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DESIGN OF A COLOR DETECTOR DEVICE WITH DISPLAY AND SPEAKER BY USING ADDITIVE MANUFACTURING AND ARDUINO BOARDS

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Abstract: *The human eye is one of the most important and complex sensory organ. Sight is the main way to perceive shapes, colors, objects, distances, etc. That is why it provides the most information that helps us to understand the world around us. Most of the common activities in people's lives require visual perception, such as driving a car, cleaning the house, reading, choosing fruits and vegetables or matching clothes. This article proposes a foray into the rapid prototyping of a color reading device that comes to the aid of people with visual impairments, such as dyschromatopsia, by using electronic components available on the market, the Arduino board and additive manufacturing using PLA material.*

Key words: *color detector, device, additive manufacturing, rapid prototyping, PLA.*

1. INTRODUCTION

The retina is made up of photoreceptor cells that react to light. These are of two types: cone cells and rod cells. These cells contain visual pigments and by gathering the information received by them, the colored image is built. Rod cells, which contain rhodopsin, are responsible for night vision. Cone cells play a role in color vision. They are of three types, each having a visual pigment sensitive to: red, green and blue (RGB) [1, 2].

One of the important characteristics of the eye is color vision. The most common form of dyschromia is red – green. Both, men and women are dyschromic, being a hereditary disease, it is determined by the affected person's X chromosome. Women having two X chromosomes, the possibility of inheriting this pathology is low compared to men who have one X and one Y chromosome. A male carrier of the responsible gene will be dyschromic and a female carrier will not be affected because it is necessary that both X chromosomes to inheritate [3].

Although the current devices cannot encompass all the complex eye functions in a single product, by researching and successively creating prototypes and new improved products, we can gradually compensate for some of these deficiencies.

During life, every person encounters a visual defect. It can be from birth or acquired over time. Most defects can be mild, such as nearsightedness or farsightedness, or severe, such as cataracts or glaucoma, leading to partial or total loss of vision. In this study, we focused on dyschromatopsia which is the inability to distinguish colors. It may be due to genetic causes, or it can be caused by eye diseases that affect the retina. Depending on the types of cones affected, there are several types of dyschromatopsia: dichromatism, monochromatopsia and achromatopsia.

The first scientific work that addressed the inability to distinguish colors appeared in 1798 and was written by John Dalton [4]. In the paper, John Dalton described his own color blindness and hypothesized that the inside of the vitreous would have a colored fluid that would cause different color perception. This was proven false after his death when his eyes were studied, and no such fluid was found.

Visual impairment acquired from birth cannot be treated. However, there are cases in which, by detecting the disease in time, different procedures can be performed to stop its evolution or even to remove it completely.

In the case of dyschromatopsia acquired at birth, it cannot yet be treated medically. If the dyschromatopsia is caused by another condition of the eyeball, then treatment specific to that disease is attempted. Instead, several products have been developed that come in aid of visually impaired people such as: Rainbow II Color Reader, Talking Color Detector, Colorino, EnChroma Glasses.

2. MATERIALS AND METHODS

In this paper, the rapid prototyping of a color detector that can display text and play audio files was pursued. The study intends to help users who cannot see colors properly, but also those whose sight is partially or totally impaired. The device is medium in size, works with a 9V

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battery, has a 40 mm speaker, LCD display for reading the identified color, has a 3,5 mm audio jack for connecting headphones, 3 volume levels (100%, 50% and 0), the ability to program the language played and displayed in any language with Latin characters via the Nano v3 development board.

2.1. Device components

2.1.1. *Arduino development board*. The Arduino Uno is a development board based on the ATmega328P microcontroller, an 8–bit processor with a maximum frequency of 20 MHz. Massimo Banzi and David Cuartielles created the Arduino in 2005 in Ivrea, Italy. They collaborated with David Mellis who made the software for the Arduino, Gianluca Martino and Tom Igoe that also contributed to the project. Thus, the five are known as the original founders of Arduino. The initial purpose of this development board was to create an easy-to-program device that could connect various elements such as relays, motors or sensors for the interactive art projects at the Interaction Design Ivrea Institute [10].

Arduino boards can read different sensors that plug into input pins. This sensor can be for light, temperature, color, proximity, magnetic sensors, etc. The information received on the input pins is processed using instructions sent to the board via a USB cable connected to the computer. The program in which the instructions are written is called Arduino Software (IDE) and the programming language is C++. Once the instructions are received, the Arduino board transmits them to the output pins, which in turn can control various electronic components such as: LCD displays, micromotors, LEDs, micro relays, speakers, etc.

The instructions sent to the Arduino board remain in its memory even if the power supply or the cable from the computer is disconnected. Deleting the instructions can be done by several methods: sending another set of instructions or pressing the existing "Reset" button on the Arduino board for a few seconds.

There are several types of Arduino development boards such as Arduino Uno, Arduino Nano, Arduino Leonardo, Arduino Zero, Arduino Due, etc. In this study,

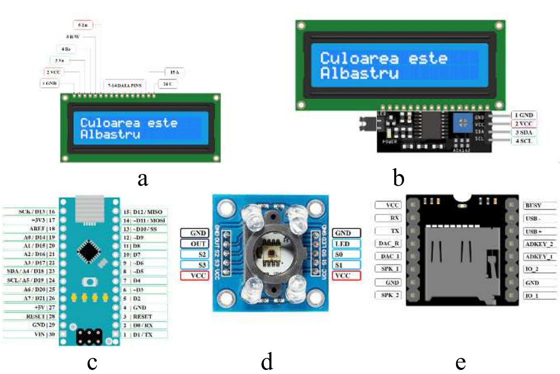


Fig. 1. Components of the color detector device: *a* – 1602 Display pins [5]; *b* – Connection with I2C [6]; *c* – Nano v3 pins [7]; *d* – TCS3200 color sensor [8]; *e* – DFPlayer Mini module [9].

Nano v3 development board was used (Fig. 1,*c*.) , which is compatible with Arduino Nano having the same features. It has the following technical specifications: ATmega328p microcontroller, 5V operating voltage, 5–12 V recommended input voltage, 14 digital I/O pins – TX, RX, D2-D13 (of which 6 PWM output pins – D3, D5, D6, D9, D10, D11), 8 Analog input pins A0-A7, mini USB connection, it supports a 9V battery power and a dimension of 18 x 45 mm.

2.1.2. *TCS3200 color sensor*. The color sensor used in this study was TCS3200 (Fig. 1,*d*) which uses an RGB chip that detects colors and four LEDs that help illuminate objects. The TCS3200 sensor consists of a photodiode array of four different types. The photodiode is a light detector that converts the received light into an electrical voltage. The component photodiodes are: sixteen red filter photodiodes, green filter photodiodes, blue filter photodiodes and sixteen photodiodes without filter, so a total of 64 photodiodes [8].

By successively selecting each type of photodiode, the level of each color can be found. The sensor has a converter that transforms the current into frequency, obtaining a rectangular signal with a frequency corresponding to the color which is read. The reading of the three colors is done separately at a range of 200 ms.

Thus, in less than a second, three values corresponding to the basic colors (red, green and blue) are obtained. Select pins S2 and S3 are used to select the photodiodes during readout by assigning different values to the pins. Depending on these values, the color detector activates the corresponding photodiodes. Thus, to activate the photodiodes, the values from Table 1 are used.

Pins S0 and S1 are used to set the output signal strength. It can have four values: 0%, 2%, 20%, 100%. In connection with the Arduino development board, this setting should be 20%, so that the HIGH and LOW values are applied to the S0 and S1 pins [11].

2.1.3. *1602 LCD Display*. Is a device capable of displaying text and character elements. The display is done in two lines, each with 16 characters. It has a parallel interface which means that to work it is necessary to receive information on several pins at the same time. The display has 16 pins as follows: GND ground voltage, VCC supply voltage, Vo contrast and brightness control, RS register selection (it differentiates data from commands), R/W selection of working mode (read or write), En display activation, D0–D7 data pins, A–C anode and cathode (performs backlight control [5].

Since the display occupies 7 of the 14 pins available on the Nano v3 board, an I2C adapter is used. This module receives data on the I2C serial bus transmitted by

Table 1

Pin Values [11]

Color	S2	S3
Red	LOW	LOW
Green	HIGH	HIGH
Blue	LOW	HIGH
None	HIGH	LOW

the Nano v3 and retransmits it to the LCD display via parallel connection. The module has 4 pins as follows: GND ground voltage, VCC supply voltage, SDA data pin, SCL sync pin (Fig. 1).

2.1.4. *DFPlayer Mini module*. It is an audio module with an 8 Ohm speaker output that has a built-in SD/TF card reader. The module decodes and can play MP3, WAV and VMA audio formats. The supply voltage is between 3.2 and 5V. It has 30 levels of volume adjustment and an adjustable 6-channel equalizer. The connection to the Nano v3 board is made through serial communication protocol. The module has 16 pins as follows: VCC supply voltage, RX receive serial data, TX serial data transmission, DAC_R 24–bit digital output (right), DAC_L 24–bit digital output (left), SPK_1 speaker negative terminal, GND ground voltage, SPK_2 speaker positive terminal, O_1 command port 1, GND ground voltage, IO_2 command port 2, ADKEY_1 / ADKEY_2 analog to digital conversion pin, USB + / USB – port, BUSY operating status (Fig. 1,*e*.) [9].

2.2. Connection diagram

The electronic components used to develop the prototype are Nano v3 development board, TCS3200 color sensor, 1602 LCD display, DFPlayer Mini sound module, 4Ω and 0.5W speaker, diameter 40 mm, 9V battery with support, on/off button, three-position switch for adjusting the volume and 3,5 mm female jack with a role in disconnecting the speaker when connecting headphones. The Nano v3 board is powered by 9V on the VIN pin and the negative voltage on the GND pin from the 9V battery. Between the VIN pin and the positive battery terminal is the on/off switch (Fig. 2).

Between the development board and the display, there are four connections. From GND pin to GND pin representing negative supply voltage, from 5V pin to VCC pin representing 5V voltage for display power. From pin A4 to pin SDA and from pin A5 to pin SCL is the serial communication between the two components.

There are seven connections between the development board and the color sensor. Same as the display, from GND pin to GND pin representing the negative supply voltage, from 5V pin to VCC pin representing the 5V voltage for powering the color sensor module. From pin D4 to pin OUT is sent the value of the frequency read by the diode array. From pin D2 to pin S2 and from pin D3 to pin S3. These connections have a role in activating the photodiodes corresponding to the color to be read. From RX1 pin to S0 pin and from TX1 to S1 pin which together set the value of the output signal on the OUT pin.

Also, there are four connections between the development board and the DFPlayer Mini. From the GND pin to the GND pin representing the negative supply voltage, from the 5V pin to the VCC pin representing the 5V voltage for powering the sound module. From D11 pin to RX pin and from D10 pin to TX pin, serial data communication is done. A resistor is connected between pins D10 and TX to attenuate background noise.

There is only one connection between the DFPlayer Mini and the speaker. The negative terminal of the

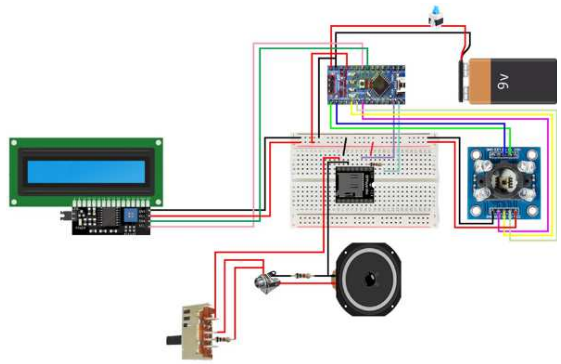


Fig. 2. Wiring diagram.

speaker and the negative terminal of the headphone jack connect to the SPK_1 pin. A switch input pin that controls the volume is tied to the SPK_2 pin. The first output pin of the volume switch is tied to the headphone jack at the positive terminal and the second is also tied to the positive terminal through a 10 Ω resistor.

Finally, the positive terminal of the headphone jack is connected to the positive terminal of the speaker and when the headphone connector is in the jack, the speaker is removed from the circuit and the audio signal only reaches the headphones.

2.3. Arduino program code

In the following paragraph, it is presented how the prototype works and how it was calibrated:

```
digitalWrite(S2,LOW); // The diodes are set for red
  digitalWrite(S3,LOW);
  // Frequency reading
  frequency = pulseIn(sensorOut, LOW);
  fRed = frequency;
  // Displays the value on the serial monitor interface
  Serial.print("R= "); // the initial name color red
  Serial.print(frequency); // displays the frequency for the
red color
  Serial.print("  ");
  delay(200);
                                    *** Repetitive sequence
```

The first step in developing the code is to calibrate the color sensor. The above sequence is to read the frequency corresponding to the color red. Pins S2 and S3 are set according to Table 1 to activate the red photodiodes. The read values are displayed in the serial monitor of the program (Fig. 3). This will allow observing the amount of red, the maximum and minimum values that will define one of the three ranges necessary to compose the basic color. Similarly, the code sequences for the colors green and blue are made.

For each color read, three ranges are made according to the values received by the sensor. Each range will be composed of the minimum value and the maximum value read by the photodiodes. For accurate calibration, the sensor was covered with a cardboard wall to eliminate external light sources, allowing the reading of real values.

In the given program sequence, the ranges characterizing the red color are defined by the "if"

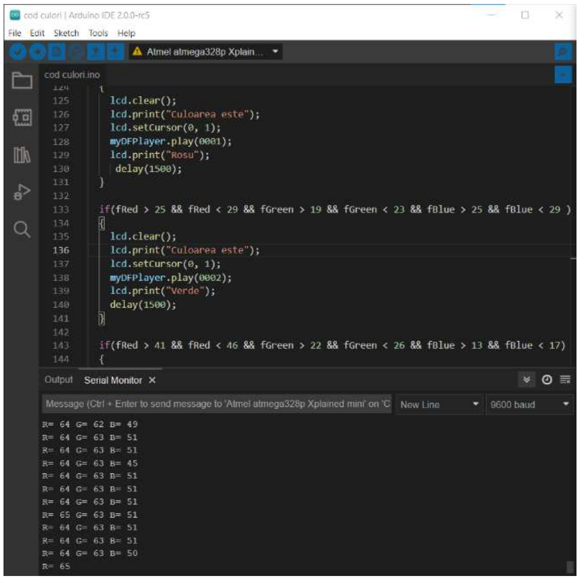


Fig. 3. Serial monitoring code.

function. The terms "fRed", "fGreen" and "fBlue" represent integer variables with a role in memorizing the read frequencies. If the received values meet the given condition, then the program will command to access the audio file along with displaying the corresponding color message on the screen. In a similar way, the code sequences for the rest of the colors such as green, blue, white, yellow, orange and black are made.

```
if(fRed > 19 && fRed < 23 && fGreen > 50 &&
fGreen <55 && fBlue > 39 && fBlue < 43)
  {
    lcd.clear();
    lcd.print("Culoarea este/The color is");
    lcd.setCursor(0, 1);
    myDFPlayer.play(0001);
    lcd.print("Rosu/Red");
     delay(1500);
  }
```

**** Repetitive sequence*

2.4. Color reader device casing design

Autodesk Inventor Professional 2021 software was used to design the device case.

A total of five components were made: the bottom half of the case, the top half, the battery cover, the sensor's cylinder and the cover handle.

The bottom half device case (Fig.4 a.) is made up of four screws supports with a role in assembling the case, three sets of four rectangular parallelepipeds each having a central hole with a diameter specific to the part, with the role of supporting the other components, such as the LCD screen, Nano v3 and the on/off button.

They were also generated with the aim of creating space inside the case to give freedom to the connection wires. An extruded cylinder on the outer surface that will cover the light from the environment in order not to deviate the values read by the sensor, on the side surfaces there is the hole for the audio jack and the hole for the Nano v3 development board jack to allow it to be reprogrammed. Also inside, it has the free space reserved for the battery cover together with the place where it will be inserted.

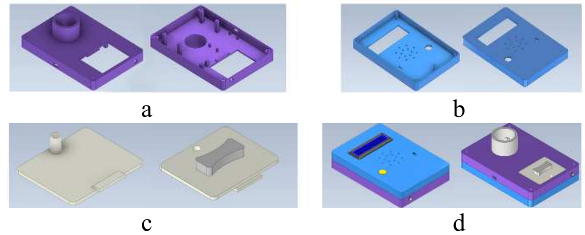


Fig. 4. Color reader device casing design: *a* – Bottom case design; *b* – Top case design; *c* – Battery cover design; *d* – Final assembly.

The last aspect is the edge of the case involved in the assembly of the two halves elements.

The top color device reader case (Fig.4,*b*) consists of multiple central holes for the speaker to allow the release of sounds, four screw holders with a role in closing the case, one is for the battery cover holding, the hole through which the LCD screen will pass, the hole for the power button and the hole for the volume switch.

The battery cover (Fig. 4,*c*) is a simple element that contains a leg for positioning and centering the cover in its intended place and the housing for the case screw head.

The last remaining element is the cylinder that covers the color sensor. It is built to prevent outside light from interfering with the sensor reader, thus keeping the read values within the same range set during its calibration.

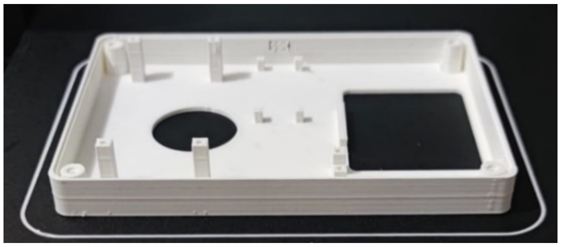
The final appearance of the case together with the electronic elements will be according to Fig. 4,*d*.

2.5. Color device detector casing additive manufacturing

3D printing includes a wide number of processes that use the principle of additive manufacturing, in which a three-dimensional object is built based on a 3D model made using a CAD program. Additive manufacturing, known as Additive Manufacturing (AM), refers to technologies that create 3D models by adding raw material, layer by layer, each having the same thickness [12].

The 3D model file is converted into a specific format called STL. The STL format is the most common format in the field of 3D printing. To create the layers, the generated file is inserted into software application that slices the 3D model, thus creating a number of flat surfaces with equal thickness, the orientation of the virtual models representing an important aspect that influences the results of the finished product [13]. The next stage is the actual printing of the part. The previously calculated layers are first deposited in the base plane, XOY, representing two dimensions and the third dimension, the height of the model, is given by their overlap. After depositing the last layer, the piece is finished.

Thus, the next step of the rapid prototyping process is the 3D printing of all the device parts. Each piece will be converted to STL format to be readable by the slicing software. The Creality Ender 3 Pro 3D printer and Ultimaker Cura software were used in this step.



a

b

Fig. 5. The additive manufacturing process of the device casing: *a* – Printed bottom casing device; *b* – Printed top casing device.

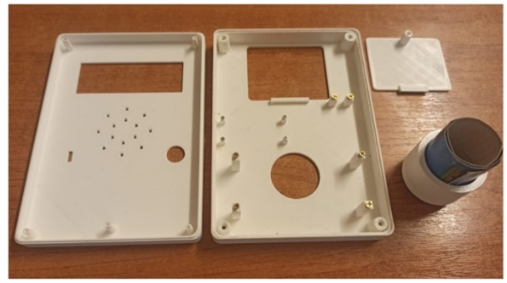
The application software will make the necessary instructions for the extruder, in case of each individual layer, according to the settings imposed by the user. For all the device case parts, the "Tri-Hexagon" filling method was chosen, with a density of 15%. The higher the density, the more space is filled. Since it is printed with PLA filament, it requires the printhead temperature between 200–235 °C and the heated platform temperature between 50–60 °C. In this case, the values of 210 °C for the print head and 50 °C for the heated platform were chosen and the printing speed was set at 50 mm/s. Finally, the software calculates all the steps necessary to generate the selected device part, giving approximate values of time, weight and length of filament used, after which it creates the G-code file that will be sent to the 3D printer.

Before printing the part, the printer places a counter around it to prepare the print head and filament so that the material is deposited properly as shown in Fig. 5.

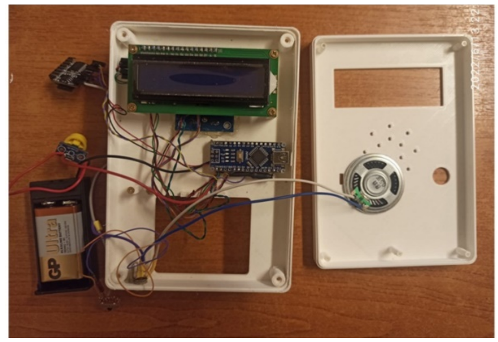
3. RESULTS OBTAINED

Following the completion of the device casing manufacturing process by using the FDM 3D printing method, the actual assembly of the color detection device was carried out. The electronic components were fixed with the help of screws that thread into device case, in the special dedicated slots, and the cover cylinder of the color reading sensor was assembled by gluing it with the bottom device case. After positioning the electronic components and fixing them, the upper case was fixed and the entire device was assembled with the help of screws, leaving the positioning of the battery cover as the last step.

In Fig. 6,*a* and *b* one can observe some device assembling operation stages can be observed. The final device is shown in Fig. 7,*a*.



a



b

Fig. 6. The prototype assembly process: *a* – Final casing parts before assembly; *b* – Assembly of electronic components.

a

b

Fig. 7. The functional prototype: *a* – The final assembly of the device; *b* – The device in operation.

The device case made of PLA material provides protection to the electronic components, preventing possible damage in case of an involuntary fall of it, and fixing the components inside the case using screws allows maintaining them in the indicated position even in the event of an impact caused by the fall of the device [14].

After assembly, the calibration of the device and its testing was initiated, for testing a set of colored cards was used as shown in Fig. 7,*b*. The results of the tests were positive, the color reading device working exactly and fulfilling all the functions, for which it was designed, the result of reading the colors being displayed both on the device display and on sound, through the speaker.

4. CONCLUSIONS

The prototype achieves its goal, which is to include the two categories of people, those suffering from dyschromatopsia and those who are blind, in a single device by simultaneously integrating the speaker and the display. In terms of performance, it manages to read several colors (red, green, blue, yellow, orange, pink, brown, dark green, black and white) in any environment thanks to the cylinder built around the color sensor, thus having its own environment with constant light. In the same way, other colors or shades can be implemented in the code to make the device much more perceptive and sensitive to a wider palette of colors.

Also, devices built for visually impaired people do not always meet the desired requirements, there is a possibility of erroneous reading caused by the large number of colors and shades assigned, the quality of the color sensor and the ambient light in which is located.

Although a device cannot replace the functions of the eye and provide the same quality of ordinary life, using the constant evolution of technologies over time, new devices can be made by redesigning and replacing the electronics with their much-improved variants, or it can produce a positive impact by lowering the production cost of such devices.

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