Automatic Classification System by Color of Plastic Bottle Caps (SISAC)

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Abstract. The following project presents an autonomous system of classification of objects by colors which it is applied to the caps of plastic bottles, emulating an automated work cell, which serves to students to know the operation of industrial processes, from construction, programming and even maintenance point of view. The entire project consists of the design of a conveyor system which has a sensor to identify colors, and actuators which allow the caps are correctly classified in the containers according to its color. The work cell was built in a modular way in such a way that in the future it can be adapted to other work cells and simulate flexible manufacturing cells, since it can be reprogrammed not only to identify by colors but also by sizes. Besides, the pieces were built using the 3D printer and the laser cutter in order to use the tools of the laboratories of our institution in the construction of elements for future laboratory equipment which will strengthen the electromechanical program.

1. Introduction

The next work shows the development of a system to select objects by color, using free software and hardware, reducing construction costs.

The system comprises three main parts, the distributor of covers, the conveyor belt and the selector, in the case of the distributor it is a mechanism that ensures that one cover passes at the same time, the conveyor belt carries the covers to the selector, and in that sensing process is carried out; Then, it reaches the selector that is responsible for locating the lid in the corresponding place according to the color.

There are multiple similar works, with some differences compared to ours, such as Padilla Magaña J, [9] which builds a system for selecting lemons by color for the University of La Salle in Bolivia, here uses a CMycam5 PixyCam vision sensor, which with the design that identifies, allows the identification of three colors, for the case lemon green, yellow and light green, leaving many restrictions for new jobs on the same platform, another work is that of Arenas Campoverde Alfredo, [10] which also used vision classifies soda caps as well as this work, but it only does it for 4 colors and the system is closed to the possibility of new colors, since they deliver a module of use of hardware
and software closed, in the work of Zhaokun Wang, Binbin Peng, Yanjun Huang and Guanqun Sun [11] of the School of Mechanical Engineering of Nanjing University of Science and Technology of China and the Department of Mechanical and Mechatronics Engineering, University of Waterloo of Canada, in December 2018 they present a classification of 7 colors for the recycling of plastic bottles, also using artificial vision, which increases the costs with the use of the cameras, and also leaving a closed job since it is for the solution of a particular problem, other works that use the TCS3200 as a sensor [2] such as that of Efraim Gregorio and Benny Achmad of the Faculty of Information and Information Technology of the Gunadarma University of Indonesia [12] that uses this sensor to compare colors in a quality process of products, it is very good although you have to feed the system initially and it will always compare color to color, it means you don't select the objects, but compares them with a single predetermined color; and thus a sweep continues and multiple works aimed at solving specific problems will be found, the work of Amitesha Sachdeva, Mahesh Gupta, Manish Pandey and Prabham Khandelwal [13] of Department of Mechanical Engineering SRM University, Modinagar Ghaziabad, can also be observed India, who built a robot arm that selects objects of various colors, however make it clear that the system works for the colors red, green and blue, leaving the system limited.

The objective of this work is to leave a platform on which the student can interact with it, that can program it and detect as many colors as possible, based on groups of 6, since the conveyor belt is designed to separate 6 colors at the same time, the work shows how the TCS3200 sensor signal is received and there is an example of programming for some colors, giving the necessary tools for the student based on the graph and the example algorithm, to develop new algorithms that carry it to the detection of new colors.

Finally it is worth saying that professional stations [3], cost up to 4000 US dollars, while this platform does not exceed 500 US dollars.

2. Materials y methods

2.1. Problem statement

Without a doubt, as the industry grows, it requires new technologies, automatic processes and technological development. For this reason, it is necessary to carry out investigations and constructions with technology that allow speeding up and reducing costs in industrial processes. This project aims to achieve the aforementioned through automation, in a process that is usually done manually in small industries, the classification of objects by colors.

For the Technological Institution Colegio Mayor de Bolívar, this project becomes a work in accordance with the policies of Colciencias that seeks to change the priorities of the traditional policy in which the emphasis is on the generation of knowledge rather than on its transfer and application [5], therefore, it is a project which does not generate new knowledge, but it applies that existing knowledge with autonomy and own criterion.

On the other hand, this project allows and promotes the generation of own technology in the institution which is translated into a low-cost endowment for the electromechanical laboratory. Likewise, it can positively impact the development of the city and the region by training students with the example of making their own tools tailored to the needs. Hence, the question arises: Can industrial solutions be given to the problem of selecting materials by colors with the tools that the institution has, such as Solid Works, 3D printer and laser cutter?

This is a technological development project; therefore it is an applied research, where acquired knowledge and existing theories will be put into practice.

To build an automatic system for classifying objects by colors at low cost as an initiative to equip the ITMB’s Electromechanics laboratory with useful tools for teaching-learning and generating own technology, the following methodology is followed (see figure 1), in item 3 each of the steps of the methodology is described.
3. Phases applied to the construction the prototype

3.1. Designing the cell using CAD techniques, for this case Solid Works.

At this stage, the detail of the morphology of the cell was done. The computer-aided design program Solid Works [1] was used for this work, software with which the institution has an academic license, and hence the construction plans resulted.

Basically, the system is composed of three fundamental parts, which are: the cap distributor, the conveyor belt where the color sensor is located, and the selector [3].

The distributor (see figure 2a) is responsible for providing the conveyor belt covers ensuring they are separated and lying down. Also, it controls the time between cap and cap and it has a rotating system that ensures that one cap passes at a time, and an internal mechanism that prevents the caps from jamming when the storage part is full. Until now, it works very well, however, a new design is being worked on, which facilitates the feeding of the distributor, since at this time, the prototype is done manually.

![Figure 2. Distributor designed in Solid Works (a.), Real Distributor (b).](image-url)
Each piece was machined in a laser cutter and it was thought that some materials were transparent for academic reasons, since in this way we could visualize the mechanisms and their operation. The distributor works with truncated standard servomotor, so that it has a 360 degree turn, here it is not of interest to control angle, but speed.

The next fundamental part is the conveyor belt (Figure 3). In this case it was not manufactured, although this is possible and as a result, costs are lowered. This project used a band which we had, for this reason there is no emphasis on the construction of it.

However, it is highlighted that the system where the sensor is located that serves for the identification of colors is on the band, also it is a presence sensor, which helps control the entire system. The band is controlled with a simple PWM, and in this way it avoids jams when sensing the color of the cap.

![Figure 3. Conveyor belt](image)

Last but not least, it is the selector, whose job is to get the cap of the identified color to the corresponding container (Figure 4), and in this way the process is finished.

![Figure 4. Rotary selector.](image)
3.2. Sensors and actuators

In this stage the actuators, such as motors, servomotors, and other elements necessary for the operation of the cell were determined. They will not be detailed, since it is not the focus of this article. However, there is a lot of literature on these devices. Basically, the system consists of a motor reducer, which is responsible for moving the conveyor belt; a standard micro servo which is responsible for stopping the cap on the conveyor belt at the time of sensing; a standard servomotor that gives mobility to the distributor and a servomotor of 9Kg * cm that is in charge to give movement to the selector. In this case the position control is necessary to be able to locate each cap of each color in the allocated compartment.

Also, the most suitable sensors for the task were selected, since the system is autonomous, the basis of its operation are the sensors, and moreover the associated electronics was added, in which Arduino technology was used for the specific case.

After several tests, it was decided to identify the color of each cap by using the RGB color sensor module TCS3200 [2] (Figure 5), compatible with Arduino technology. It is an economic sensor, easy to use and above all that, it worked well for the assigned task.

The other sensor used is an infrared presence sensor reference E18-D80NK [6] (Figure 6), and this is used when the cap starts to enter the sensing area. The order can be given to the micro servo that stops the cap for 300 milliseconds so that the TCS3200 can read and perform the processing on the Arduino.
3.3. Developing a modular design that facilitates the maneuverability and safe use of the prototype to locate the system

Having already the design and the planes of the pieces together with the location of the actuators and sensors, as well as the associated electronics, we proceed to the construction of each of the elements that make up the cell. It is intended that the vast majority of elements can manufacture using the 3D printer. However, the drawings are not shown in this document because the number of pages is limited but if any design is required, the author can be contacted by email. Consequently, only figure 7 is shown as evidence.

![Figure 7](image-url)  
*Figure 7. View of some of the planes used for the construction of the prototype.*

3.4. Programming the electronic cards that control the system

Having already assembled all the elements of the cell, and each sensor and each actuator being in place, we proceed to the programming of the system, which when using the Arduino control cards as a
base, free software will be used for its programming. The result is already the cell working as a system for selecting objects by colors.

Basically, the system starts to work and when the cap is detected by the infrared sensor, it is the signal to activate the micro servo that is located to stop the cap for a period of time and the color sensor can take the information, which will be processed on the Arduino card, and since the algorithm has determined what color the cap is, the order is given to the servomotor that is in the selector to guide the cap to the assigned tank. Currently, there are no security systems as interpreting that there are no more caps, or that there are bottlenecks in the band. However, this work is underway for the next version.

3.5. Corroborating the proper functioning of the prototype through the design and application of functional tests of the system
The functional tests prepared to check the operation of the built system are below.

The results of the application of the tests are presented in the results section.

| Table 1. Operating tests of the cell |
|-------------------------------------|
| **Test design**                     |
| Collecting data with TCS3200 sensor exposed to ambient light and without any objects present in the band |
| Gathering data with TCS3200 sensor exposed to ambient light and objects present in the band |
| Collecting data with sensor TCS3200 located on a tunnel that hides the caps from the ambient light when they are sensed and any object presents in the band |
| Gathering data with sensor TCS3200 located on a tunnel that hides the cap of the ambient light when they are sensed and objects present in the band |

4. Results
In this section it will be shown in more detail how the TCS3200 sensor was able to take the information more effectively, thus achieving close to 100% efficiency at the time of selecting the caps.

The main result is the operation of the prototype, making the selection of each of the caps and placing them in their assigned deposit according to the color: red, blue, green, yellow, white or black. These colors were selected for this specific case, showing the great variety of colors it can face.

This prototype, unlike the commercial ones at the educational level, gives the possibility of simultaneously selecting up to 6 colors, but leaving open the possibility of including new selection of colors by adjusting the algorithm. In this way, the possibility for the student to interact with the system is open, since it can be reprogrammed.

Then, it will be shown in more detail how we worked with the TCS3200 sensor, the data that was taken and how the input data was improved.

It was selected as a sensitive element the light, in the visible range (400 nm - 700 nm) the TCS3200 that transforms the perceived light intensity into frequency. This element can be configured to work with red, green, blue or any filters [7]. The microcontroller, in this case an Arduino UNO card, configures the sensor and takes 100 measurements in approximately 1.2 seconds in order to make a statistic because it was found that with a single reading there were errors of up to 10%, since with the taking of the 100 measurements it was reduced to 0.
The first tests were done exposing the sensor, being exposed to ambient light, and the results showed a great variety of interference. The sensor takes RGB readings; this means the range of red, green and blue light of the element that will measure, or the light that is affecting the sensor. For the case shown in Figure 8, the sensor is without the presence of an object. The result would be that there is no object, but it can be seen how the signals are intertwined. However, the tendency is that the strongest signal is green, followed by red and finally blue.

**Figure 8.** Data collected with the TCS3200 sensor in a natural environment.

On the other hand, it is not fulfilled throughout the course of the 100 samples; in fact it occurs in 79% of cases. These variations mean that if only one reading is taken, there is a 21% chance of error. In order to improve this situation, it was decided to control the environment, which is nothing more than tunnelling on the conveyor belt (see figure 9) to avoid external light as much as possible, and thus improve the sensor data collection.

**Figure 9.** Sensing tunnel on the conveyor belt
After several tests, the improvement in the signal for the 100 samples was noted, going to 96% of hits (see figure 10), both without the presence of objects, and with the presence of the caps.

Figure 10. Data collected with the TCS3200 sensor in a controlled environment

Having already eliminated most of the noise, we proceeded to do the same for the identification of each of the colors, since with the improved signal, the selection algorithm could be programmed, passing for the case of blue 85% effectiveness to 100%, as can be seen in the comparison of the graphs in figure 11. The upper graph is in natural environment and the lower graph in controlled environment, even for some colors the signals are much more constant and stable.

Figure 11. Data comparison for blue color, superior in natural environment, lower controlled environment
It is valid to add that the program was made in a modular way, or with subroutines, which makes the main program simply have the correct sequence of the call of these subroutines, as can be seen below.

```c
//********************main program***********

void loop(){
presencia(); //the presencia subroutine is called that identifies if there is an object. (IR sensor)
if (pre==1){ //If pre equals 1, it is because there is an object. and continues to identify the color.
p=60; // The mini servo is sent at 60 degrees for the color sensor data capture.
servomini(); //With p = 60, take the mini servo to this position.
delay(1200); // data collection time, and is the maximum time required for the selector to go to its destination.
calcu ( ); // Color selection algorithm
p=20; // The mini servo is sent at 20 degrees to let the object pass.
servomini(); //With p = 20, take the mini servo to this position.
servom(); // The selector servo motor goes to the position that the calculo subroutine sends, according to the identified color.
}
//************************************************************
```

With this data collected by the TCS3200 sensor, the algorithm for the selection of colors was carried out, for example, observing the behaviour of figure 11 at the bottom where the tendency is clear that red is greater than green and green greater than blue, it can be determined for this case that the object is blue, in the same way the analysis is done for each of the covers and the result is shown below, it should be noted that for reasons of space only will show the part of the algorithm that was used to identify the color, since turning on the conveyor belt, adjusting the PWM, giving the order to the servo motor of the positioning angle for the final classification of the covers, is a simpler job that even arrives to be routine for those who work with microprocessors.

```c
//********************calculation********************

void calculo(){
r=0; // variables started at 0. Have already been declared in the setup.
g=0;
b=0;
h=0;
n=0;
w=0;
s=0;
may=0;
for (c=1; c<=100; c++){ // 100 data taken by the TCS3200 sensor
    //*************TCS3200 sensor data socket********************
    //****This is the routine to capture the red, green and blue data*****
    //*****on the TCS3200 sensor according to the filters applied******
    digitalWrite(s2, LOW);
digitalWrite(s3, LOW);
    rojo = pulseIn(out, digitalRead(out) == HIGH ? LOW : HIGH);
digitalWrite(s3, HIGH);
    azul = pulseIn(out, digitalRead(out) == HIGH ? LOW : HIGH);
digitalWrite(s2, HIGH);
    verde = pulseIn(out, digitalRead(out) == HIGH ? LOW : HIGH);
//********************************************************************
```
//*********Color selection**********
if (rojo < azul && verde > azul && rojo < 25 && verde > 20) //conditions for red
{
    r = r + 1;
}

//**********blue**********
else if (rojo > verde && verde > azul && azul < 25) //conditions for blue
{
    b = b + 1;
}

//**********green**********
else if (rojo > verde && abs(azul - verde) < 10 && rojo > 20) //conditions for green
{
    g = g + 1;
}

//**********white**********
else if (azul < 15 && rojo < 15 && verde < 15) //conditions for white
{
    w = w + 1;
}

//**********black**********
else if (azul < rojo && rojo < verde && verde > 40) //conditions for black
{
    n = n + 1;
}

//**********yellow**********
else if (rojo < verde && verde < azul && rojo < 18) //conditions for yellow
{
    h = h + 1;
}

else //otherwise it is not one of the colors to select
{
    s = s + 1;
}

//delay(10);

****Here it is defined which one obtained greater****
****successes, that determines the detected color****

if (may < r)
{
    may = r;
}
if (may < g)
{
    may = g;
}
if (may < b)
{
    may = b;
}
if (may < h)
{
    may = h;
}
if (may<n){
    may=n;
}
if (may<w){
    may=w;
}
if (may<s){
    may=s;
}

//*******************************
************************************
//****Here the times of successes are compared with the correct data of each******
//****color and the detected color is printed as well as the value is given to********
//**given to the motorcycle servo to place the lid on the corresponding container***
//*******************************************************************

if (may>10){
    if (may==r){
        Serial.print(may);
        Serial.println("rojo");
p2=50; //servo position for red
        servo (); //Call the servo subroutine to place the selector in the corresponding container.
    }
    if (may==g){
        Serial.print(may);
        Serial.println("verde");
p2=65; //servo position for green
        servo (); //Call the servo subroutine to place the selector in the corresponding container.
    }
    if (may==b){
        Serial.print(may);
        Serial.println("azul");
p2=80; //servo position for blue
        servo (); //Call the servo subroutine to place the selector in the corresponding container.
    }
    if (may==h){
        Serial.print(may);
        Serial.println("amarillo");
p2=115; //servo position for yellow
        servo (); //Call the servo subroutine to place the selector in the corresponding container.
    }
    if (may==n){
        Serial.print(may);
        Serial.println("negro");
p2=105; //servo position for black
        servo (); //Call the servo subroutine to place the selector in the corresponding container.
    }
    if (may==w){
        Serial.print(may);
        Serial.println("blanco");
p2=130; //servo position for white
        servo (); //Call the servo subroutine to place the selector in the corresponding container.
    }
}
servo(); //Call the servo subroutine to place the selector in the corresponding container.
}
}

//***************************END*****************************************************************************

It is in the hands of students other applications, such as selecting sizes or other objects, since the industry has experienced a quantitative growth in terms of brands and products in a considerable way [8], and in this way there is a prototype that approaches the concept Flexible manufacturing.

5. Conclusions
The main conclusion is the achievement of the proposed objective, since a solution was achieved to the question posed. Moreover, it is clear that from the technological programs can be given solutions to real problems of the industry.

As a laboratory team, students were brought into direct contact with the equipments, not only for maintenance work, but also for programming and design.

A relatively inexpensive solution was achieved, since the most economical equipment in the market, for the selection of colors costs for about US $ 4600 and only selects two colors (Recreational Didactic Technology EIRL, 2013) which brings its own card already programmed, while this prototype did not reach USD 1500 (see figure 12).

Regarding the TCS3200 sensor, its efficiency was evidenced for a project like this one. It is very fast since 100 samples are taken in less than 1.2 seconds, which allow to make a statistic to ensure the color selection with an effectiveness of 100% as long as it is in optimal working conditions, for example, that there are no external lights among others.

The fact that the Technological Institution Colegio Mayor de Bolivar has equipment such as a 3D printer, laser cutter, among others, facilitates the learning and development of technology-based equipment. These products are typified in COLCIENCIAS, similar to the generation of new knowledge; making groups of research are strengthened. Moreover, they are generating and appropriating technologies that are normally brought from abroad.

Figure 12. SISAC
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References
[1] Dassault Systèmes SolidWorks Corporation, «Solid Works Education: Learn. Create. Succeed.» 2010. [En línea]. Available: https://www.solidworks.com/sw/docs/Student_WB_2011_ESP.pdf. [Último acceso: 2018].
[2] DF Robot, «DF Robot: Drive the Future.» 2017. [En línea]. Available: https://media.digikey.com/pdf/Data%20Sheets/DFRobot%20PDFs/SEN0101_Web.pdf. [Último acceso: 2018].
[3] FESTO AG & CO. KG, «Estación de Clasificación: Final.» 2018. [En línea]. Available: https://www.festo-didactic.com/es-es/productos/mps-sistema-de-produccion-modular/estaciones/estacion-de-clasificacion-final.htm?fbid=ZXMuZXMuNTQ3LjEOljE4LjYwNi4zOTQ4&basket=add&vid=5918.
[4] Tecnología Didáctica Recreacional EIRL, «TECNODIDÁCTICA. Educación STEM.» 2013. [En línea]. Available: http://www.tecnodidactica.pe/index.php/productos/entrenamiento-industrial/lnea-de-transporte-y-clasificacion-st00220024.html.
[5] COLCIENCIAS, «COLCIENCIAS: Ciencia, Tecnología e Innovación.» 2016. [En línea]. Available: http://www.colciencias.gov.co/sites/default/files/ckeditor_files/politiciadeactores-snctei.pdf. [Último acceso: 2018].
[6] 61mcu, «Adjustable Infrared Sensor Switch Manual.» 2016. [En línea]. Available: http://dl.3bc.pl/kamami_wa/e18-80nk-ds.pdf.
[7] H. A. Rodríguez-Arias, D. Ruiz y J. R. Castro-Suárez, «Design And Implementation Of A Photocolorimeter Using Microcontrollers To Determine Analyzes In Aqueous Solutions.» 16 th LACCEI International Multi-Conference for Engineering, Education, and Technology: “Innovation in Education and Inclusion”, 2018.
[8] L. Solís and M. Carpena, «Prototipo de un selector automático de materiales y colores,» Escuela Profesional de Ingeniería Industria, Universidad Ricardo Palma, Lima, 2010.
[9] J. Padiña-Magaña, I. Sánchez-Suárez and P. Oseguera-Espinoza «Control Untomático de una máquina seleccionadora por color mediante la PxyCam CMUCAM5 para aseguramiento de la calidad,» Revista de Tecnología e Innovación, Vol 3, No. 8 Pag 35-44, Septiembre 2016, Bolivia.
[10] A. Arenas, «Diseño e implementación de prototipo a escala de máquina clasificadora de color por visión,» Universidad Católica de Santiago de Guayaquil, Septiembre 2018, Ecuador
[11] W. Zhao kun, P. Binbin, Y. Huang and G. Sun, «Classification for plastic bottles recycling based on image recognition,» Waste Management, Vol 88, Pag. 170-181, Abril 2019, Elsevier Ltd.
[12] G. Efraim and A. Benny, «Development of Robotic Arm for Color Based Goods Sorter in Factory Using TCS3200 Sensor with a Web-Based Monitoring System,» 2018 Third International Conference on Informatics and Computing (ICIC), Agosto 2018, DOI 10.1109/IAC.2018.8780461, IEEE, Indonesia.
[13] A. Sachdeva, M. Gupta, M. Pandey and P. Khandelwal, «Development Of Industrial Automatic Multi Colour Sorting and Counting Machine Using Arduino Nano Microcontroller and TCS3200 Colour Sensor,» The International Journal of Engineering and Science (IIES), Vol. 6, Pag. 56-59, 2017. India