\text{LDR,MIN}})^{1/2} - R_{\text{LDR,MIN}} \times (R_{\text{LDR,MAX}})^{1/2}}{R_{\text{LDR,MAX}}^{1/2} - R_{\text{LDR,MIN}}^{1/2}} \]  

(4)

Here \( R_{\text{LDR,MAX}} \) and \( R_{\text{LDR,MIN}} \) can be found by measuring the resistance of the LDR in the dark and in normal condition with the filters attached in front of the LDR.

C. Data evaluation procedure

The objective is to map different colors and save the data in the memory of the device (e.g., a robot) so when any unknown color is placed in front of the sensor it can detect the color by using the mapped data in the memory. We used square boxes of different colors to experimentally record data to generate a unique vector table for each color [Table I]. The boxes used are placed in front of the sensor. Output data from the LDR is digitally converted with Atmega8 microcontroller chip using 8-bit resolution (Value range: 0-255) and is recorded. So for each color we got three data, one for the red light, one for the blue light, and the other for the green light.

D. Features of the experiment

Some of the features of the experiment were as following,

1) Surface type of the object used: Paper surface (A4, 80gm).
2) Colors in the paper were printed from: HP laser jet printer.
3) Distance of object from light source: 27 mm (horizontal)(approx.)
4) Distance of the sensors from object: 35mm (horizontal) (approx.)
5) The green light source used using a white LED and placing green cellophane paper (4 layers) in front of it.
6) Resistor R3 value found: 30kΩ
7) Intensity of blue light was the smallest and red light was the highest. (random light sources had been used in the experiment)

Following figure illustrates the placement of the sensor and object,

![Sensor arrangement diagram](image)

When object is placed in the desired position, a signal is sent to the microcontroller to turn on the light sources. Then the values from the LDRs were sent to the A/D conversion pins of the microcontroller. The value can be taken either turning all the LEDs and taking the data at once or by turning the LEDs one by one and taking the respective LDR data. For experimental purpose we used the later one.

IV. DATA ANALYSIS

Experimentally we recorded color data for fifteen colors. Following colors are used to experimentally take the data for analysis [Fig.5].

![Color samples](image)

And the data recorded are listed in the following table, Table I: Experimental data

<table>
<thead>
<tr>
<th>Object Color</th>
<th>X_r</th>
<th>X_g</th>
<th>X_b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>36</td>
<td>91</td>
<td>158</td>
</tr>
<tr>
<td>Green</td>
<td>90</td>
<td>64</td>
<td>138</td>
</tr>
<tr>
<td>Blue</td>
<td>109</td>
<td>127</td>
<td>90</td>
</tr>
<tr>
<td>Magenta (B+R)</td>
<td>39</td>
<td>101</td>
<td>152</td>
</tr>
<tr>
<td>Yellow (G+R)</td>
<td>34</td>
<td>48</td>
<td>132</td>
</tr>
<tr>
<td>Cyan (B+G)</td>
<td>123</td>
<td>75</td>
<td>102</td>
</tr>
<tr>
<td>Orange</td>
<td>35</td>
<td>70</td>
<td>177</td>
</tr>
<tr>
<td>Violet</td>
<td>63</td>
<td>112</td>
<td>156</td>
</tr>
<tr>
<td>Color</td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td>---------------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Light yellow</td>
<td>32</td>
<td>51</td>
<td>106</td>
</tr>
<tr>
<td>Light Magenta</td>
<td>33</td>
<td>84</td>
<td>124</td>
</tr>
<tr>
<td>Dark green</td>
<td>99</td>
<td>85</td>
<td>146</td>
</tr>
<tr>
<td>Dark red</td>
<td>55</td>
<td>93</td>
<td>155</td>
</tr>
<tr>
<td>Red-orange</td>
<td>36</td>
<td>85</td>
<td>166</td>
</tr>
<tr>
<td>Yellow orange</td>
<td>42</td>
<td>60</td>
<td>158</td>
</tr>
</tbody>
</table>

\[ X_{r,b,g} = \text{Digitally converted value from the LDRs for the red, blue and green light source respectively.} \]

A real color wheel is shown below.

Fig.6: The real color wheel [5]

From the figure [Fig.6] the distribution colors in the real color wheel can easily be analyzed. From Fig.6 color corresponding to the number 7, 19, and 31 are red, blue and green colors respectively. In between these colors, at numbers 1, 13, and 31, are the secondary colors i.e. yellow, magenta, and cyan respectively. Consider the colors in between yellow and red. These colors are the mixture of yellow and red color. Within this range and approximately at the middle of yellow and red lies the orange. Now if we gradually increase red portion in orange color then the color becomes rich with red and we can name it as red-orange. Also if we proceed gradually from the orange towards the yellow color i.e. increase the yellow in orange then we can find orange colors rich with yellow and can be called yellow-orange. Similarly other color gradients in between green and yellow, green and cyan, cyan and blue, blue and magenta, and magenta and red can be defined.

From the experimental data [Table-I], we observe that, for red object the value in red LDR us the lowest and the blue is the highest. Similarly for a green object the green LDR value is the lowest and blue is the highest again unlike the blue object where blue LDR reading is the highest, this may happen because of the blue light intensity used in the experiment and also the cellophane papers are not accurate color filters. After analyzing the data we observed that, the data follows a specific pattern for different colors as we expected and which is the need of our detection device. Data for every color that has been taken is unique as seen from Table-I.

V. COLOR EVALUATION PROCESS/ALGORITHM

Two different processes has been developed and discussed. We denoted them as process A and process B.

A. Process A

To identify any unknown color \( X \) we defined a parameter, Proximity Factor (PF) which is defined as how close the unknown color is likely to be the one which is mapped already. Mathematically,

\[
PF_{k,S} = \sqrt{\frac{1}{3} \sum (X_i - Y_{j,k})^2}
\]

Where,
- \( PF = \text{Proximity Factor} \)
- \( X_i = \text{Unknown Data Vector} \)
- \( Y_{j,k} = \text{Known Data Vector} \)
- \( i = g, r, b \)
- \( j = g, r, b \)
- \( k = \text{mapped colors from the table} \)
- \( S = \text{Surface type} \)

Surface type has not been used as a variable but used as a specification by which it may be possible for the user of the device to know what type of surface can be used to be detected by the device.

So, \( PF_{\text{green},S} \) determines how close the unknown color, \( X \) is to the green color that has been mapped previously in the device. Similarly \( PF_{\text{orange},S} \) determines how close the unknown color, \( X \) is to the orange color and so on.

Example:

Say, any unknown color \( X \) is placed and the data from the three LDRs are as following after being digitally converted,

\( X_r = 90 \), \( X_g = 100 \), \( X_b = 220 \)

Then, for green color,

\[
PF_{\text{green}} = \sqrt{\frac{1}{3} \sum (X_i - Y_{g,\text{green}})^2} = 50
\]

For dark green as listed in the table [Table I]

\[
PF_{\text{darkgreen}} = \sqrt{\frac{1}{3} \sum (X_i - Y_{g,\text{darkgreen}})^2} = 42.82
\]
the squared value of the differences between the pairs of upon the intensity of the light sources used. We observed that, entirely surface dependent. to be saved for further detection of that color. Even it is not primary reasons is the difference in the intensity of the light sources. Similarly, 

\[
P_{F_{\text{yellow}}} = \sqrt{\frac{1}{3}[(90 - 48)^2 + (100 - 34)^2 + (220 - 132)^2]} 
\]

\[
P_{F_{\text{yellow}}} = 67.98, \quad P_{F_{\text{orange}}} = 48.73, \quad P_{F_{\text{red}}} = 51.45 
\]

\[
P_{F_{\text{blue}}} = 78.20, \quad P_{F_{\text{yellow-orange}}} = 48.47 \text{ etc.} 
\]

So, dark green is the most likely color matched to the unknown color with a value of, \(PF=42.82\)

**B. Process B**

In this process, the data found for different colors need not to be saved for further detection of that color. Even it is not entirely surface dependent.

This process is dependent on the sensor materials; largely upon the intensity of the light sources used. We observed that, the squared value of the differences between the pairs of reading taken from different LDRs can give a good approximation of the color that has to be detected. This process can detect most of the colors in the color wheel if the experimental value for the sensor is taken properly.

We defined three parameters, \(X_{\text{BR}}, X_{\text{RG}}, X_{\text{GB}}\)

Where,

\[
X_{\text{BR}} = (X_b - X_r)^2 
\]

\[
X_{\text{RG}} = (X_r - X_g)^2 
\]

\[
X_{\text{GB}} = (X_g - X_b)^2 
\]

From experimental data, we observed that,

\[X_{\text{BR}} > X_{\text{GB}} > X_{\text{RG}}, \text{ for red, yellow and orange} \quad \text{(L1)}\]

\[X_{\text{GR}} > X_{\text{BR}} > X_{\text{RG}}, \text{ for green , light green, dark green} \quad \text{(L2)}\]

\[X_{\text{GB}} > X_{\text{BR}} > X_{\text{RG}}, \text{ for Blue, dark blue, light blue} \quad \text{(L3)}\]

\[X_{\text{RG}} > X_{\text{GB}} > X_{\text{BR}}, \text{ for cyan} \quad \text{(L4)}\]

\[X_{\text{BR}} > X_{\text{RG}} > X_{\text{GB}}, \text{ for magenta and violet} \quad \text{(L5)}\]

Since these logic equations (which are based on experimental data and thus when experimental conditions change) such as light intensities are different from the conditions we followed, the above logic equations may come up for colors other than specified above e.g. (L1) may be satisfied for colors other than red, yellow and orange in different experimental conditions) generate the main baseline for different colors we named them base logic equations and the variables used as the base variables.

So for any unknown colored object \(X, X_{\text{BR}}, X_{\text{GB}}\) and \(X_{\text{RG}}\) is calculated at first.

If the values satisfy (L1) then the color is red, yellow or orange. If it satisfies (L2) then the color is green (light, pure or dark) and so on. Now the task is to distinguish among the colors that falls under the same logic equations e.g. (L1) carries three colors in it; red, orange and blue.

To distinguish between these colors, we analyzed the data for these three colors along with the other colors which lies in between these three colors. The region can be shown with the help of the following figure [Fig.7].

Experimental conditions are very susceptible to change; one of the primary reasons is the difference in the intensity of the light sources.

\[\text{Red, } \frac{X_g}{X_r + X_b} > = 0.440, \text{ similarly for, } \]

Deep Red-Orange: 0.400 to 0.440

Medium Red-Orange: 0.370 to 0.400

Light Red-orange: 0.340 to 0.370

Orange, 0.300 to 0.340

Yellow-Orange: 0.290 to 0.300 etc.

Similarly for the colors e.g. colors in between magenta and red, blue and magenta, green and cyan and also cyan and blue can be distinguished with the help of the following factors,

\[\frac{X_g}{X_r + X_b} \text{ or, } \frac{X_r}{X_g + X_b} \text{ or, } \frac{X_b}{X_r + X_g}\]

Again, each of these colors can be dark, normal or light. This can be differentiated too.
lightness of the colors, following factors may be useful as we observed from the data. Following parameters can be effective to detect lightness,

\[
\frac{X_g}{X_r + X_b + X_g}, \frac{X_b}{X_r + X_b + X_g}, \frac{X_r}{X_r + X_b + X_g}
\]

Similarly, based on just only these three variables, \(X_r, X_b, X_g\) and \(X_e\) detected by the sensor several different factors may be approximated to define a color of the object even the color is the shades of different colors.

VI. RESULTS AND DISCUSSION

We implemented both the techniques in a robot built locally. The robot is designed to sense the color from the object (Rectangular box, 5x5x4) and hence place the objects in required positions. The results were as following,

A. Process A

- Can not detect colors from the surface which is not calibrated in the experiment.
- Produces false detection for the colors closed to the one that has been mapped but not exactly the same color e.g. orange colors has been shown as red if the red percentage is little higher.
- Uses previously saved color values. So if the surface is changed produces false detection.
- Large number of colors can be mapped but has the limitations of different colors having very close Proximity factor.

B. Process B

- No color value is saved, only some logic equations and the color name corresponding to that logic are saved in the device, so it works with only with the value found from the object and matching it with the logics.
- Since no color value is saved, it works very well with different surfaces e.g. we used glossy book surface, even cloth surface and the device worked perfectly.
- Not only color even the shades (dark, light) can also be detected by suitable programming.
- Accuracy largely depends upon the light sources used. But many colors independent of the surface can be easily detected.

VII. CONCLUSION

A very low cost method of color detection process has been described. We implemented both the processes in a robot built locally. The robot can pick different objects sense their colors and can sort them accordingly. Accuracy of detection process may be increased by,

1) Combining process A and B simultaneously.
2) Accuracy can also be increased by placing actual RGB color filters.
3) Incorporating accessories like lenses (convex) to intensify the reflected light towards the LDRs.

We are currently working to develop a new model which is co-ordinate geometry based model using the same sensor arrangement except replacing the cellophane papers with actual color filters. The method involves creating different planes of colors based on the experimental data and later extracting the position of any unknown color in that plane.

VIII. NOMENCLATURE

<table>
<thead>
<tr>
<th>1) Symbol</th>
<th>2) Meaning</th>
<th>3) Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Current</td>
<td>Amp</td>
</tr>
<tr>
<td>V</td>
<td>Voltage</td>
<td>Volt</td>
</tr>
<tr>
<td>R</td>
<td>Resistance</td>
<td>Ohm</td>
</tr>
<tr>
<td>PF</td>
<td>Proximity Factor</td>
<td>-</td>
</tr>
<tr>
<td>LDR</td>
<td>Light Dependent Resistor</td>
<td>Ohm</td>
</tr>
<tr>
<td>(V_{max})</td>
<td>Maximum voltage range across the LDR</td>
<td>Volt</td>
</tr>
<tr>
<td>(V_{min})</td>
<td>Minimum voltage across the LDR</td>
<td>Volt</td>
</tr>
<tr>
<td>(R_{LDR,\text{MAX}})</td>
<td>Maximum Resistance of LDR</td>
<td>Ohm</td>
</tr>
<tr>
<td>(R_{LDR,\text{MIN}})</td>
<td>Minimum Resistance of LDR</td>
<td>Ohm</td>
</tr>
<tr>
<td>(X_{r,b,g})</td>
<td>Digitally converted values found for LDRs associated with red, blue and green filter respectively</td>
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</tr>
<tr>
<td>(X_{X_R}, X_{X_G}, X_{GB})</td>
<td>Squared value of the difference of the values found from the LDR</td>
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</table>

REFERENCES


