Tactica: An Android-Based Low-Cost Assistive Tactile Device on Basic Braille Notation Reading for Visually Impaired Students in SPED Centers with IoT Technology

Dennis A. Martillano, Iyan Oliver A. Alvarez, Mark Isaiah O. Cataquian, Gabriel Jose S. Santiago, and Ken Michael M. Sevilla
Malayan Colleges Laguna, Pulo Diezmo, Cabuyao City Laguna 4025, Philippines
Email: dennis.martillano@upou.edu.ph, alvarez_iyan@yahoo.com.ph, {isaiahcataquian2, gjssantiago25, kenmichaelsevilla}@gmail.com

Abstract —Providing proper education for visually impaired students has been a challenge considering the scarcity in terms of resources provided. One of the reasons for the lack of resources is the prohibitive prices of available assistive technology for visually impaired students. Assistive technologies mainly for beginners are also limited as most products are for intermediate learners which can cause discouragement of Braille learning for students who have no prior knowledge to Braille. Also, technology that can provide basic learning in Braille for visually impaired people who are not school-based is limited. This study aims to improve the assistive technology for Braille notation reading by developing and designing an android-based improvised tactile braille device coined as TACTICA. TACTICA is a low-cost and portable assistive technology that can be used as a supplementary tool by teachers and visually impaired students who are beginners in braille notation. With the use of the Modified Nurun Based Methodology intended for IoT based projects based on the study [1], quantitative techniques were used for the analysis of the requirements, the iterative processes in the development of the device and the tests that will be performed for the whole system. The study focused on the used of improvised, low-cost and recyclable materials in creating the 3-character braille cells. The braille device was infused with microcontroller and IoT Technology that allows communication to a developed mobile application intended for Special Education (SPED) Teachers

Index Terms—Assistive technologies, braille, internet of things

I. Introduction

As a developing country, Philippines' access to assistive technologies is severely limited and there are not enough facilities to cater the increasing number of disabled children including visually impaired students. Attitudinal, institutional, structural, informational, and technological barriers in regular schools have significantly contributed in deprivation of right to education for visually impaired students [2]. Blindness in the Philippines is really an issue that is alarming for the nation. The limited access to assistive technologies that can provide appropriate learning style for children with visual impairment is one of the major reasons why there is an increase in the number of visually impaired students with poor educational attainment. It is evident that there is a need to improve the way assistive technology is provided for children with visual impairment to help them achieve their desired educational outcomes.

Based on the Philippine Senate Press Release in 2018, there are a total of 648 recognized SPED centers and regular schools who offer programs for disabled children including visually impaired students in the Philippines. Of this number, a total of 471 SPED centers and regular schools are catering elementary students and the remaining 177 are for catering the high school students. [3] The SPED program of Department of Education provides a general approach in catering the needs of student with disabilities. This program aims to provide access to quality education for learners with exceptionalities by giving them their individual and unique needs. In 2012, based on the SPED early enrolment in government elementary schools, it shows that there were 40,181 Children with Disabilities students enrolled in government schools. Of this number, 4,925 are visually impaired students. These statistics does not include other special cases where Visually Impaired learners are not school-based and/or remotely away from Special Education centers.

As a counteract to the limited access to assistive technologies, a new trend in technology such as the use of readily available low-cost microcontroller and Internet of Things are gradually implemented which can benefit people with disability by improving their quality of life. The term Internet of Things (IoT) generally refers to the connectivity and capability extended to everyday things being used that is not considered as computer. With the emergence of Internet of Things, it has drastically affect the everyday lives of people. It has become a solution not only for business, but also in government, transportations, and even education [4]. This has led the study to align the objectives to the use and integration of technologies mention herein.

The first objective of the study is to provide access to alternative assistive technology by developing an assistive Braille notation tactile reading device using a low-cost and readily available microcontroller and improvised tactile technology. The second objective is to

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Corresponding author email: dennis.martillano@upou.edu.ph
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design and develop a scaled, three-character Braille notation tactile reading device, incorporated with an audio and speech recognition system that will cater the needs of visually impaired students who are beginners in Braille notation reading. The last objective is to develop a portable Braille notation tactile reading device that allows device to device communication using an IoT technology that will provide basic learning for visually impaired students in community-based set-up by creating an android application that can connect with the device for students who are not school-based.

II. Literature Review

Assistive Technology is defined as any product, equipment, and software programs that help people with disabilities including visually impaired people to increase, maintain, and improve their functional capabilities [5]. Assistive Technology however, can only enhance students' basic skills, not replace them. It serves as an important tool in educational process. For visually impaired students, these assistive technologies are more than an educational tool, it is a Fundamental Work Tool that serves as their pen and paper allowing them to complete educational tasks and participate on class as well. Every visually impaired student's need are unique and should be matched with necessary tools or technology instead of matching the existing technology to the student needs. Functional use of these assistive technologies requires redundant sensory feedback. With this, it enables visually impaired students to maximize their communication rate and improve their literacy [6].

A. *Assistive Technology Tailored to Person with Visual Impairment Needs*

Assistive Technology enables visually impaired people to achieve educational success, improve their communication skills, and literacy that helps them to be more productive citizen and contribute to the development of society. The current challenge is to provide access and guidelines in the use of assistive technology for people with visual impairment. Although, there are a lot of new assistive technologies that are being created focused on helping the visually impaired people. Children which are often beginners are still having a difficult time using and familiarizing with these new devices due to the complication and the long period of time required to be adapted. Moreover, user might be overwhelmed by the device or technically intimidated because of too much functionalities and physical peripherals. Also, most of the devices require extensive configuration which is not applicable to children and/or beginners [7].

According to [8], there is no specific solution for access to appropriate assistive technology that is suitable to address the specific needs of every person with visual impairment. Even students with same visual loss may require different specification or type of assistive technology that is based on their distinct needs. And to be able to identify these unique needs of each student, collaboration between experts in education of students with visual impairments, general assistive technology, general educational technology and educational evaluators must be conducted.

III. Results and Discussions

In this study, a Modified Nurun-Based Prototyping, a prototyping method intended for the development of Internet of things projects was utilized. The methodology has 3 main stages. These are Research, Model, and Realize. In the Research Stage, the study collected insights and developed areas of opportunities leading to the objectives. The team analyzed the nature of the problem, learned the state of the teachers and students in a SPED Center and the technologies that they are currently using. The researchers visited a SPED Center in the to gather information about their current state in assisting visually impaired students. In the Model Stage, a rapid and iterative process was conducted to develop concepts and learn within a given time frame and tested per unit or module. The final prototype design and actual braille device was created in the realize stage solidified by a User Acceptance Test. Results of the test can be viewed in the succeeding part of this paper

Unit testing was performed by the developers in the development of the system to check the progress with the use of test cases. User acceptance testing was performed by the SPED teacher and visually impaired students in Carmona Elementary School to evaluate the aesthetics, usability and usefulness of both the mobile application and the device.

Table I to IV show the results of the performed unit testing. Unit testing is performed on the four components of the system which are Braille cells/dots, Wemos WIFI module (IoT Device), speech recognition module and the mobile application. Testing is done iteratively until passed remarks are achieved.

TABLE I: Unit Testing: Braille Cells/DOTS

Test No	Test Procedures	Materials/Data	Results	Remarks
1	Sending signals to emboss or engrave Braille dots	Arduino 12 v Power supply 18 Relay Switches Breadboard Connecting wires	All relay switches were able to run but some Braille dots did not emboss properly	Failed
2	Adjusting of relay extensions	Arduino 12 v Power supply 18 Relay Switches Breadboard Connecting wires	All Braille dots were able to emboss properly	Passed
3	Reducing the size of orifice of the Braille dots	Arduino 12 v Power supply 18 Relay Switches Breadboard Connecting wires	The size of the orifice is reduced however some of the Braille dots were affected and is not properly embossing.	Failed
4	Adjusting the position of Braille dots to emboss properly*	Arduino 12 v Power supply 18 Relay Switches Breadboard Connecting wires	The Braille dots were able to emboss properly	Passed

*Performed when Braille dots is not embossing properly.

TABLE II: UNIT TESTING: WEMOS WIFI MODULE

Test No	Test Procedures	Materials/Data	Results	Remarks
1	Sending of data from Wemos to Arduino	Wemos Arduino Connecting wires	Sending garbage data	Failed
2	Set a common ground for Wemos and Arduino and reduce baud rate of Arduino to Wemos from 115200 to 9600	Wemos Arduino Connecting wires	The data in form of string has been successfully transmitted	Passed

TABLE III: UNIT TESTING: SPEECH RECOGNITION MODULE

Test No	Test Procedures	Materials/Data	Results	Remarks
1	Integration of Google speech recognition to the android application	Android Application Google speech recognition intent	The speech recognition is working but failed to recognize some words	Failed
2	Integration of Google speech recognition to the android application incorporated with external microphone	Android Application Google speech recognition intent External Microphone	Better speech recognition is achieved	Passed

TABLE IV: UNIT TESTING: MOBILE APPLICATION

Test No	Test Procedures	Materials/Data	Results	Remarks
1	Adding of words in the word bank	Data in form of string	The words is validated and added successfully. Only 3-character words are accepted by the application	Passed
2	Creating of drills from the words added	Data in form of string Array of string	Drills are successfully created. Drills are validated with the range of 5-10 words	Passed
3	Viewing and emulating of drills	Array of string	The drills are able to be viewed and emulated showing the correct Braille equivalent of each word	Passed
4	Downloading and uploading of BRL files	Data in form of string	The string is successfully converted into a BRL file with the use of external software. The files are successfully retrieved and can be downloaded	Passed
5	Sending of drills to the device	Data in form of string Array of string	The data is successfully sent to the cloud server and is retrieved by the Wemos to the device	Passed

In the UAT conducted, the questions were aligned with the objectives of the study. The developers acquired the results of the evaluation done by the SPED teachers and visually impaired students of the identified SPED Center by calculating the averages of the ratings using a 4-Point Likert Scale. Students were supervised by the SPED teachers in answering UAT by providing them specialized printed braille embossed questions base on the instruments used. Both the averages of the questions' ratings which are related to the second objective for teachers and students are computed where the evaluation of the teachers got an average of 3.4 and the evaluation of the students got an average of 3.33. The general average is also computed where both averages of teachers and students were used.

Fig. 1. 4-Point likert scale interpretation

UAT Questions	Category	Rating	Interpretation
Teacher			
1.) The audio is helpful in assisting the students in using the device	Usability	4	Strongly Agree
2.) The Braille device provides basic Braille notations appropriate for beginners	Usefulness	4	Strongly Agree
3.) The speech recognition is assistive in terms of validating the students' answers	Usefulness	3	Agree
4.) The spacing, size and scale and 3 – Character design of the Braille device are suitable to notation reading	Aesthetics	3	Agree
5.) The improvised materials used and in the braille device are appropriate and are near the standards of some commercial braille devices	Aesthetics	3	Agree
	Average	3.4	Strongly Agree
Student			
1.) I can understand the instructions through the audio	Usability	3.67	Agree
2.) I can easily familiarized myself and use the Braille device at first try	Usability	3	Agree
3.) I can recognize if I am reading the letters and words correctly through the speech recognition	Usefulness	3.33	Agree
4.) I can practice basic Braille notation reading using the device	Usefulness	3.67	Agree
5.) I can easily adapt with the spacing, size and scale of the Braille device	Aesthetic	3	Agree
6.) I can easily recognize the characters	Aesthetic	3.33	Agree
7.) I can identify if the Braille dots are embossed or engraved in tutorial and drill mode	Usability	3.33	Agree
	Average	3.33	Strongly Agree
	General Average	3.37	Strongly Agree

Fig. 2. UAT summary based on objective 2.

UAT Questions	Category	Rating	Interpretation
Teacher			
1.) The device is portable enough with few required configurations	Usability	4	Strongly Agree
2.) The Braille device is capable of embossing or engraving the fetched words from the drill created through the mobile application via Wifi or Internet	Usefulness	4	Strongly Agree
3.) The Braille device is capable of of embossing or engraving the pre-defined words and characters in the tutorial mode	Usefulness	4	Strongly Agree
4.) The Braille device be readily used as a portable Braille device in school-based or community-based when needed	Usefulness	3	Agree
5.) The mobile application is able to add words that can be included in the drills	Usefulness	4	Strongly Agree
6.) The mobile application is able to create, view, and send different drills for the students	Usefulness	4	Strongly Agree
	Average	3.8	Strongly Agree
Student			
1.) I can use the tutorial by myself with minimal assistance of my teacher	Usefulness	3.33	Agree
2.) I can read the words in the drills sent by my teacher to the braille device	Usefulness	3	Agree
	Average	3.165	Agree
	General Average	3.48	Strongly Agree

Fig. 3. UAT summary based on objective 3.

Overall, the questions related to the second objective which is: "To design and develop a scaled, three-character Braille notation tactile reading device, incorporated with an audio and speech recognition system that will cater the needs of visually impaired students who are beginners in Braille notation reading" got a general average of 3.37 which has an interpretation of "Agree". The same procedure was used for the third objective which is: "To develop a portable Braille notation tactile reading device that allows device to device communication using an IoT technology that will provide basic learning for visually impaired students in community-based set-up. Both the averages of the questions' ratings for teachers and students were computed where the evaluation of the teachers got an average of 3.8 and the evaluation of the students got an average of 3.165. With this, the general average of the questions related to the third objective got a general average of 3.48 which has an interpretation of "Agree". Fig. 1 shows the 4-Point Likert Scale interpretation. Fig. 2 and Fig. 3 show the summary of the UAT conducted

An improvised tactile technology was used to create a low-cost Braille device. This is the main objective of this study. Braille devices are expensive because of the materials like solenoids which are used for the embossing and engraving of the Braille dots. Braille devices usually cost around Php 40,000 to Php 250,000 which greatly limits SPED schools or visually impaired people in having the chance to use it.

Fig. 4 shows the materials used to create the improvised tactile technology and the rest of the materials used to create the device. With the use of electronic relays, recycled plastic sticks, cardboard materials and papers, the study was able to create a tactile technology which has the same function as what is usually used on Braille devices like solenoids. Arduino mega is used to control what Braille dot to emboss and engrave. Overall, the device costs Php 3,870.00 which is dramatically lesser than the Braille devices sold in markets today as seen in the succeeding figure.

ITEM	PRICE	QTY	TOTAL PRICE
RELAY	₱35.00	18	₱630.00
HEADER PINS	₱35.00	2	₱70.00
ARDUINO MEGA 2560	₱835.00	1	₱835.00
WEMOS	₱380.00	1	₱380.00
FOLDER	₱7.00	1	₱7.00
BLACK BOX	₱105.00	2	₱210.00
SWITCH	₱15.00	18	₱270.00
PCB	₱45.00	2	₱90.00
CONNECTING WIRES	₱8.00	50	₱400.00
MICRO SD ADAPTER	₱180.00	1	₱180.00
AUDIO JACK	₱25.00	1	₱25.00
ADAPTER JACK BREADBOARD	₱165.00	1	₱165.00
TRANSISTOR	₱6.00	15	₱90.00
DIODE	₱2.00	10	₱20.00
RESISTOR	₱1.00	18	₱18.00
POWER BANK	₱480.00	1	₱480.00
GRAND TOTAL			₱3,870.00

Fig. 4. List of materials used for the device and its costs.

Fig. 5 shows the representation of how the improvised tactile technology works. The mechanism of the relay is used and an original concept in the study. Inside the relay is an electromagnet which creates magnetism when electricity flows in it. This is triggered by the output pins in the microcontroller. One Braille dot is supported by one relay. When the relay is switched on, the dot is engraved such that when the relay is switched off, the dot is embossed. Plastic stick was used as the Braille dots. It was used because it is light weight and can be easily supported by the relay and its size can be adjusted. A "stopper" which is made of paper is attached in the middle of the stick to control the height of the Braille dot and to prevent it from being pulled out of the device. In order to stabilize the position and the spacing of the plastic sticks with the relay, folder cardboard is used. The folder has six holes punched in it that represents one cell which has 6 Braille dots.

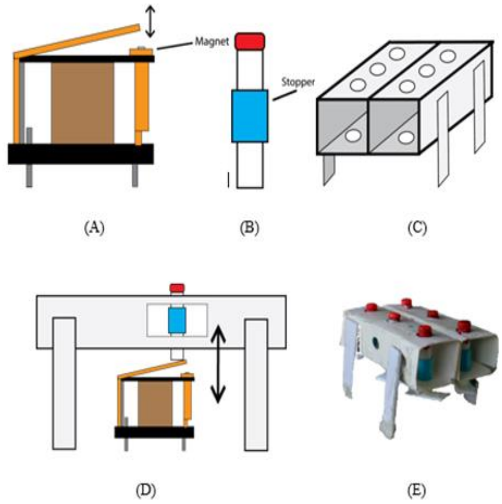

Fig. 5. Representation of improvised tactile technology (A) relay (B) plastic stick (C) folder (D) mechanism (E) actual improvised tactile technology.

Fig. 6 represents comparison of TACTICA's functionality compared to other existing Braille notation reading devices. The figure shows that TACTICA was able to perform the expected core functionalities of a Braille notation reading device such as embossing and engraving pins, refreshable Braille, speech recognition, and audio system. Also, TACTICA's cost is significantly lower compared to other existing devices which makes TACTICA accessible in terms of costs and functionality.

Product (Price)	Engrave and Emboss	Refreshable Braille	Speech Recognition	Audio System	Read Braille Notation	Internet Connectivity
TACTICA(₱3,870.00)	✓	✓	✓	✓	✗	✓
Braillex Apex BT (₱156,159.00 - ₱260,439.00)	✓	✗	✗	✗	✗	✓
Braillex Elba (₱208,299.00 - ₱307,365.00)	✗	✗	✗	✓	✓	✓
Optacon (₱52,140.00 - ₱260,700.00)	✗	✗	✗	✓	✓	✗
Braille Embosser (₱100,000.00 - ₱250,000.00)	✓	✗	✗	✗	✗	✗
Braille Typewriter (₱40,000.00)	✓	✗	✗	✗	✗	✗
BrailleNote (₱286,770.00)	✓	✓	✗	✗	✗	✗

Fig. 6. TACTICA's functionality compared to other existing braille reading device.

Fig. 7 shows the pictorial diagram of the device. The device is composed of 3 braille cells with 6 dots each. The cells are scaled in a bigger aspect to support the need of students who are just beginners in braille notations. The improvised tactile embosses and engraves accordingly base on the mode passed to it by a mobile application thorugh the IoT Technology. There are two modes: Tutorial Mode and Drill Mode. Tutorial Mode allows students to read basic characters and predefined words. The drill mode allows the teacher to pass series of 3-character words to the device. A speech recognition was integrated in the mobile app to assist in validating the answers while reading the words in the device. The teacher must use the mobile app's audio catch to allow the students to speak or tell the words being read one by one. An assistive audio system was also included in the braille device to prompt the students and the teacher on what to do in the drill mode.

In order to send drills from the mobile application and validate the answers through speech recognition, the device is connected to the internet or a wireless network if internet is not available with the use of Wemos which is an IoT enabled device that connects to WIFI.

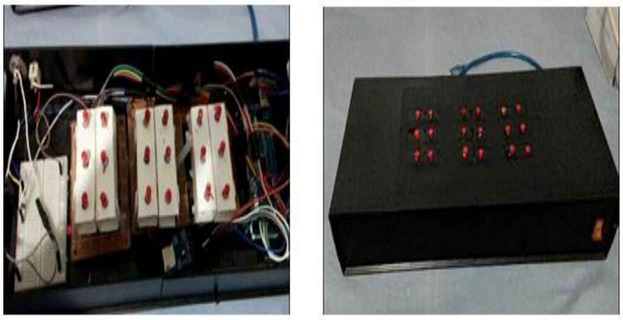

Fig. 7. Pictorial diagram of the device.

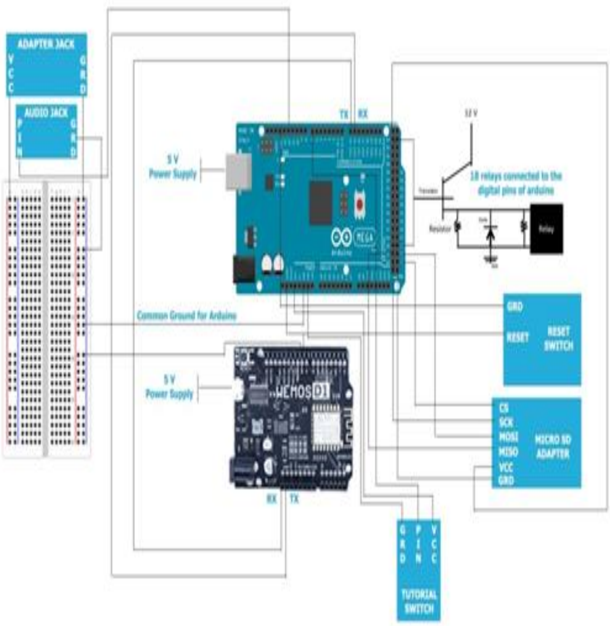

Fig. 8. Circuit diagram of the system

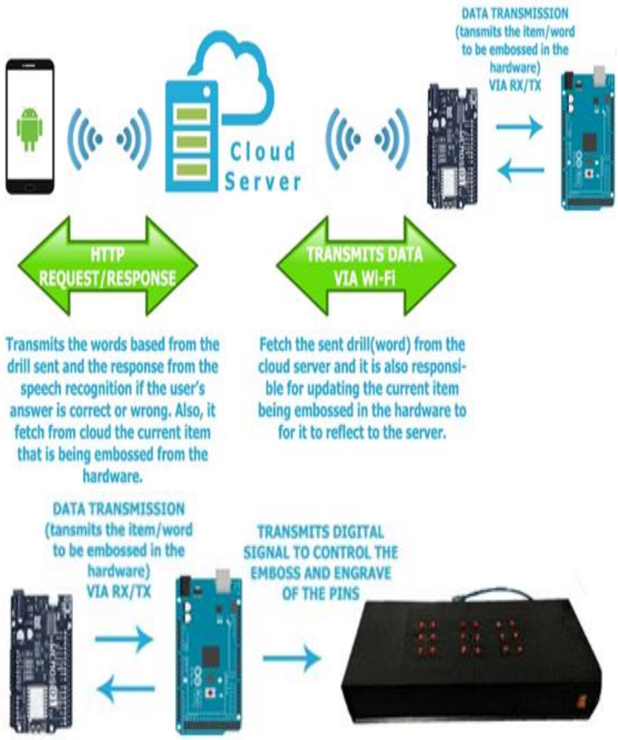

Fig. 9. Block diagram of the system setup.

(a)

Fig. 10-a. TACTICA mobile application interface for word bank, create drill, sending drills and the interface for the Speech Recognition.

(b)

Fig. 10-b. TACTICA mobile application interface for viewing drills, braille emulator and the special feature to upload and download BRL or Braille files that can be used by SPED teachers.

Fig. 8 shows the circuit diagram of the system. The circuit utilizes an Arduino microncroller, a Wemos WIFI board and shows the connection of a tactile dot through a relay swicth Figure 9 shows block diagram of the system setup.

This communication set -up is based on the study [9] that utilizes a Wemos WIFI module to transmit data via an http protocol between the mobile application and the braille device.

In the block diagram, the mobile application will send the data to the cloud server which contains the words or item from the drill sent. Second, Wemos wifi module will fetch the data sent by the android application and sends it to Arduino Mega via its RX/TX serial ports. Lastly, the Arduino Mega will transmit digital signal to control the embossing and engraving of the dots in the improvised tactile technology.

Fig. 10 a and b show the mobile application, the application allows the SPED teachers to view, create and send drills for students by adding or choosing words in the word bank. Drills from the application are sent to the device and is read by the students. Also, teachers could have a quick reference to the Braille equivalent of the words. Lastly, as an additional feature, the teachers can upload and download BRL files in the application which are used by some Braille embossers. The text inputted by the teacher to the application will be converted into a BRL file then the teachers can download and use the files that are created.

Fig. 11. Visually impaired students during the actual test of the braille device

From left to right.

Student Information	Type of Visual Impairment	Braille Reading Level
Vince (8 years old) not yet included in classroom	VI (Refracted Vision)	Level 1 Braille
Hanna (9 years old) with inclusion in normal classroom	Totally Blind (Inborn)	Level 1 – Level 2
Joy (11 years old) done with incubation leading to level 1 Braille	Totally Blind (Glaucoma)	Level 1

Fig. 12. Visually impaired students who tested the device and their profiles

Fig. 11 shows the actual picture of the Visually Impaired students who tested and used the developed brailled device. The testing was supervised and granted by the SPED Center and the SPED Teacher. Students were given time to familiarize themselves with the braille device before giving them tutotials and drills. The students who participated in the testing have different types of Visual Impairement as seen in the table within the figure in Fig. 12. This is important in order to get better results in terms of functionality and to check the capability of the device to adapt to different types of students who are beginners in braille notations.

IV. Conclusions and Recommendations

The study was able to develop an alternative assistive technology that can help visually impaired practice or learn Braille notation reading. The first objective was to provide access to alternative assistive technology for reading Braille notations and it was met by creating an improvised tactile technology with the use of low-cost microcontroller and materials like electronic relays, recycled plastic sticks, cardboard and paper. The second objective was to develop an assistive technology for visually impaired students who are beginners in Braille notation reading. This wa achieved by creating a device which is scaled and is minimized to 3-characters incorporated with speech recognition and audio technology. The third objective is to develop a portable Braille device that allows device to device communication using an IoT technology that will provide basic learning for visually impaired students in community-based set-up. This objective was met by creating a mobile application which can create, and view drills consisted of five to ten 3-character words which are passed and retrieved by the device.

Currently, the device is capable of embossing uncontracted words with the maximum of 3 characters. Also, the speech recognition is integrated in the mobile application where internet is required for its functionality. To further improve the system, the study would like to recommend the following as an extension to this study: (1) Increase the maximum number of characters and add the embossing of contracted words so that it can be used by visually impaired students who already have prior knowledge in Braille notation reading. This recommendation is also based from the suggestion of the SPED teacher that aligns to the embossing and engraving of words according to the level of the visually impaired students (2) Integrate the speech recognition within the device which will result to faster feedbacks and validations. (3) Include the embossing of numbers and symbols which can be very useful for mathematical operations. For the android application, saving words, BRL files, and drills are thorugh a cloud server, the developers recommend an additional module/function: Having an account for both the students and teachers to be able to save more data in the cloud server that can be used for displaying information to monitor the progress of the students, specifically, the student/teacher name, drill taken and its date, score, and words that the user got right or wrong.

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Dennis A. Martillano is a graduate of bachelor of science and computer engineering from STI College Southwoods. He has units in mathematics from the University of the Philippines and a master's degree holder in information technology. He is also a graduate degree holder in distance education from the University of the Philippines. He is currently taking up his doctor in information technology where he is specializing in medical data mining in Technological Institute of the Philippines. Currently, he is teaching in the College of Computer and Information Science at Malayan Colleges.

Iyan Oliver A. Alvarez is a graduate of bachelor of science in information technology student from Malayan Colleges Laguna. He lives in Santa Rosa, Laguna. He is knowledgeable in several programming languages, such as C++, C#, PHP, Java, Swift, and ASP.NET. One of his latest works is named 'TMS' or 'Time Management System' created during his internship days in Ampleon Semiconductor Philippines. He and his team also won 1st runner up in UMAK IT Olympics in the Mobile Application Category. Currently, he is working as a programmer in OOCL.

Mark Isaiah O. Cataquian graduated as a bachelor of science in information technology in Malayan Colleges Laguna and currently employed in accenture as an associate software engineer. He lives in San Pedro, Laguna. He is knowledgeable in several programming languages, such as C++, C#, Java, Swift and ASP. He also practice troubleshooting in both software and hardware during his internship in EMS Group Of Companies.

Gabriel Jose S. Santiago is a graduate of bachelor of science in information technology from Malayan Colleges Laguna. He lives in Santa Rosa, Laguna. He is knowledgeable in several programming languages such as C, C++, C, Java, and PHP. He has developed and design several websites during his internship at CREOTEC PHILIPPINES, INCORPORATED. He is also the lead developer of the android application that won as 1st runner up in UMAK IT Skills Olympics. Currently, he is an Associate Software Engineer in INFOR PSSC Incorporated.

Ken Michael M. Sevilla is a graduate of bachelor of science in information technology from Malayan Colleges Laguna. He lives in Sta. Rosa, Laguna. He is familiar with different programming languages such as C++, C#, PHP, Java, and ASP. He has developed different websites for Creotec Philippines Incorporated during his practicum like evaluation system and inventory system. He and his team also won 1st runner up in UMAK IT Olympics in the Mobile Application Category. Currently, he is a programmer in OOCL.