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RGB free colorimeter for sensing and sorting of pigmented spheres

Colorímetro libre RGB para la sensorización y clasificación de esferas pigmentadas

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Abstract

The present work shows the design, development and testing of a first prototype system for classifying color pigmented spherical objects. The objective is the analysis of efficiency and error that digital photoelectric devices can have. Based on the detection of color patterns called RGB model (Red, Green & Blue) the system is composed of a digital color detector sensor TCS3472 controlled by an open source electronic platform Arduino. The ATMega328P microcontroller processes the data obtained by the sensor, which then executes the actions responsible for moving the servomotor that controls the selector mechanism which, in turn, consists of an access and output channel to three containers. An external control panel with four push buttons: start, pause, reset and emergency; the latter configured for the total disconnection of the system in case of possible jamming failures. Finally, the system delivers the results of the sphere separation by color on the control panel and physically in the repositories of the structure.

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Keywords: colorimeter, color sorter, TCS3472 sensor.

Resumen

El presente trabajo muestra el diseño, elaboración y pruebas de un primer sistema prototipo clasificador de objetos esféricos pigmentados de colores. El objetivo versa sobre el análisis de eficiencia y error que pueden tener los dispositivos digitales fotoeléctricos. Basado en la detección de patrones de color denominado modelo RGB (Red, Green & Blue) el sistema se compone de un sensor detector de color digital TCS3472 controlado por una plataforma electrónica de código abierto Arduino. El microcontrolador ATMega328P procesa los datos obtenidos por el sensor, que seguido ejecuta las acciones encargadas de mover el servomotor que controla el mecanismo selector que, a su vez, consta de un canal de acceso y salida hacia tres contenedores. Un panel de mando externo con cuatro pulsadores: inicio, pausa, reseteo y emergencia; este último configurado para la desconexión total del sistema por posibles fallos de atascamiento. Finalmente, el sistema entrega los resultados de la separación de esferas por color en el panel de mando y físicamente en los repositorios de la estructura.
Palabras clave: colorímetro, clasificador de colores, sensor TCS3472.

Introduction

With the vertiginous advance of technology in recent years, various electronic systems have been designed to help automate industrial processes in different fields, such as production, food, manufacturing, maintenance, etc. The classification of objects is part of a production process, in this case, the color of the object is the main parameter to take into account in this process. (Filote Razo, 2016).

A more advanced application of the system is the detection of objects by shape and its application in supermarkets. Here, the cashier has to distinguish several dozens of products without barcodes, such as vegetables, sausages, breads, etc. Remembering all these goods is a heavy task and even more so if it changes every day. Therefore, automated recognition requires a system that can reduce the cashier's workload. (Morimoto, 2018) The development of the present project is accompanied by a previous study of articles concerning the use of color sensors for object classification that have considered a TCS3472 sensor, and that provides perceived wavelength values of light according to the RGB model.

A spherical object has been defined as the subject of study for the classification. This is replicated in 4 bodies with a different color (blue, red, green, yellow). Thus, after determining the model and color of the object, we proceed to establish the mathematical model to be used for color detection based on the saturation of the color and the luminosity reflected on the body.

By being able to classify objects based on their coloration, future applications for this classification system are thought of, being the manufacture of fruit sorting and packaging.

In 2020, a group of researchers from the National University of Colombia developed and evaluated a prototype for measuring the color of fresh vegetables, using DHT11 sensors for temperature and TCS230-3200 for color. Through tests carried out it was deduced that the color measurement with the prototype is dynamic, because it avoids the use of a lighting system, since the color sensor has integrated LED devices. After the analysis of the results it was concluded that the prototype developed by integrating components such as sensors and data acquisition card and free software, allows to evaluate the color in a different way; 2) the average error recorded by the prototype was 15.57 %, lower value than that recorded by the commercial colorimeter was 27.45 %. (Sarria-Dussán, Garzón-García, & Melo-Sevilla, 2020).

Similarly Hermoza Llanos (2018) in his research conducted in Sacha Inchi producing companies in Lima, determines as main objective the design of a peeled fruit sorting system by color. All materials in contact with the seeds were considered as non-contaminating, the final output flow is 200 Kg/h distinguishing between dark brown and almond colored seeds. A TCS3472 RGB color sensor, a vibrating table and an LCD screen were used as materials.

A research conducted in 2018 in Italy to determine the impact of light pollution on a vehicular driver used the RGB sensor type TCS34725 as a luminance meter as it allows the possibility to adjust the data acquisition rate, between very high or low rates the latter range of obtaining is necessary for situations where there is little traffic or partially uninhabited areas in order to reduce the amount of data. (C.D. Galatanu, 2018)

Tests carried out showed that the structure of the system is suitable for modifications to an image processing system capable of controlling the quality of the seeds to be processed. It is concluded that the cost, dimensions and final processing capacity of the system, make it competent compared to other options currently existing in the market, in addition to increasing productivity in the seed selection process, since it translates into shorter production times and therefore greater commercial gains. (Hermoza Llanos, 2018). According to these authors, the electronic color interpretation system that is intended to be realized is feasible and has tools that are within reach such as, for example, the RGB sensor TCS3472, microcontrollers of the ATMEGA series, etc. The communication between these devices and the visualization through a physical graphic interface can be done since, in the analyzed researches, the architecture used and the programming algorithms used can be observed.

Methodology

The classifier system has an RGB sensor, a servomotor, a 7-segment display to visualize the number of hits of the classifier, programming algorithms to meet the main objective which is to classify objects according to color. The RGB sensor is the main element of the system, since it can be used to determine the color of the object, which is not possible without the help of the code. By means of these, the acquired data can be processed and functions can be sent to the actuators to perform the classification procedure. These actuators are the servomotors that direct the object to a specific place according to the detected color. The visual interface is a 7-segment display that shows the count of each classified object. The following figure shows the architecture of the exposed process.

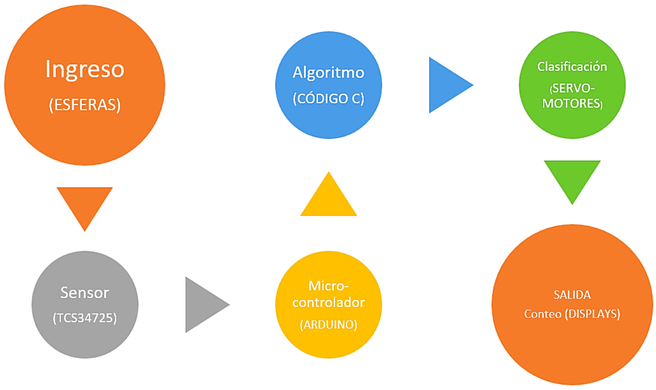

Figure 1 Block diagram of operation

Test objects

Figure 2 RGB color sensor

The bodies selected for sorting are made of wood, because of their easy sizing to the main storage funnel, and the shape that future research will entail. These, at the time of the tests, have a diameter of 2cm and a weight of 70gr covered with blue, green, yellow and red acrylic paint. The importance of these wooden objects lies in the similar and irregular shape of their surface, like a vegetable. And their color, which will inevitably change due to natural aging. These color effects are visible over time and not necessarily at the time of experimentation.

The color of a surface is described by a color composition: red, green and blue. Thus, in a colored image each pixel is represented by a certain value of these components. In the RGB color space, the pixel p (i) is defined by an ordered triplet of red, green and blue coordinates (r(i), g(i), b(i)), representing the red, green and blue light intensities respectively. The intensity value varies from 0 to 255. (A. Kanade, 2015)

Table 1. Color *analysis*

Color	*λ (nm)*	*Colors analogs*	*λ (nm)*	*Color type*
Blue	436-495	Blue Turquoise Blue Violaceous	489.04 380-500	Monochromatic
Red	620-700	Red Orange	600-500	Monochromatic
Green	495-570	Green Blue Yellow Greenish	555-574	Monochromatic
Yellow	566-589	Orange	592-620	Monochromatic

RGB sensorization

This device has the ability to provide a digital RGB return from its incident light in a sharp and accurate manner. Thanks to its integrated infrared filter in the photodiodes along with its high sensitivity, dynamic range place it as an ideal color sensor solution for use under lighting conditions and through attenuating materials. (TAOS, 2012)

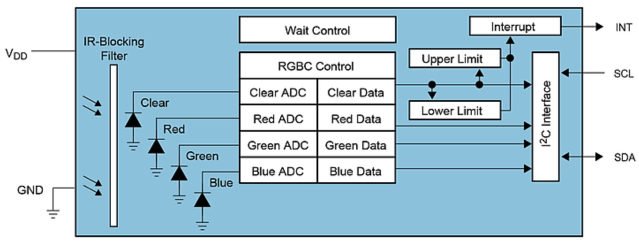

Figure 3. RGB color sensor

The data taken by the RGB sensor are sent to the processing board, where through the Arduino IDE the data will be processed to calibrate the sensor, control the speed of the servomotor and count the sorted objects. It is necessary to carefully set the speed at which to work and install the necessary libraries to avoid problems in the execution of the program.

These algorithms are created through a flow chart shown in the methodology section. The importance of the algorithms is due to the fact that, the classification process will be performed correctly and through tests it will be possible to reduce the margin of error, if any.

The servomotors will be in charge of routing the route with the specific angle to where the classified sphere should arrive according to its color, the programming plays an important role in this stage since it will be the physical basis of the classification.

Through the use of 7-segment displays, the number of objects that have been sorted can be visualized. These are placed with labels to identify which color corresponds to a certain quantity.

Mathematical model

- The parameters taken into account to describe the color are:
- L: brightness
- a: Red/green coordinates where +a indicates red and -a indicates green.
- b: Yellow/blue coordinates in which +b indicates yellow and -b indicates blue.
- c: represents the chroma key.
- h: corresponds to the hue defined as an angle (in degrees) on the color wheel.

Once the color data is obtained, it is compared with other samples to evaluate their differences (Ruíz Martinez, 2002). (Ruíz Martinez, 2002).

If these differences are called ΔL, Δa, y $\Delta b$for the axes L, a and b respectively, the total distance between two colors is given by Δ whose formula is:

$$\Delta = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \qquad (1)$$

With the data acquired from the RGB sensors, it is divided for 255 in order to have values in the range of 0 to 1 as shown below.

$$R' = \frac{R}{255} \quad (2)$$

$$G' = \frac{G}{255} \quad (3)$$

$$B' = \frac{B}{255} \quad (4)$$

With this data, the pitch is calculated with the following formula:

$$H = \begin{cases} 0^0 & \Delta = 0 \\ 60^0 * \left(\frac{G' - B'}{\Delta} mod6\right), C_{max} = R' \\ 60^0 * \left(\frac{B' - R'}{\Delta} + 2\right), C_{max} = G' \\ 60^0 * \left(\frac{R' - G'}{\Delta} + 4\right), C_{max} = B' \end{cases} \quad (5)$$

The brightness is calculated depending on the luminosity:

$$S = \begin{cases} 0\,, & \Delta = 0 \\ \frac{\Delta}{1 - |2L - 1|}, \Delta <> 0 \end{cases} \quad (6)$$

Where:

S: saturation.

Δtotal color differential

L: Luminosity.

For the calculation of the percentage error, a standard statistical formula is used in which the actual value and the approximate value are used:

$$e = \frac{|V_{REAL} - V_{apox}|}{V_{REAL}} * 100\%$$
(7)

System development

Principle of operation

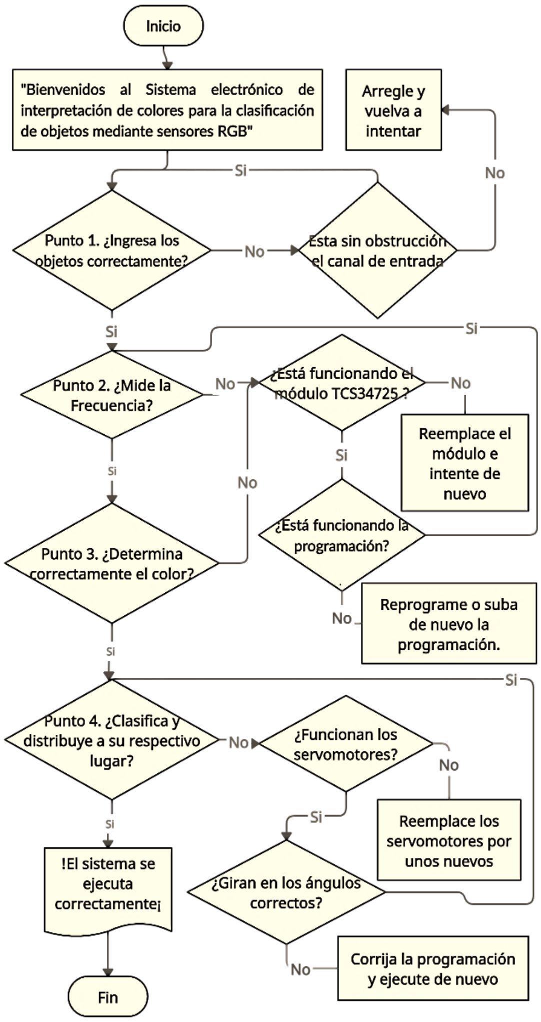

Figure 4 Control Program

In this way, the principle of operation of the system is represented. Thus, the sphere enters the upper part of the structure through a circular duct of 2.3cm in diameter until it reaches the TSC34725 sensor. This is in charge of measuring the frequency of the visible spectrum, determining its color. If there is a problem such as external light leakage inside the cavity, the system will not work properly and will show values not established in the programming, i.e. an alert. Therefore, the user must re-enter the object to be classified and verify that there is no filtration of ambient light inside the mechanism. If the measurement made by the sensor is within the programmed parameters, the sphere will move to the classification stage. Here, the servomotor will move within the four positions previously defined and depending on the value provided by the sensor. Each one will be taken to the containers according to its color. For this action a Me-0634 detector sensor is provided, which allows the system to be automatic, even if it has a manual mode.

Since the spheres are sized according to the design, possible blockages are reduced. Even so, it could be the case that the servo runs through the propeller prematurely, then it will be necessary to intervene with an anti-jamming function. The second and third points focus even more on the action of the RGB sensor TSC34725. This is responsible for measuring the frequency of the visible spectrum by extracting the color of the sphere. As the same can have external variations such as light and ambient temperature, the system is designed to cover and place the sensor on the basis of displacement of the sphere to reduce to the minimum possible sudden changes. Therefore, if it were to fail while controlling these parameters, a complete module replacement would be necessary.

Finally, this point four focuses on the mechanical part of the system, which includes the servomotors, may have failures either programming, physical and electrical, these should be corrected first by programming, if this process does not work, the status and operation of the servomotors should be verified.

Table 2. Main components of the system

Hardware	*Reason for selection*
Sensor TCS34725	It has an activatable IR signal filter.
ATMega 328P	High performance, low power consumption and optimized for C compilers.
HiTec Servomotor	Load handling up to 4Kg
7-segment display	Efficiency and implementation

Potentiometer 50kΩ	For adjusting the current flow.

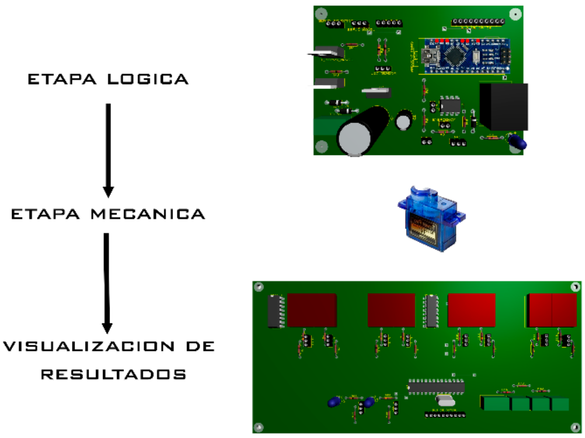

Figure 5 Electronic structure of the system

The electronic boards define the communication structure of the classification system by stages. In this way the logic stage, contains the programming code (algorithms) that allow the proper operation on control parameters that exerts on the physical components, i.e. servos, mechanical stage that according to the sensor data locates the objects (spheres) in the place established in the structure, in angle and time.

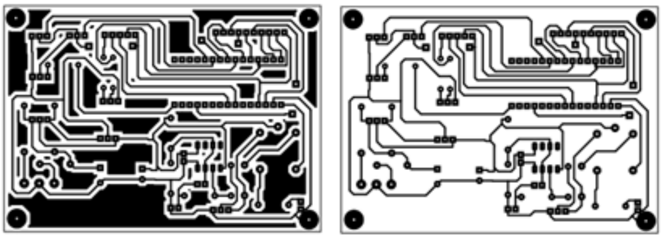

Figure 6 Electronic control circuit and serial connection

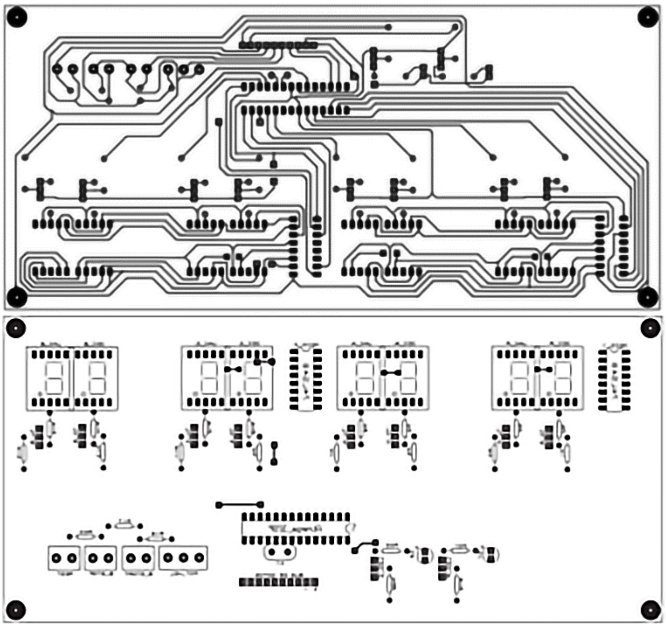

Figure 7 Control and display panel circuit.

After the electrical communication tests on the breadboard, the printed circuit boards are designed. These provide stability and reliability to the control and data visualization system, since the movement to which it is exposed by the servomotors can directly affect the connection and its collateral effects.

Source code and programming

The systematization of the sensor, the processing of the data obtained by it and the configuration of the selector mechanism is performed on a programmable Arduino Nano board, with the use of the Adafruit_TCS34725 library for the interpretation of the recorded values.

First, the necessary libraries are included according to the chosen sensor, this is done from the IDE library. Then, we proceed to declare the variables for the counting of red, yellow and green spheres, additionally we create a buffer where the counting of the spheres is stored to send them by serial communication to the displays.

At this point, the variables in which the hit count of classified spheres will be stored and a buffer for displaying the hits on the screen are established.

Number of occurrences or events

Counting variables
int countR=0;
int countN=0;
int accountG=0;
int accountA=0;
byte buf[4];

Then the pins to which the modules will be connected are declared, which consist of LEDs for the start and end of the process, as well as the button that allows the system to start.

Table 4. *External Actions*

Control Outputs
const int led_start=3;
const int ledSensor=4;
const int led_pare=5;
const int buttonStart=6;
const int enced;
serovo=13;

At this stage the code that is executed once (void setup) is set. It is usually set to mark general operating parameters such as module startup and preconfigurations. There may be more stages of the same type called functions.

Now, for the motion control, the pins for the servomotors are assigned, in this case the pins (7 and 8) for PWM outputs will be used. Afterwards, the Arduino serial communication is declared at the 9600 bits per second (baud rate) required for the microcontroller.

Table 5. *Position Control*

Servo control
topServo.attach(7);
bottomServo.attach(8);
Serial.begin(9600);

In the "void setup" the programming that does not depend on repetitions is established, that is to say that they will be executed only once. A clear example is when the operation range is defined for each frequency (color), from there it is calculated for all those used (red, green, blue and yellow) which in turn will be stored in a buffer parameter (buff) the number that will be recorded. If one of the conditions is not met, the counter will return its previous value, i.e. unchanged, this is because it can represent values with variation due to external changes such as ambient brightness. In case of errors, the hexadecimal code is printed in the serial monitor, besides serving as an aid to verify that it is working correctly.

In this part, you set the limits of the data obtained from the sensor that the algorithm accepts to describe the color. If one of the conditions is not met, the counter will return the last correct value. If the received data is outside the parameters, the received value is printed on the Arduino IDE serial monitor.

Table 6. *Color detection*

Color ranges
if((r < 2.15) & (r > 1.8) & (g < 0.75)&(g > 0.45)){   color = 1; // Red

```
  buf[0]=1+countR++;
  cont=0;
}
if((g < 1.4) & (g > 1) & (b < 0.6)&(b > 0.35)){
  color = 2; // Yellow
  buf[1]=1+countN++;
  cont=0;
}
if((r < 1.15) && (g > 1.20) && (b < 0.8)){
  color = 3; // Green
  buf[2]=1+countG++;
  cont=0;
}
if ((r < 1) && (g < 1.2) && (b > 1)){
  color = 4; // Blue
  buf[3]=1+countB++;
  cont=0;
}
else{
  cont++;
  if(cont==5){
  /*buf[0]=accountR++;
  buf[1]=countN++;
  buf[2]=G++ account;
```

```
    buf[3]=countB++;*/
    output=0;
    cont=0;
    }
  }
  Serial.write(0xff);
  for(int i=0;i<sizeof(buf);i++){
     Serial.write(buf[i]);
     delay(2);
  }
  return color;
}
```

In this stage, functions are created and executed in loops depending on the data obtained from the sensors. It starts with the analog and digital readings from the RGB sensor and the power button, respectively. An anti-bounce function is created so that the state of the button remains stored applying a delay of 20 milliseconds, this allows that when the button is pressed, only one state remains stored and not the other states that are presented at the moment of short-circuiting positive and negative with the button.

After the previous function we proceed to perform an 'if' conditional where it is indicated if the status of the button is 1 or if the infrared LED detects a sphere, the main function called "main_system" will be executed, otherwise the function "OFF" will be executed. When using a push-button, an anti-bounce function must be performed in the code since the residual currents generated when pressing it can send wrong values to the board, this function provides a 20ms delay that allows saving only one value at the moment of pressing the push-button.

Table 7. *Off Control*

Shutdown Control

void loop() {
 	
  ReadBall=analogRead(DetecBall);
  status=digitalRead(startButton);
  //ANTI-REBOUND FUNCTION
  if(status==HIGH && statusPrevious==LOW){
    output=1-output;
    delay(20);
  }
  statePrevious=status;
  if(output==1llReadBall<7){
  systemPrincipal();
  }else{
   shutdown();
  }
}

Table 8. *Color libraries*

Acquisition of sensor readings	Description
ReadBall=analogRead(DetecBall);	Take readings from the sensor

	connected to analog pin A1.
Servo movement	Description
digitalWrite(encedico_servo, HIGH);	Controls the section that transports the sphere to one of the containers.
Sensor data storage	Description
tcs.getRawData(&red, &green, &blue, &clearcol);	Stores the RGB spectrum data in the assigned variables for further processing.

Table 9. HTML *color analysis*

HTML	#7828
RGB (r,g,b) B	(120, 40, 140)
CMYK(c,m,y,k)C	(70, 100, 0)
HSV (h, s, v)	(288^0, 71%, 55%)

Violet: between 420 and 400 nm wavelength. Attenuated violet: between 400 and 380 nm, it constitutes a band with a double connotation, because on the one hand it is considered as part of the visible violet light and on the other hand it is part of the ultraviolet radiation (UV). Visible ultraviolet light: between 380 and 310nm. Although by definition UV radiation is not visible, a part of this radiation is called UVA or near ultraviolet.

The instrument (colorimeter) is composed of two devices: the control and sorting device. The first, composed of controls that allow the system to activate, pause, restart, accelerate or stop its operation. The second has a section for transporting, sensing, transporting and locating.

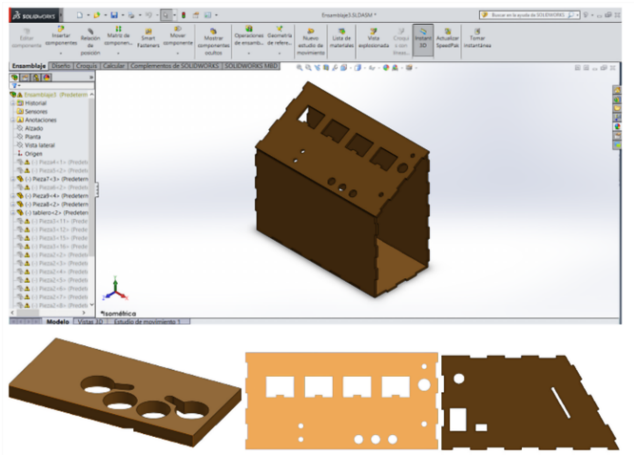

Figure. 5 3D CAD control

Table 10. *Elements and* symbology

	ment and function in the system
	gment display: counters
	en Led: Indicates that it is working
	Led: Indicates that it is stopped
	ton: Starts the system
	ton: Pauses the system
	ton: Resets the system
	entiometer: Accelerates or slows d speed
	ton: Emergency
	Led: ON = emergency; OFF = normal

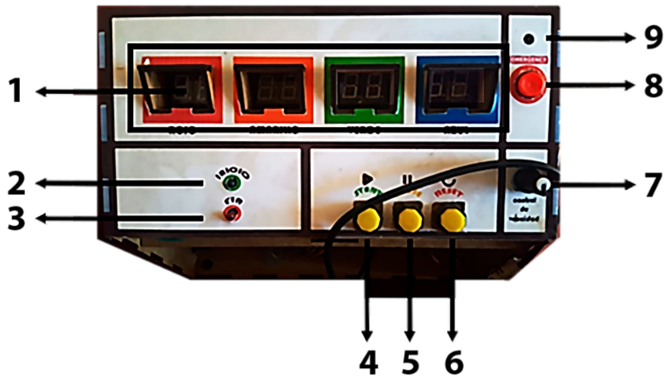

Figure. 6 Control and visualization implementation

The transport section, designed specifically for the test objects and their dimensions, carries the spheres to the duct in which the digital sensor is located. Under these placement conditions, the component extracts the colors of each of the objects arranged in the chute as they arrive. When the color is known, the servomotor locates them at the correct angle in their respective repository, and in parallel sends a signal to the optoelectronic devices for counting and numerical display.

Results

The group of non-degraded color tests chosen, allows us to establish the degree of efficiency in the specific detection of the solid colors of a wide gamma that it is understood would be detected. In the end, this allows us to know if the system composed mainly by the sensor based on the criteria of sensitivity and luminosity configuration, as well as its location, are acceptable for this type of process. For this, three primary colors and a secondary one are chosen, which will allow us to know the number of hits in the detection of these essential colors.

On the number of tests (1089 per sphere) separated in ranges of 99 consecutive repetitions for each one. And, taking into account the effectiveness of the sensor that is given by the saturation and luminance of the object, as well as the configuration divided into three stages, with percentages of tone in the saturation and luminance of 50%, 75%, 100%, obtaining the following:

The unforeseen initial conditions between 0 and 50% allow us to perform a test with error reduction and adequate illumination and saturation conditions.

Table 6. *Hit and Miss T1 (50%)*

Samples	Colors	Hits	Saturation	Brightness	Error
1089	Blue	1016	50%	50%	0,060%
	Green	1035			0,049%
	Yellow	1023			0,060%
	Red	1009			0,073%
Total		**4083**	**Total**		**0,242 %**

In all the events, the saturation and luminosity are maintained. And from this, a total of 273 failures are obtained divided into 73 for the blue color with an error percentage of 0.060%, 54 for the green color with an error of 0.064%, 66 for the yellow color with a percentage error of 0.066% and 80 failures for the red color with an error percentage of 0.073%.

Table 7. *Hit and Miss T2 (75%)*

Samples	Colors	Hits	Saturation	Brightness	Error
1089	Blue	1031	75%	75%	0,053%
	Green	1024			0,059%
	Yellow	1036			0,048%

Red	1031		0,053%
Total	**4119**	**Total**	**0,213%**

In all the insertions the system maintains the saturation and luminosity stable with the parameter set to 75% and this results in a total of 4119 hits and 237 misses divided into 58 for the blue color, with a percentage error of 0.053%, 65 for the green color with an error of 0.059%, 53 for the yellow color with a percentage error of 0.048% and 61 misses for the red color with an error percentage of 0.053%.

Table 8. *Hit and Miss T3 (100%)*

Samples	Colors	Hits	Saturation	Brightness	Error
1089	Blue	1071	100%	100%	0,016%
	Green	1054			0,032%
	Yellow	1066			0,021%
	Red	1067			0,020%
Total		**4258**	**Total**		**0,089%**

Stabilizing the brightness and saturation to 100%, the system shows no variation in this factor, and from this we obtain a total of 98 failures divided into 18 for the blue color, with an error percentage of 0.016%, 35 for the green color with an error of 0.032%, 23 for the yellow color with a percentage error of 0.021% and 22 failures for the red color with an error percentage of 0.020%.

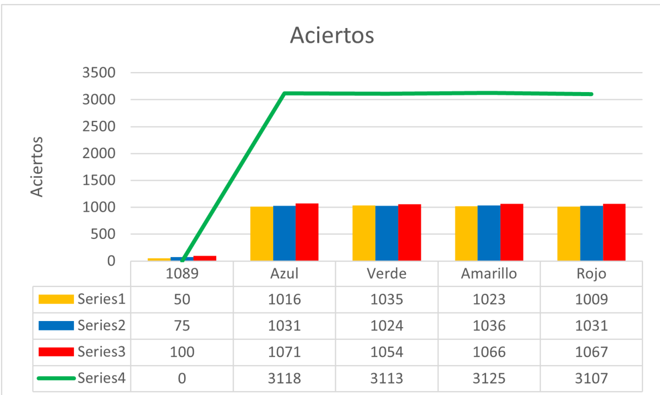

Figure. 7 Efficiency increase

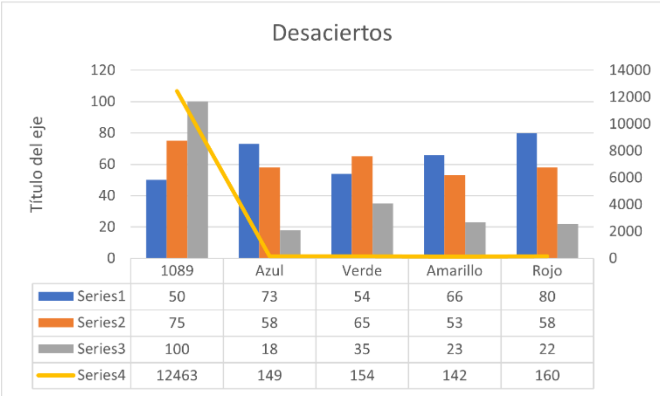

Figure. 8 Error Decrement

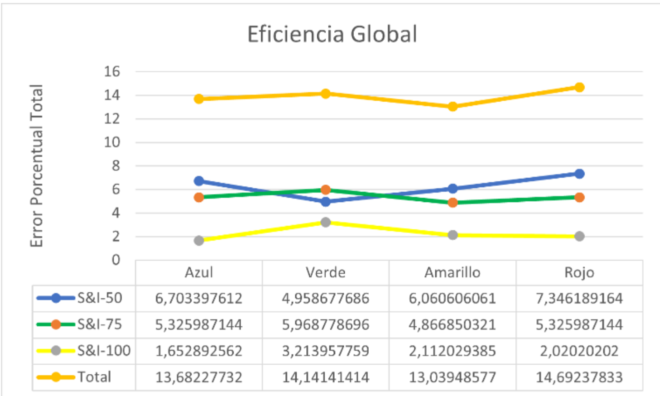

Figure. 9 3D CAD classifier

Color Yellow

Series 1, limited to 50% sensitivity and luminosity, detects 1023 blue spheres out of a total of 1089 tests of this color on the sphere. That is, a difference of 66 misses corresponding to only 6.1% error in the expected sensing, which, on the contrary, shows 93.9% effectiveness in its determination (efficiency).

Series 2, defined at 75% sensitivity and brightness, detected 1036 blue spheres out of a total of 1089 tests of this color on the sphere. On the other hand, there were 53 misses, which corresponds to 4.9% of failures in detection, with 95.1% of effectiveness in detection.

Series 3, established at 100% sensitivity and luminosity, detected 1066 blue spheres out of a total of 1089 tests of this color on the sphere. That, in its defect presents 23 errors that correspond to only

2.1% of error in its discovery; with a 97.9% of effectiveness in its detection.

Color Blue

Series 1, limited to 50% sensitivity and brightness, detects 1016 blue spheres out of a total of 1089 tests of this color on the sphere. That is, a difference of 73 misses corresponding to only 6.7% error in the expected sensing, which, on the contrary, shows 93.3% effectiveness in its determination (efficiency).

Series 2, defined at 75% sensitivity and brightness, detected 1031 blue spheres out of a total of 1089 tests of this color on the sphere. On the other hand, there were 58 misses, which corresponds to 5.3% of failures in detection, with 94.7% of effectiveness in detection.

Series 3, established at 100% sensitivity and luminosity, detected 1071 blue spheres out of a total of 1089 tests of this color on the sphere. That, in its defect presents 18 errors that correspond to only 1.65% of error in its discovery; with a 95.1% of effectiveness in its detection.

At the end of the test series 1 with an intensified sensitivity and brightness from 50% to 100% shows an increase of 5.1% in the detection of the number of blue spheres, i.e. 55 additional spheres with an equal and inversely proportional reduction of the error.

Color Red

Series 1, limited to 50% sensitivity and brightness, detects 1009 blue spheres out of a total of 1089 tests of this color on the sphere. That is, a difference of 80 misses corresponding to only 7.3% error in the expected sensing, which, on the contrary, shows 93.3% effectiveness in its determination (efficiency).

Series 2, defined at 75% sensitivity and brightness, detected 1031 blue spheres out of a total of 1089 tests of this color on the sphere. On the other hand, there were 58 misses, which corresponds to 5.3% of failures in detection, with 94.7% of effectiveness in detection.

Series 3, established at 100% sensitivity and luminosity, detected 1067 blue spheres out of a total of 1089 tests of this color on the sphere. That, in its defect presents 22 errors that correspond to only 2% of error in its discovery; with a 98% of effectiveness in its detection.

Color Green

Series 1, limited to 50% sensitivity and brightness, detects 1035 green spheres out of a total of 1089 tests of this color on the sphere. That is, a difference of 54 misses corresponding to only 4.9% error in the expected sensing, which, on the contrary, shows 95.1% effectiveness in its determination (efficiency).

Series 2, defined at 75% sensitivity and brightness, detected 1024 green spheres out of a total of 1089 tests of this color on the sphere. On the other hand, there were 65 misses, which corresponds to 5.9% of failures in its detection, with 94.1% of effectiveness in its detection. Series 3, established at 100% sensitivity and luminosity, detected 1054 green spheres out of a total of 1089 tests of this color on the sphere. That, in its defect presents 35 misses that correspond to only 3.2% of error in its discovery; with a 96.8% of effectiveness in its detection.

Testing of the classification system

Figure 10 Complete sorting device

The classifier system contemplates a sequential scheme where there is a point of entry of the spheres, then it is directed with an actuator to the TCS3472 sensor, this is responsible for determining based on algorithms a correct decision (code), determining the position of the servo in the following degrees (red 58°, yellow 92°, green 134° and blue 175°), at the end the sphere descends to be placed on the base of which were presented f, as follows:

The spheres, by complying with regular proportions and in accordance with the design of the structure, did not present inconveniences as expected in the circuit of travel of this one, giving an optimal work flow for the operation tests in the first 152 samples. To guarantee a better result, a stopper was added in the ejection zone so that it does not hit the surface of the base and consequently there is no greater wear on the paint.

In test sequence 153, the sorter jammed, requiring the emergency button to be pressed to bring the prototype to a complete stop. This behavior was repeated in a subsequent range of 130 to 160 runs on the mechanism.

When running the 752 test, the classifier suffered the jamming of a green sphere, being necessary to press the emergency button to stop the mechanism, however, it got stuck in its cavity, so it was necessary to restart the system and disconnect the power of the prototype to unjam the button.

Conclusions

The use of the sensor itself, the white LED, helped to avoid the principle of color saturation, which supports the principle of luminosity, which contributed to the fact that by bouncing the light from it on the sphere, the real wavelength value of the color used on it can be obtained. At the end of the test series 1 with an intensified sensitivity and luminosity from 50% to 100% presents an increase of 5.1% in the detection of the number of blue spheres, i.e. 55 additional ones with an equal and inversely proportional reduction of the error.

At the end of the test series 2 with an intensified sensitivity and luminosity from 50% to 100%, there was an increase of 1.7% in the detection of the number of green spheres, i.e. 19 additional spheres, with an equal and inversely proportional reduction of the error. At the end of the test series 3 with an intensified sensitivity and luminosity from 50% to 100%, there was an increase of 3.9% in the detection of the number of blue spheres, i.e. 19 additional spheres with an equal and inversely proportional reduction of the error.

At the end of the test series 4 with a sensitivity and luminosity intensified from 50% to 100% presents an increase of 5.3% in the detection of the number of blue spheres, i.e. 58 additional spheres with an equal and inversely proportional reduction of the error. The tests performed were able to determine that the higher the percentage of hue, saturation and luminosity, the greater the number of spheres classified. With a percentage of 100 % in each of the above mentioned parameters, the error could be reduced from 6.26 % to 2.27 % with respect to the average error among all colors.

The saturation of the spherical object was an important factor in the classification. The blue color is greatly affected by this parameter, since at first it had an incidence of error equal to 6.70 % with saturation equal to 50 %, which could be reduced to 1.74 % with a saturation of 100 %. The mechanical prototype, although it works properly in 96%, since it has only two displays for each color to count the number of hits, it does not allow to display more than 99 tests with positive results continuously for each one before having to restart the system.

When the emergency button got stuck and the system was continuously restarted, it was determined that the cavity that houses it is narrower on the inner edge due to a fault in the construction of the container, making it necessary to replace it with a switch that provides more safety in its operation because the mechanism does not interact with the structure that contains it.

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