RGB Color Sensor

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***Abstract*— A color sensor design with a wide dynamic range is presented to detect Red (R), Green (G), and Blue (B) colors from an object. The device is susceptible to disturbances and varying light conditions. The color identification is based on sensing R, G, B colors reflected from the object using a photoresistor. The color sensor does not need optical devices and color filters. It has the capability to track every color at a working distance of 8 cm without considering the environmental light conditions.**

I. Introduction

Different color spaces help quantify color attributes numerically, and RGB color space is one of them. In this paper, we have proposed a RGB color sensor, which is one of the primary color sensors commonly used in many applications. RGB color space comprises more than 16 million colors, which are arranged in a 3D space, where integer values of components R (Red), G (Green), and B (Blue), ranging from 0 to 255. This RGB color sensor follows the principle that all the colors can be generated by mixing the red (R), blue (B), and green (G) colors in appropriate percentages[1]. RGB color sensor will use an external means of emitting light and then analyze the reflected light from the object in order to determine its color. Light-emitting diodes and photoresistors are involved in this process.

Color gives essential information in many industrial processes to facilitate production and packaging processes. Therefore, color detection has become a necessary feature in modern industry, and with that purpose, many color sensors were invented. In the market, there are many complicated and sophisticated color sensors available. But due to their expensiveness, they cannot be used for less demanding and low-cost applications. Therefore, we came up with this low-cost color sensor as a solution. This sensor can be used for low-cost applications in the food industry, paints, textiles, and other industries that use color information. Also, this sensor is suitable for use in any external light environment without disturbances.

II. Initial Specifications

- This sensor is able to detect all R, G, and B values ranging from 0 to 255 (256 color levels). Therefore it can identify any color in the RGB colour space.
- The sensor operates in the temperature range of 0-55 ℃. In this range, all the components are working properly.
- There should be a voltage input of 5V for the sensor to function properly. With this voltage level, all the components work properly.
- The optimum current range for the sensor is 20mA - 30mA. This current range is better for the components to work properly and safely.
- The response time of the sensor is 15 seconds. Each color of LEDs is on for 5 seconds. This time is enough for LEDs to stabilize and produce a fair and uniform illuminance on the object.
- The accuracy of the sensor is expected to be around 90%.

III. Methods

We have included information regarding the sensor design in this section. It covers the operation principle, circuit diagrams, testing setup, calibration setup, verification and validation procedures, and statistical analysis. Furthermore, the necessary equipment, setups, and processes for calibration, verification, and validation procedures are included. In this video the process is given https://www.youtube.com/watch?v=ljAL5dPOcGE

A. *The principle of operation*

In order to identify a color, an RGB sensor must contain two main components, namely a light source and a light detector. In the proposed sensor, LEDs (light-emitting diodes) and photoresistors are used as light sources and a light detector, respectively. The principle of operation of this RGB color sensor is the same as most other sensors in the market.

The LEDs are used to emit red, blue, and green colored light, whereas the photoresistor is used to sense the intensity of the reflected light from the object. The photoresistor exhibits photoconductivity and changes its resistance depending on the light intensity falling on it[2]. The resistance of the photoresistor increases when the intensity of the light decreases. For each object whose color is to be detected, the three colored LEDs (red, green, and blue lights) are turned on sequentially, and data is recorded by the photoresistor simultaneously. The output of the sensor is analyzed and interpreted by an Arduino UNO, and the result is displayed as a voltage value.

B. *Testing setup*

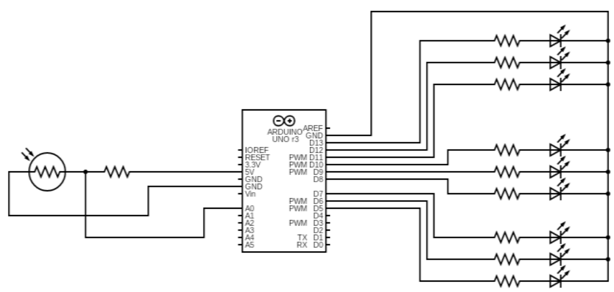

Fig. 1. Circuit diagram of the color sensor

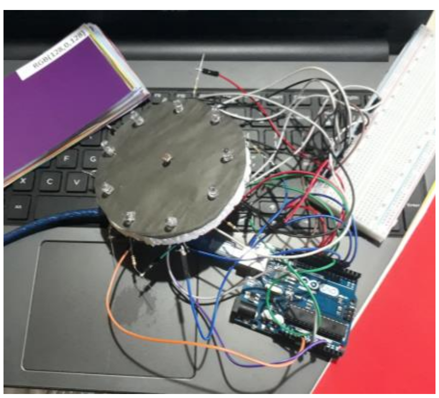

Fig. 2. Testing setup of the sensor without cover

Fig. 1 shows the circuit diagram of the sensor, and Fig. 2 indicates the implemented testing setup of the sensor. As shown in the circuit diagram, 9 LEDs are used for the sensor; 3 LEDs from each red, blue & green colors. 9 LEDs are placed 40° apart. It has been observed that 9 LEDs structure gives fairly uniform illumination to the object. This 9 LED system provides more accurate and precise data related to light intensities. One photoresistor is placed in the middle of the LED circle in order to sense the intensity of the reflected light from the object. 100Ω & 10kΩ resistors are connected in series with LEDs and the photoresistor. A breadboard is used to connect components easily, and Arduino UNO is used as a user-friendly device to make programming easy.

Fig. 3. Testing setup of the sensor with cover

Since surrounding light disturbances also affect the sensor's accuracy, as shown in the Fig. 3 we used a black-colored cover to keep the photoresistor and RGB LEDs covered. In addition, another black color barrier is used between the photoresistor and RGB LEDs to ensure the light is the reflected one from the object, not from the LEDs directly.

C. *Calibration setup*

In the Calibration process, these steps are followed. First, Colour samples with known RGB values in the Fig. 4 are held upon the circuit (LEDs and the photoresistor). Using the Arduino circuit, red, green, and blue LED bulbs are turned on in sequence. Then, the Arduino output voltage values for R, G, and B are recorded. These values are proportional to the intensity of the chosen color and displayed as the operating voltage(5V) into integer values between 0 and 1023. After recording values for color samples, a relation between the output value and the RGB color value (0-255) is established using linear interpolation. The best-fit curve with minimum error is calculated using the LMS method.

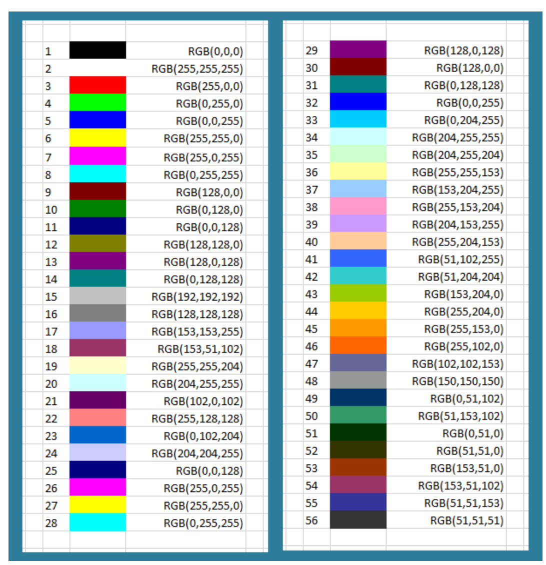

Fig. 4. RGB values of selected colors

D. Verification method and Validation methods

For both verification and validation, we used the same method. From the 50 different colors we used, only 40 colors were chosen for calibrating. The remaining 10 colors were selected for verification and validation. They are held upon the sensor one by one and observe the output RGB values given by the sensor. Then we can compare those values with actual RGB values of the colors and come to the conclusion of whether the sensor is a valid sensor. Also, we can verify the sensor by confirming whether the sensor meets all the initial specifications.

IV. Results

Under this section, Observations, input-output characteristics graphs, calibration results, statical analysis, parameter values selected to model the input-output characteristics, verification and validation results, and the final specifications are presented.

A. Observations

In the calibration process, the voltage outputs are recorded. Then we get 3 readings for each R, G, B value and get the average value. In the Table 1 it shows the average and standard deviation values of the readings. If the standard deviation is very high, the process was repeated. By looking at the values in the Table 1, we can conclude that the reliability of these data is less.

TABLE I. OBSERVATIONS TABLE

RGB Value	Red		Green		Blue	
	Average R	***Standard deviation***	***Average G***	***Standard deviation***	***Average B***	***Standard deviation***
0	808.73	91.05	782.20	65.21	905.69	15.16
51	873.83	34.04	834.63	62.75	921.50	2.12
102	823.50	7.78	830.25	26.91	885.80	7.82
128	691.00	75.73	702.40	50.35	855.00	16.37
153	673.83	61.94	657.60	126.03	823.75	32.33
204	551.20	39.20	625.86	132.31	768.20	33.06
255	527.00	64.44	470.33	41.19	745.33	52.13

The curve for the red value is given in Fig. 5 green value is given in Fig. 6, and the blue value is given in Fig. 7. Using these curves, we can obtain any RGB value of an object.

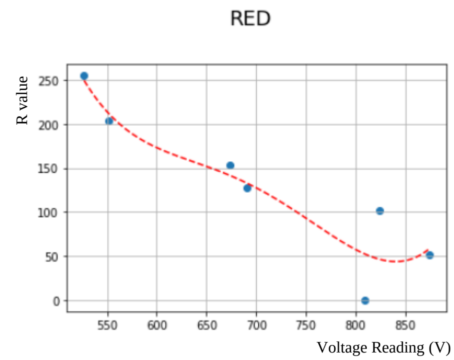

Fig. 5. The variation of R value vs voltage reading

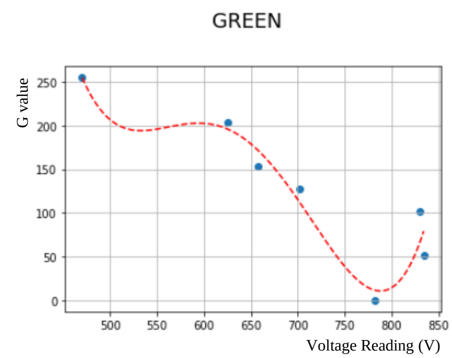

Fig. 6. The variation of G value vs voltage reading

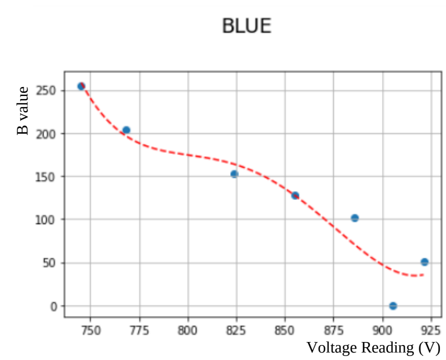

Fig. 7. The variation of B value vs voltage reading

B. Equation of the curve

We select the 4th order polynomial curve from the finalized data as the best fit curve because it has a R^2 value closer to 1. R^2 explains to what extent the variance of one variable explains the variance of the second variable. This will equal 1 for a perfect fit and tends towards 0 for a bad fit.

$$ax^4 + bx^3 + cx^2 + dx + e = 0$$

Table 2 below shows the parameter values of the above equation for each red, green, and blue curves. By looking at the

R^2 values of the table the green and blue curves show a better relationship between input and output values.

TABLE II. PARAMETER VALUES OF THE EQUATION

Parameter	Red	Green	Blue
a	1.0487×10^{-7}	2.5029×10^{-7}	1.8885×10^{-6}
b	-0.2924×10^{-4}	-6.3929×10^{-4}	-6.3236×10^{-3}
c	0.3036	0.60344	7.9371
d	-139.5621	-250.0221	- 4419.8772
e	24202.7691	38625.5069	921693.2122
R^2	0.8648	0.9354	0.9333

C. *Verification and validation results*

It is important to get the coefficients of the equation of each curve to the maximum possible number of decimals for the accuracy of the sensor we design. Averaged readings were used with a python program to obtain these coefficients. Then add the 4th order equation to the Arduino code and use the same system we used for the calibration to the validation process.

The papers with known RGB values are used and compare the results of our sensor with the actual RGB values as given in the Table 3.

TABLE III. COMPARISON BETWEEN TRUE VALUES AND RESULTS

	Red	Green	Blue
True value	**Result**	**Result**	**Result**
0	23	31	15
51	64	62	59
102	132	135	127
128	163	162	155
153	184	186	178
204	260	254	249
255	320	322	319

As the Table 3 all the outputs have deviated to one side from the true value. So the accuracy of the sensor is lower than we initially expected.

D. *Final specifications*

- Ability to detect all R,G,B values ranging from 0-255
- Operating temperature range 0^oC-25^oC
- Operating voltage 5V
- Operating current range 20mA - 30mA
- Response time 15 seconds
- Accuracy 65%-75%

V. DISCUSSION

A. *Difficulties and solutions*

Under this section, we have discussed the difficulties we faced and how we overcame them.

Surrounding light disturbances affect the accuracy of the readings. Therefore we need to keep the photoresistor and RGB LED cover. A black-colored cover can be used to avoid the exposure of the photoresistor to the light outside. It is important to ensure the light is reflected only from the color papers, not from the LED directly. So a black colour barrier can be used in between the photoresistor and RGB LED.

It is important to select colors that have a good variation of r,g,b values. And the readings obtained should be sufficient enough to plot a good curve. So it was difficult to select color papers. So we considered all aspects and selected colors to print.

It was challenging to get the accurate RGB values for the calibration. Even though we need RGB values of the colors, CMYK values are required for printing. So we had to convert all R, G, B values we selected into CMYK and then print. The RGB values of The color papers we created using the computer changed when printing due to some errors in the printers. Since we could not afford an RGB sensor, we were unable to measure the actual RGB values of the papers which we used for calibration. We had to proceed with minor errors. So for some readings, we got high standard deviations. To reduce the effect of errors, we obtained repetitive readings and finally got the average values of the readings.

It was difficult to obtain the best fit curve with minimum errors. We studied R^2 Parameter and selected a curve. As we selected a Quartic regression, the coefficients should be highly accurate to the decimal point. If a slight variation happens, it highly affects the final value of the measurement.

B. *Strengths*

1) the 9 LEDs structure gives fairly uniform illumination to the object: The angle between the LED light path of the sensor and the sample surface is an important factor. Since we used 9 LEDs placed 40° apart in the setup, it gives reasonably uniform illumination to the object, and a fair amount of reflected light intensity dropped on the photoresistor. The effect of height on measurement is also an essential factor to be considered. Therefore the distance between the LED structure and the object is kept at a fixed height of 8cm, which is optimum to obtain more accurate and precise readings.

2) Able to measure the Entire color range: RGB color space comprises more than 16 million colors, which are arranged in a 3D space, where integer values of components R (Red), G (Green), and B (Blue), ranging from 0 to 255, constitute coordinates of this space. In the process of calibrating the sensor, we used a sample of about 40 colors which represents the entire RGB color space. Therefore, this sensor can measure and identify any colour in the RGB colour space.

3) The accuracy of the sensor measurements is not affected by Surrounding light: Surrounding light disturbances is another factor that can affect the accuracy of the sensor. Therefore, a black-colored cover is used to avoid the exposure of the photoresistor to the light outside. Because of the black cover, surrounding lights does not affect the accuracy of the measurements. Therefore, the sensor can be used under any surrounding conditions without affecting the accuracy of the measure.

4) Low cost: The components we have used for this sensor are very cheap and easy to be found. Therefore, this sensor is significantly cheaper than sensors available in the market and very cost-effective.

C. Weaknesses

1) The accuracy of the measurements is moderate: Compared with the sensors available in the market, the accuracy of the measurements of this sensor is much lower. The objects we used to calibrate the sensor are not with the exact RGB values as we expected. There are few deviations from the real RGB value. And, also we could not find the best fit curve for the input-output characteristic graph. The correlation of the graphs is around 0.9. This has affected the accuracy of the sensor. Factors such as the light illumination intensity on the target, the angle between the LEDs light path of the sensor and the sample surface might also affect the accuracy of the sensor.

2) Not water resistant: The sensor proposed in this paper is not designed to be used in applications related to liquids and water. Therefore, the sensor and components are not water-resistant, and contact with water could malfunction the sensor.

3) The circuit is complex to handle: This sensor contains a breadboard, an Arduino UNO, a LED structure and a photoresistor fixed to a rigifoam, and a black cover around the LED structure. All these components and jumping wires make the sensor more complex to handle.

4) High response time: To increase the accuracy of the sensor, we have to keep a LED on for a long time. Therefore, response time takes longer than a commercial sensor.

D. Comparison between the designed sensor and commercial products

The sensor device generates a digital return of red, green, and blue (RGB) light sensing values. It has the ability to detect any color in the RGB color range, which is 0 to 255, but the accuracy is low compared to other sensor devices. This sensor can be used under varying light conditions since the outside environment's light is blocked by a shield. Apart from the Arduino board, the cost is somewhat economical compared to the sensors in the market. The response time is comparatively customizable but higher than other sensor devices. The sensor consists of several components such as Arduino UNO, breadboard, etc. Therefore, it is not much user-friendly compared to the sensors available in the market. Furthermore, the sensor cannot be easily used as a portable device [3],[4],[5].

VI. Conclusion

This report mainly discussed designing RGB color sensors using the principle that all the colors can be generated by mixing the red (R), blue (B), and green (G) colors in appropriate percentages to get the desired color. We used 9 LEDs as a light source and a photoresistor as a light sensor for this suggested method to obtain accurate results. In this sensor, Arduino has been used to control the circuit and get the readings. Python has been used for statical analysis and obtaining the curves and parameters. This report has discussed the principle of operation, designing the setup, calibration method, validation, and verification method. Finally, Observations, input-output characteristics graphs, calibration results, and parameter values are selected to model the input-output characteristics. Furthermore, weaknesses and strengths of the sensor, the difficulties faced, and how to overcome them are discussed. We have provided a comparison of the sensor with other similar sensors available in the market. Some initial specifications could not be achieved as final specifications, and the possible reasons are mentioned in this report.

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