An Enhanced Open Source Refreshable Braille Display DISBRA 2.0

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Abstract. A World Health Organization study states that there are 2.2 billion people with some sort of visual impairment. Some of those people are considered blind. A way blind people can communicate is by using a tactile alphabet called Braille. The percentual of blind people that can read Braille in developing countries is very low, about 10%, since the cost of tools for teaching Braille can be high. Additionally, not enough tutors are available to teach the students. Usually, a commercial tactile display costs over 800 dollars ($US), using components that are both expensive and hard to repair. This paper proposes enhancements for the DISBRA, a low-cost, open source, single digit Braille display that is inexpensive and made using cheaper electronical components and 3D printed parts. The DISBRA can be used to train tutors without teacher input, besides being an aid in teaching students. The improvements proposed by this paper eliminate the need for an external control device for the DISBRA, reducing its cost and making it a standalone solution. The DISBRA 2.0 prototype was tested by individuals without visual impairment. After one session of less than two hours they could correctly identify a character using only touch 68.46% of the time. While looking at the Braille the success rate was 86.15%.

Keywords: e-learning and distant learning · Haptic user interface · Interface for disabled and senior people · Accessibility · Refreshable Braille display · Visual impairment

1 Introduction

According to research by the World Health Organization (WHO) published in 2019, 2.2 billion people had serious vision problems [1] and an estimated 200 million people suffered from blindness [2].

People with disabilities face barriers in education and employment. They do not have enough access to basic services such as health, therapies, and computerized tools. Specifically, people with disabilities have difficulties when they need to express their opinions or share ideas. They are left in an unequal position when compared to people who can communicate by normal means. According to the WHO, these barriers are more present in developing countries where there are higher rates of poverty and low levels of success in education [3].

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The segments of the population that normally have most restricted access to eye health include people with less economic means, women, the elderly, people disadvantaged by various disabilities, ethnic minorities and refugees. Consequently, these groups concentrate the largest number of blind people [1].

Also, according to the WHO, investments in assistive technologies are beneficial for these groups. These types of technology provide possibilities for people to return to their homes and communities in order to live independently. This allows them to participate in education, the workforce and enjoy life in public, in addition to reducing the burden of various support services [3].

For all of the opportunities braille offers, paradoxically there is a decline in knowledge and study of the Braille code ("un-braille-ization"). According to the study by Forcelini, García and Schultz [4], 90% of blind people in the USA lacked proper Braille reading skills. A similar proportion is found in Brazil. Some of the main factors for this low level of Braille education, cited by the study, are the lack of instructors, social prejudice and the high cost of Braille teaching technologies.

Studies also denote that there are a large number of reading applications available but emphasize that books in digital audio format known as audiobooks and screen reading software are not proper substitutes for reading information in Braille [4]. Braille literacy for visually challenged people contains the same educational aims as normal literacy methods have for people with vision [5]. In developing countries most of the Braille teachers are visually challenged themselves. Also worthy of note is that the literacy rate for visually challenged people is as low as 3% to 5% in most developing countries. The conventional technique for learning Braille is bulky and requires assistance [5].

DISBRA was created as a way to facilitate learning and spread reading in Braille [6]. This work proposes the enhancement of DISBRA's advantages [6], a low-cost open-source Braille display using cheap electronic parts and 3D-printed components to form Braille characters. DISBRA can be used for teaching Braille without the need for a tutor [6], or train Braille tutors without teacher training. The proposed improvements enhance the initial prototype by adding the following: the possibility of using the teaching or tutor mode without a smartphone; using electronic components to play audio files; and minor improvements for Braille cell alignment issues.

2 Theory

In this section, information about the Braille system, dynamic Braille displays, as well as some notions about the Braille literacy process will be presented, alongside coverage of some relevant issues.

2.1 The Braille System

One of the ways in which a blind person can communicate and learn is through a tactile alphabet, known as Braille. This is the main way of transmitting information through tactile means and it is one of the most common ways of communicating with blind people in our daily lives [2].

There are also studies that indicate the advantage of using Braille reading for learning, since learning by actively reading Braille text leads to a greater understanding of the content by the students when compared to simply receiving the information passively, via audio format [7, 8]. The study by Russomanno [8] also states that for situations where understanding information in a text is the main priority, in settings such as education, reading in Braille should be considered the optimal mode of transmitting information.

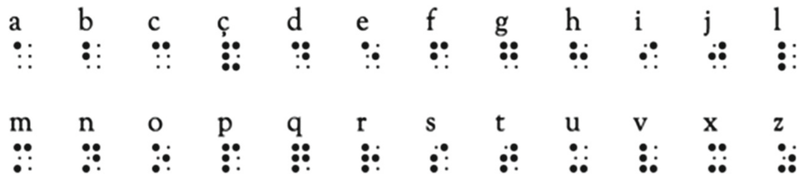

Fig. 1. The Braille alphabet [9]

Text in Braille can be formed in cells of 4 lines by 2 columns of dots or 3 lines by 2 columns of dots. Each cell can represent a letter of the alphabet or a number [7]. In this project, we will use the 3 by 2 format of Braille as shown in Fig. 1.

For the experiments, the Roman alphabet with 26 letters is used. Despite the use of the Portuguese language the tests do not include any accents.

2.2 Braille Displays

There are several devices capable of providing writing and assembling for Braille text on the market. Prices for commercial tactile displays range from 800 to 3000 dollars ($US). The cost will depend on factors such as the number of digits and the fact that, more often than not, the displays are equipped with small piezoelectric actuators. This type of component requires high voltage, around 200 V. The pieces are expensive and difficult to repair [10] and demand costly power supplies. DISBRA uses cheaper stepper motors and drivers [6] and costs about 30 dollars. This difference in cost also resides in the main difference between the commercial aims of the devices. The more expensive device displays text with multiple digits, while DISBRA has only one digit in the use of a single cell for basic Braille education.

2.3 Braille Alphabetization

The literacy process in the Braille system has, as one of its main objectives, the development of reading with the fingers and also the purpose of producing texts manually. When starting to learn the Braille System, the student must have already gone through a preparatory period, aiming at the development of fine motor coordination and tactile perception to discriminate the letter shapes, as the distinctions are very slight [11]. The DISBRA can be used to aid teaching the alphabet in Braille, since its simplified one-digit display can be used in the development of reading skills for individual letters.

Usually, during Braille education, the teacher works with concrete objects whether they are prefabricated or developed in the classroom, showing the idea of the shape of the letters and leading the student to experiment and trace the letters with their fingers. The objects of interest are the representation of the alphabet and alphanumeric Braille made of Ethyl Vinyl Acetate rubber - EVA and / or Medium Density Fiberboard (MDF) [11].

After carrying out the activities that allow Braille cells to be recognized, the clamp and punch are used as a writing instrument. The recognition of the combination of the points will present a letter, which in turn is combined to form words. Braille makes it possible to study raised paintings and read technical books more efficiently [11].

The quality of Braille teaching is decisive for reading Braille and aids in acquiring reading habits. If students are motivated to constantly practice this method of reading and writing, this activity can quickly become more enjoyable and instructive [11].

3 Proposed Solution

The proposed solution is to improve the DISBRA. That is to say, to build a low-cost Braille display with the objective of being a device that is easily replicated by a person with little specialized knowledge in microcontrollers. Originally, the DISBRA was controlled via an application for mobile devices. Its main advantage was that it was inexpensive. In order to create this device with lower costs, a combination of Arduino controller and electronic components with physical components that could be produced using 3D printing techniques was used [6]. The improvements focus on removing one's dependence on an external device, such as a smartphone, to control the DISBRA. With this change, the DISBRA 2.0 becomes a standalone solution for teaching fundamental Braille. We will also see the reduction of Braille cell alignment issues caused by power supply limitations on DISBRA's Arduino board. Each change proposed will be presented below.

3.1 Changes on the Interface and Usability

This new version, DISBRA 2.0, increases DISBRA's flexibility and reduces its cost by removing the need to use an external device, usually a smartphone, to control the display. For this purpose, an audio reproduction system was used. The system was then programmed to provide feedback that enables DISBRA's control menus to provide a solution directly on the DISBRA 2.0. To provide for this functionality, a module for playing MP3 files, the DFPlayer mini along with a small speaker and 4 buttons, were added to the prototype.

In Fig. 2 you can see the DISBRA in Version 1.0. In this version it is a simple display and needs an external controller in order to function. In DISBRA 2.0 the biggest difference for a user that had used the original DISBRA would be a new layout that accommodates 4 buttons and the speaker on the DISBRA 2.0 cover. The DISBRA 2.0 is a standalone solution, which does not need an external controller to properly function.

In Fig. 3, it is possible to see the prototype used to define the positions of the controls and the final positions that were integrated on the DISBRA 2.0 cover. The positioning considered the opinions of the people involved in the DISBRA 2.0 tests. During the tests,

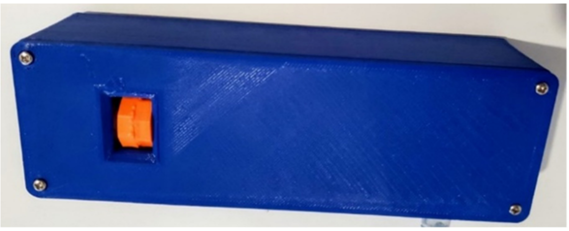

Fig. 2. The DISBRA [6]

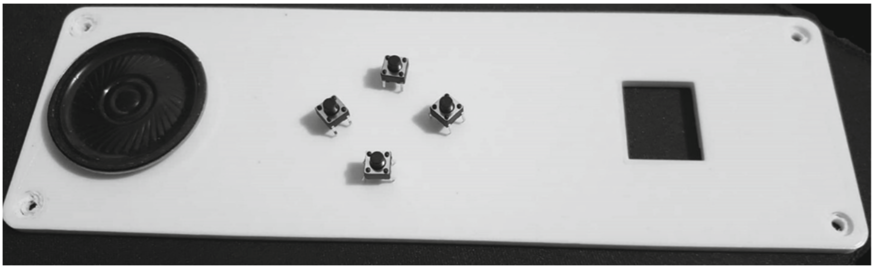

Fig. 3. The DISBRA 2.0 cover

the components were connected to the Arduino board and glued to the original DISBRA cover.

The audios used in the tests for the DISBRA 2.0 prototype were recorded in MP3 and stored on a microSD card. The audios represent the equivalent of the solution menus for mobile devices in addition to the letters of the alphabet and the success/error feedback for the question mode. The user could navigate the solution by listening to the menu, using the buttons on the left and right to move forward and backward through the menu options and the buttons above (up) and below (down) to enter and exit the submenus of each option. With these controls and audio files, the researcher reprogrammed the Arduino so the volunteers could use the DISBRA 2.0 solution without needing a smartphone or any other external control device, due to the menus now being presented in audio format. The functionality of connecting to the smartphone, or other Bluetooth devices, was not removed from DISBRA 2.0, but its use is optional. The hardware components for this operation can be removed, to reduce further costs, without affecting usability.

Original Menus versus Audio Menus. The main challenge for this improvement was to replicate the experience of navigating solutions on a smartphone using only audio and buttons to represent and control all menus and interactions needed to navigate the DISBRA 2.0 as a standalone tutor. The original DISBRA used an Android app to display its menus and provide audio feedback to its users.

The main solution (implemented for Android mobiles) was comprised of a teaching, or tutor, mode alongside a question mode.

In the tutor mode there were six divisions, called modules, four of them containing five letters, one containing six letters, and the last containing all 26 letters on the alphabet.

The question mode was also divided into six modules to test the user's ability to read the characters for each module. The app would select a letter from the current module at random, send it to the display, and when the user clicked an answer option it would evaluate and send the proper feedback to the user.

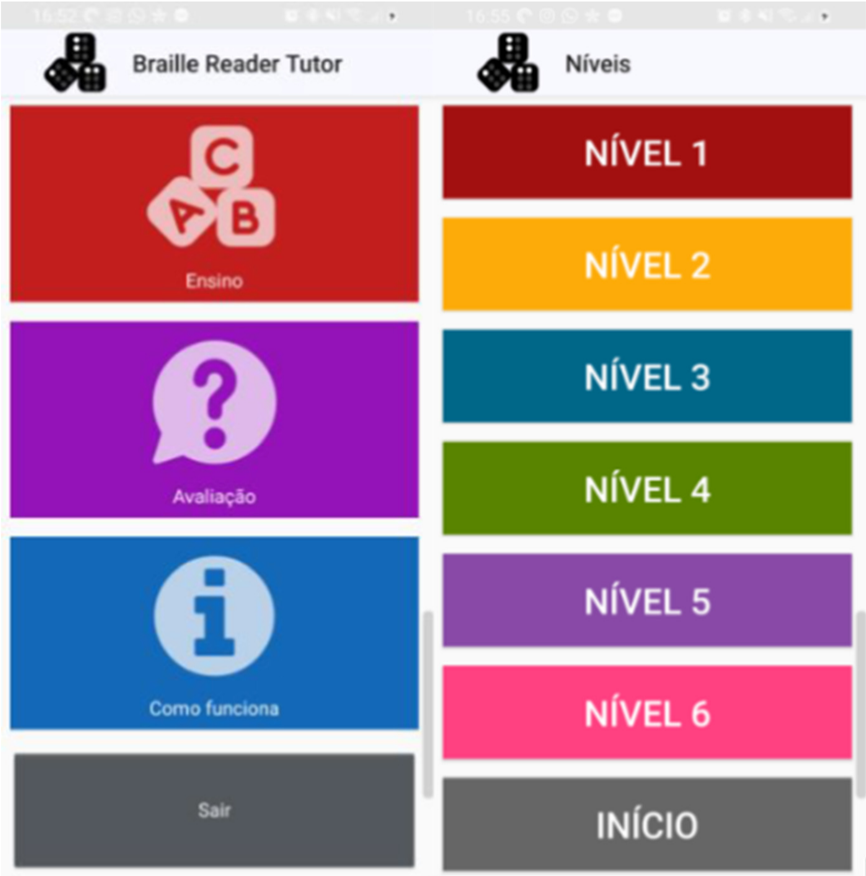

Fig. 4. The DISBRA Android menus [6]

Figure 4 shows the layout and color scheme for the Android solution for the DISBRA in its first version. This was the solution used by volunteers during the test phase for the DISBRA project. They used a smartphone to control the display and process all teaching and question modes.

Figure 5 shows the diagram for the Audio navigation used to display character A in module one during tutor mode for the DISBRA 2.0. Button pressures needed for this action are shown as arrows.

As the user turns on DISBRA 2.0, the speaker announces that the solution at the start, for it to play an MP3 file that would announce "Tutor Mode". It is the first option for the main menu. If he clicks the right button, the state would change, and the speaker

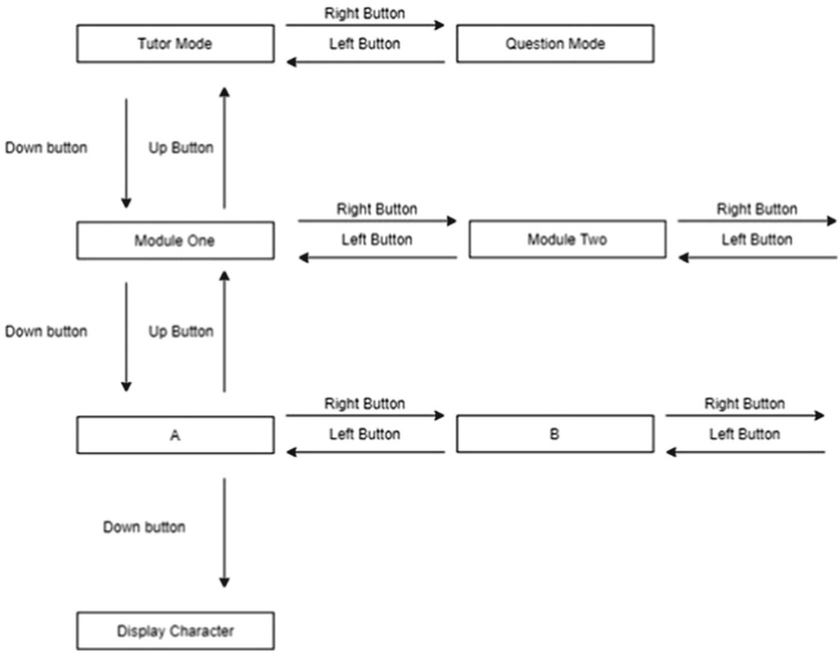

Fig. 5. The DISBRA 2.0 menu navigation diagram for the tutor mode

would announce “Question Mode”. If the user clicks the down button, in the state of tutor mode, the solution will change the state and announce that it is now at the “Module One” stage. Again, clicking the left or right buttons would go to the options for this submenu. If the user clicks the down button in the module one state, the system would, again, change its state and announce “A”. While at this stage, the left and right buttons could be used to navigate all the letter options for this module. If the user clicks the down button at the letter a stage, the display digits would rotate and the Braille equivalent for letter a would be formed by its dots. This last action does not change the current state for the solution. Clicking the up button at all stages, except in the tutor or question modes, would change the state to the previous upper submenu. Clicking up twice from the letter a stage would bring the user back to the tutor mode stage.

Figure 6 shows the diagram for the Audio navigation used to input the character A as an answer for the question mode of module one on the DISBRA 2.0 display. The button presses needed for this action are shown as arrows. The audio feedback will announce if the user has selected the correct answer for the random character displayed.

As the user turns on the DISBRA 2.0, the speaker announces that the solution is in its start state, so it would play an MP3 file that would announce “Tutor Mode”, since it’s the first option for this menu. If he clicked the right button, the state would change, and the speaker would announce “Question Mode”. If the user clicks the down button, while on the question mode state, the solution will change the state and announce that it is now in the “Module One Questions” state. Again, clicking the left or right buttons would cycle on the options for this submenu. If the user clicks the down button in the module

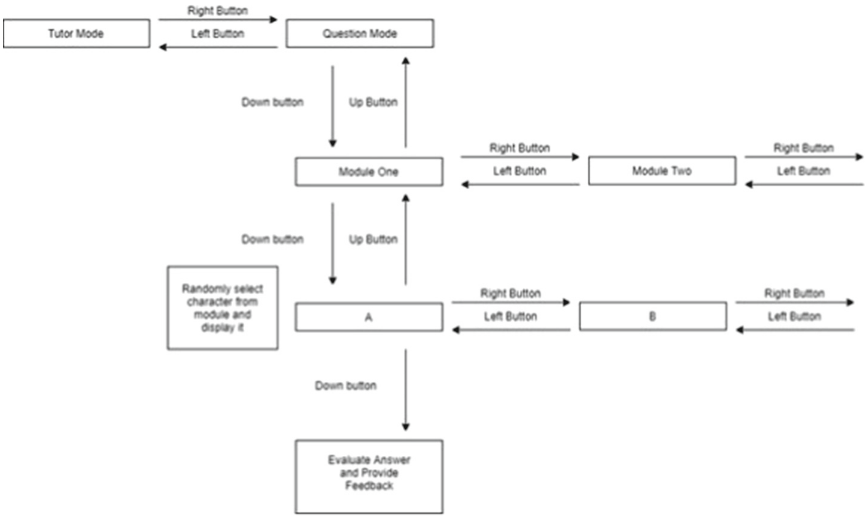

Fig. 6. The DISBRA menu navigation diagram for the question mode

one questions state, the system will randomly select a letter for this module, display it by rotating and aligning the dots on the digits, then change its state and announce "A". While in this submenu, the left and right buttons could be used to navigate all the letter options for this module. If the user clicks the down button in the letter a state, the solution will check if this is the correct answer for the displayed character, then send an audible feedback for the evaluation – correct/ incorrect choice. The system will, again, randomly select a character, display and await new inputs. Clicking the up button on all states, except in the tutor or question modes, would change the state to the previous upper submenu. Clicking up twice from the letter a state would bring the user back to the question mode state.

Table 1. DISBRA modules and letters for the modules.

Module	Letters
One	A, B, D, G, Q
Two	C, F, N, Y, W
Three	E, H, P, O, V
Four	I, J, R, M, U
Five	K, L, T, S, X, Z
Six	All 26 letters on the alphabet

Table 1 shows the letters selected for each module. The number of modules was defined based on the work by [12]. The letters were selected randomly as proposed by [13].

3.2 Reducing the Braille Display Alignment Issues

During the DISBRA tests, a feedback by one of the volunteers was that the display, formed by an extruded octagon formed in 3D printing, had a tendency to sometimes lack alignment. There was a problem with the power supply to the prototype's stepper motor drivers. This problem was fixed for the DISBRA 2.0 by removing the power supply for the stepper motor controllers from the Arduino board and using a direct connection to the external power source that also feeds the Arduino (Fig. 7).

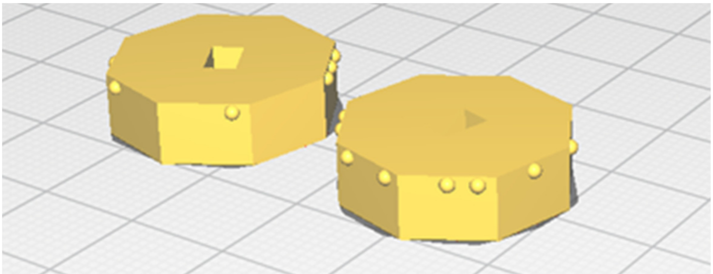

Fig. 7. The Braille cell disks [6]

Figure 5 illustrates the digits used to form the Braille cell. By spinning and aligning the faces of this extruded octagon, the Braille cell is formed. During the longer DISBRA tests the display would often lose its alignment, obliging the researcher to manually realign the cell. Once the new circuit design for the DISBRA 2.0 solved the energy supply problems, the occurrence of alignment problems dropped significantly, greatly improving the readability for the cell during long tests. The test results compare the effectiveness of reading only properly aligned characters in both DISBRA and DISBRA 2.0, comparing only the impacts of removing the use of the smartphone and the use of audio menus. The impact of this improvement for the alignment was not measured since there was no data to compare it to the original solution (Fig. 8).

With the use of two 3D printed extruded octagons, each forming half of a braille cell or digit, it is possible to form combinations of the dot arrangements shown in Fig. 6. These combinations are sufficient to assemble all the characters in Braille used for the Roman alphabet. The main advantage of DISBRA is its cost being approximately 30 dollars. This is not significantly impacted by adding MP3 reproduction and standalone navigation capabilities for the DISBRA 2.0 version. The cost of a DISBRA 2.0 is approximately 36 dollars. If the user decides not to install a Bluetooth module during the assembly, the cost of DISBRA 2.0 is reduced to 24 dollars.

Figure 9 shows a simplified scheme for DISBRA 2.0 electronics. The Braille cell digit for both DISBRA versions is composed of two 3D printed extruded octagons. The 3D model replicates a standard Braille cell. Each dot is 2 mm wide, 0.65 mm tall. The dots are 2.7 mm apart from each other, both vertically and horizontally. Each digit is attached to a stepper motor (model 28BYJ-48) as shown in Fig. 9. Each motor is connected to an Arduino nano ATmega328 for control and to the external power source for power supply. A Bluetooth module (HC-06) can also be connected to the solution to control

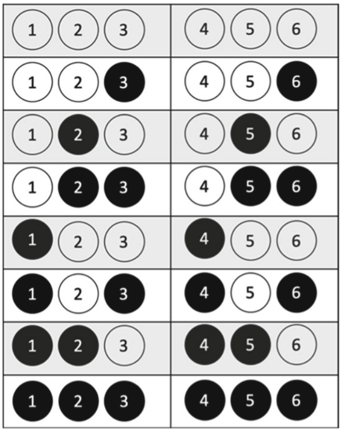

Fig. 8. The Dotted Faces for the Braille Cell [6], the cells filled in black show where the protuberances are on each face of the display digit.

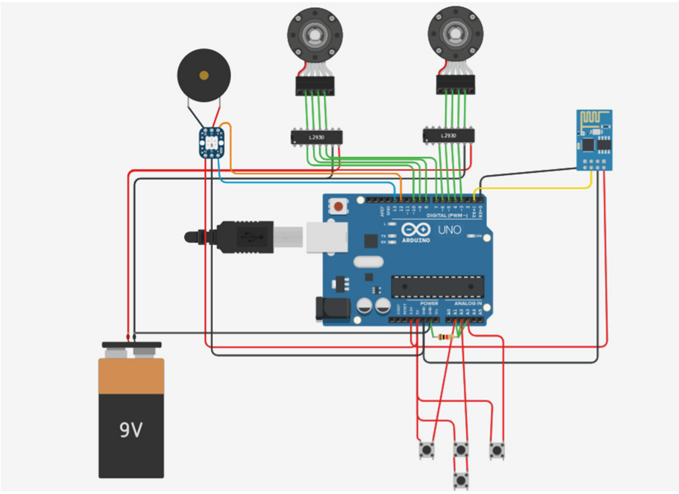

Fig. 9. Simplified electronic scheme for the DISBRA 2.0.

the display remotely and wirelessly. For the new user interface, 4 simple buttons are added, with a pull-down resistor for each. A DFPlayer mini is connected to the Arduino. This module reproduces MP3 audio files stored on a microSD card. The DFPlayer mini module controls a small speaker that is 40 mm wide, 0.5 W and 8 Ω.

4 Analysis

To validate the proposal, initial tests were carried out with 5 volunteers, the same number used in DISBRA tests. None of them had training or knew the Braille alphabet. This was also the setup for the tests using DISBRA [5]. Braille literacy for visually challenged people has the same procedure as normal educational methods have for people with vision [5].

The number of volunteers was based on [14]. The author affirms that 80% of the usability discoveries are found after testing the solution with only 5 volunteers.

Before testing and being evaluated on the DISBRA 2.0, the volunteers studied each module. They could spend as much time as they wanted on this phase. After they studied a module, a smaller test containing only the letters for that module was applied. If the results for this test were above or equal to 80%, the volunteers could advance to the next module. The final results are based on the sixth and final module. The volunteers were tested for all 26 letters in this module.

The volunteers had time to study the characters in DISBRA 2.0 and underwent a test, first with their eyes covered, then being able to see the Braille display. The success rate for character recognition using only touch was 68.46% while using the DISBRA 2.0. The same result for the original DISBRA was 69.23%. With the possibility of seeing the display, the success rate obtained by the volunteers using the new DISBRA 2.0 was 86.15%, results comparable to that of DISBRA. The volunteers for the previous research scored 86.82% of success in this scenario.

The researcher encouraged the volunteers to comment on the process and on their overall impression of DISBRA 2.0. Two of the points for improvement raised by the volunteers were the use of an amplifier in the speaker if the solution was ever to be used in environments with normal background noise, such as on the street; or adding a headphone entry for the purpose of listening more clearly to the menus. They also pointed out the possible use of different material for the elevated dots on the display, possibly metal spheres. Sometimes defects in 3D printing were enough to cause confusion between the characters. When this happened, the disks were re-printed and changed for the tests. They also asked for an adjustment in the distance of the disks that compose the cell, moving them apart a little, to improve readability for beginners. The volunteers had the opportunity to use DISBRA 2.0 during their training and tests, without the necessity of using an external control device. The navigation by audio menus had good feedback. The test results indicate that the teaching capabilities of the DISBRA was not diminished by removing the external component of a smartphone screen to guide the volunteers.

DISBRA 2.0 improves affordability and positively alters the use of DISBRA, becoming a completely standalone solution. This is achieved by reprogramming the Arduino solution to remove the necessity of the usage of smartphones or other external control devices. According to Kavitha, Privadarshini and Saradha [11], this type of solution (where the user has control over the display and receive feedbacks that can be evaluated) in the form of text or audio can be used for teaching Braille even when the tutors are not trained in Braille, or even so that these tutors can learn Braille without the need for extra assistance, enabling people without disabilities to learn Braille using only such a device.

5 Final Considerations

The objective of this research was to implement improvements in the DISBRA system, a low-cost Braille display which can be used in teaching Braille [5]. The enhancements were made in order to improve its viability, giving more freedom to users while also reducing its cost, proposing and implementing a new standalone solution, the DISBRA 2.0. There were also improvements to the prototype's circuit, based on the feedback for the alignment errors received during the tests of Version 1.0. The Braille teaching scenario still shows a deficit in tutors. The number of people with visual impairments will grow [4, 5]. Tools like the DISBRA could be used to help train new tutors.

Based on this observation, this work presented the DISBRA 2.0 with a series of improvements implemented with regard to DISBRA, while promoting a solution capable of teaching the identification of Braille characters and their correspondence to the Roman alphabet without the need for a human tutor. The tests results showed no significant loss of effectiveness in the teaching method by removing external control devices.

For future works, the researcher recommends the development of the improvements suggested during this evaluation, as well as new rounds of testing of the proposed solution with more volunteers. Use of the device for a longer period will allow for further evaluation of results for its use as a major tool for learning Braille.

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