A Multifunctional Communication System for Differently Abled People

K.M.S.T. Gunaratne[1], V.P. Senanayaka[1], E.I. Walakuluarachchi[1], Lakmini Malasinghe[1]

[1]Department of Electrical and Electronic Engineering, Faculty of Engineering, Sri Lanka Institute of Information Technology, New Kandy Rd, Malabe, Sri Lanka

ABSTRACT

A person should be able to connect with other people to have a fulfilling life. Having challenges such as being blind, deaf, or mute is a significant concern in this matter. According to world statistics and research, it has shown that 0.2% of the world's population lives with severe deaf blindness. This project aims to design and develop a communication system to improve interactions between a person without any disability and a deaf-blind person or between two deaf-blind people. Each may communicate differently, so this system will have a textual display for those who can see, a speech output for those who can hear, and a tactile braille display for those who cannot see or hear. This system can benefit educational institutes and care homes facilitating people with the above disabilities. The primary purpose of this system is to make the differently abled people feel independent and confident by seeing, hearing, and talking to each other without facing the barriers in the translation.

KEYWORDS: *Visually Impaired, Deaf and Mute, Voice to Text, American Sign Language, Braille Keyboard, Hand Gestures, Convolution Neutral Networks.*

1 INTRODUCTION

Blindness is a visual impairment that significantly limits interaction, education, work, and independence. Deafness is a disability that weakens the hearing and causes them unable to hear, whereas mute is a disability that impairs speech and causes them unable to talk. People with disabilities like blindness, deafness, and muteness face many difficulties in their day-to-day life when communicating with each other and with a person without any disabilities. Due to the high negligence of the public on the importance of learning sign language and braille, the deaf-blind community had to be bound to a specific group where they associated with only a few numbers of people in the society. This situation has deprived many opportunities they would have received and their will to freely associate with the rest of the society.

When considering the Sri Lankan educational institutes, most of the schools dedicated for special need students operate while keeping the students away from their houses. Research carried out in association with the Lady Ridgway Hospital and the Riyanzi Alagiyawanna Special school revealed the following details supporting the project idea,

- Students having a severe deaf-blind condition are not capable of communicating with each other.
- Only a few numbers of hearing aids are available in the schools to be used by the students while they are expensive.
- Minimum human-computer interactions are used for the teaching and learning process.
- Having to allocate a translator to mediate a conversation is a hindrance to communication.
- Some students mentioned they are in need of a system where they can communicate with individuals who are completely unaware of the Sign Language or Braille.

https://doi.org/10.54389/RAUO7575

To address this problem, the project has a system to facilitate communication among impaired persons based on their ability. The device accepts the input message from the sender who has a disability and transforms it to be transmitted throughout the system under the selected mode. Once the message has been transmitted to the receiver, it is transformed again based on that person's preference. As outputs, there is a textual display for those who can see, a voice for those who can hear, and a tactile braille plate for those who cannot see or hear. To achieve this end goal, objectives were identified under three areas. First objective being the development of a Hand Gesture Recognition (HGR) system that detect the gestures related to the American Sign Language (ASL) given by the user and translate it to the required fields of voice, text, or braille to give an output. Second being the design and development of a braille input and output mechanism that take braille as an input and translate it to text, voice or take voice or hand gestures and translate them to braille outputs. Final objective for the design and development of a Voice Recognition System (VRS) for people without disabilities who are incapable of communicating with deaf, blind, or mute people.

The majority of the research attempts on developing an aid for differently abled people has been limited to a single study area, where it only addresses either deaf, blind, or mute scenarios. This novel approach addresses all three areas and developed as a single product could enhance the effectiveness of the communication among above-mentioned community.

1.1 Related Work

Hand Gesture Recognition

The ability to communicate is essential to human existence. It is a simple and efficient way to express ideas, emotions, and opinions. But a significant percentage of the world's population lacks this ability. Sign Language (SL) is an extremely useful tool for deaf and mute persons to communicate in everyday life. Sign Language Recognition (SLR) is an issue that has been researched for decades. Nevertheless, our society is still far from having a perfect solution. Even though developing such technologies can be extremely difficult due to the existence of multiple sign languages and a lack of large datasets, recent breakthroughs in Artificial Intelligence and Machine Learning have played a vital role in automating and upgrading such systems.

The Static Gesture Recognition consists of two distinct operating phases: Training and Recognition. Training is considered an offline activity. It is only relevant when users wish to add new movements to the database of sign motions. The hand movements are detected in real time by the recognizing phase. The backbone of the system is made up of three major modules (V. Nguyen, M. Chew and S. Demidenko, 2015): Pre-Process, Descriptor, and Classifier. During the training phase, a variety of training images are analyzed, described, and stored in the sign database alongside their corresponding text.

Various communities have conducted extensive research on sign recognition. Research on hand gestures can be divided into three categories (Klimis Symeonidis, 2000): glove-based, vision-based, and study of drawing gestures. A new system-prototype called the “Sharojan Bridge” to facilitate deaf-blind community in their communication needs. In the Sharojan Bridge, they used a wearable technology to acquire the hand gestures using the sensors fixed to a pair of gloves (Rastogi, Rohit, Shashank Mittal, and Sajan Agarwal, 2015). “MyVox”; a communication device that has proven to be a valuable tool for an “Usher Syndrome” patient who can now interact with people without the aid of an interpreter (F. Ramirez-Garibay, C. M. Olivarria, A. F. Eufracio Aguilera and J. C. Huegel, 2014). Research was conducted in Spain to enable hard of hearing people to interact effectively with others. The goal of that study was to let deaf and hard of hearing persons communicate with one other without learning sign language. They created a tool that makes use of a 3G mobile device's video calling function (Fernando López, Javier Tejedor, 2006). Research to produce a prototype that can translate signs to voice (Foong, Oi Mean, Tan Jung Low, and Satrio Wibowo, 2008). In this system, it was created utilizing a "Feed Forward Neural Network." For the prototype, sets of universal hand signs were recorded using a video camera and used to train an artificial intelligent tool. Following development and testing, the Neural Network system produced satisfactory results. For 70 input photos, the system achieved a recognition rate of 78.6%. (Prateem Chakraborty, Prashant Sarawgi, Ankit Mehrotra, Gaurav Agarwal, Ratika Pradhan, 2008) provided four basic yet effective approaches for implementing hand gesture recognition:

Subtraction, Gradient, PCA, and Rotation Invariant. The methods used to retrieve the correct matches were successful.

The difficulties in creating sign language recognition extend from picture acquisition to classification. Researchers are currently trying to figure out the optimal approach for acquiring images. Gathering photos with a camera introduces the challenges of image pre-processing.

Voice Recognition

Usually, the voice recognition is accomplished by employing the most popular kind of headphones. Audio streams from regular and blind users should be recorded and at all times while recording, the microphone is placed on the tip of the tongue, allowing ambient noise to be reduced (Extended Abstract: Write Like You Talk? Research on the Effects of Voice to Text Applications When Used as Part of the Writing Process, 2015). When comparing ambient audio levels (acoustic energy in certain circumstances) with newly recorded samples, this might be a good place to start. Speakers tend to leave "artifacts" like as breaths/sighs, teeth speak, and echo, making endpoint detection more difficult. By normalizing and reducing any noise created during encoding, the features can be extracted accurately. East Subtraction using picture averaging filters (E.g., Cepstral mean) (CMS) (A New Technique for Speaker-independent Isolated Word Recognition, 2002). The provision of a keypad-based gadget for impaired individuals who are unable to communicate verbally is the primary aim of this initiative. The ARP9600 is a voice module that enables users to pre-record a voice and keep it in the device memory. Each button on the device is associated with a certain activity and has a pre-recorded voice that could be modified according to the preferences of the user. The acceleration sensor detects any shifts in the orientation of the head, and then transmits that data to the microcontroller for processing. The microcontroller is responsible for controlling the device in left, right, front, and rear directions depending on the direction of the acceleration. Therefore, the device enables users to tap the words they wish to communicate from the device keyboard, which consists of pre-prepared words or phrases, or by using head movements, which are then converted into audio phrases. Additionally, the device also enables users to use a combination of both methods (Python Speech Recognition Module - a Complete Introduction - AskPython, 2021).

Braille System

1. Braille Language

Each braille character or "cell" is made up of six dot places. These dot placements make a rectangle with two columns of three dots each. At any of the six spots, a single dot or any combination of dots may be raised. There are 64 English braille options in all, counting spaces with no dots. When referring to a braille character, the places where dots are elevated can be described. Each dot within a cell is assigned a number. As shown in Figure 1, the dots are generally numbered 1 through 6 from top left to lower left.

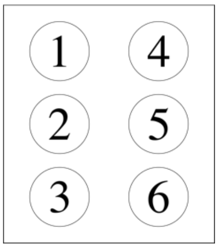


Figure 1. Braille Cell.

The equivalent written text is translated into grade one braille exactly letter for letter. This is the greatest code for beginners to use since it helps them become familiar with the code and understand many of the code's properties as they are learning to read braille. English grade 1 braille includes of the alphabet's 26 regular letters as well as punctuation as shown in the Figure 2. braille for the first grade of English includes all 26 regular letters of the alphabet in addition to punctuation marks.

Figure 2. Braille Characters.

Contracted braille is the usual approach for replicating most textbooks and publications. Cells are used separately or in conjunction with others in this system to generate a variety of contractions or full words. Uncontracted braille, for example as shown in Figure 3, takes twelve cell spaces for the sentence “you like him”. This is how it would look,

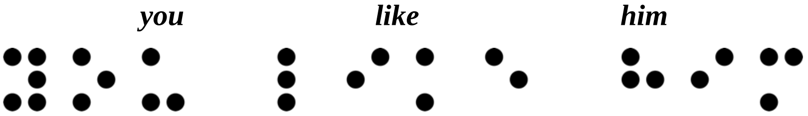


Figure 3. Uncontracted Braille sign for 'you like him'.

This identical phrase would require only six cell spaces to write in contracted braille. This is since the letters y and l are also used for the whole words you and like. Similarly, the letter h and m are combined to make the word him. This is how it would look as in the Figure 4,

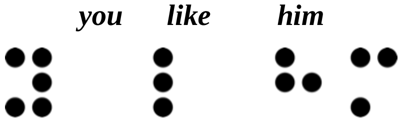


Figure 4. Contracted Braille sign for 'you like him'.

2. Solenoids

A solenoid is an electronic device that features a coil of wire, a casing, and a movable plunger (armature). As soon as electricity is sent through the coil, a magnetic field is created that pulls the plunger in. A solenoid, put another way, is a device that transforms electrical energy into mechanical work. Solenoids can be broken down further into subcategories as in the Table 1 according on its construction, style, and intended use.

Table 1 - Types of Solenoids.

Solenoid	Details
DC – C Frame Solenoid	Solenoid construction is referred to as a "C frame" in this context. The DC C-Frame solenoid consists of only a C-shaped frame that encloses the coil.
DC – D Frame Solenoid	A D-frame solenoid's regulated stroke action and compatibility with AC power make it functionally equivalent to a C-frame solenoid.
Linear Solenoid	Most individuals have encountered linear solenoids in the past. To exert a pulling or pushing force on a mechanical component, we use a torsion spring, which consists of a coil of wire wound around a moveable metal core.
Rotary Solenoid	A rotary solenoid is a special kind of solenoid that may be utilized whenever simple automated control is required. Like other solenoids, it consists of a coil and a core, but its function differs from the norm.

2 METHODOLOGY

Figure 5 shows the design block diagram of the entire system. The inputs and the outputs are indicated clearly to have a proper understanding on the intended deliverables of the project. Some of the main potential combinations of blindness, deafness, and muteness that a person may experience will be considered in this approach. The device will accept the input message from the sender who has a disability and transform it to be transmitted throughout the system depending on the requirements. Once the message has been transmitted to the receiver, it is transformed again based on that person's abilities and preference.

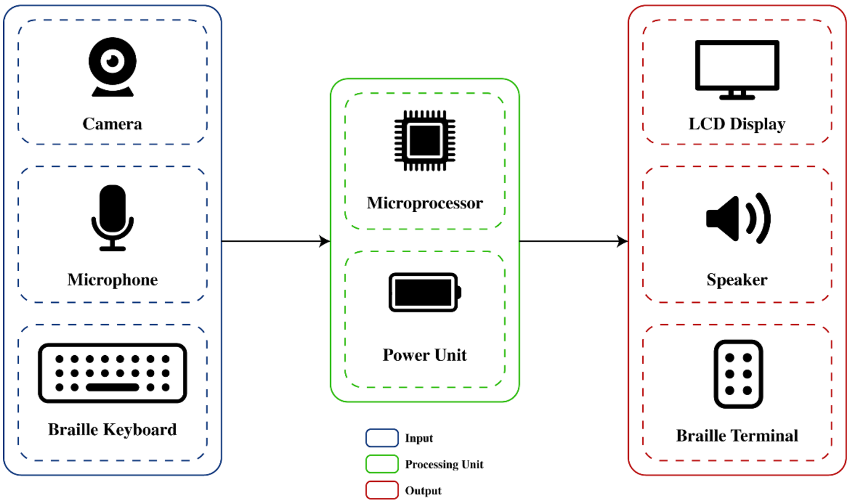


Figure 5. Design Overview.

For example, when considering an instance where two people trying to communicate; one experiencing an inability in both hearing and talking (Person A) while the other person is all deaf, blind, and mute (Person B). In such a case, person 'A' will give inputs to the system using hand gestures (Sign language). Using the hand gesture recognition, the system will identify this message and convert it into a text message which will reconverted into a braille output as per the requirement of person 'B'. This can be done in the other way around when person 'B' tries to respond to the message given by the person 'A'as in the Figure 6.

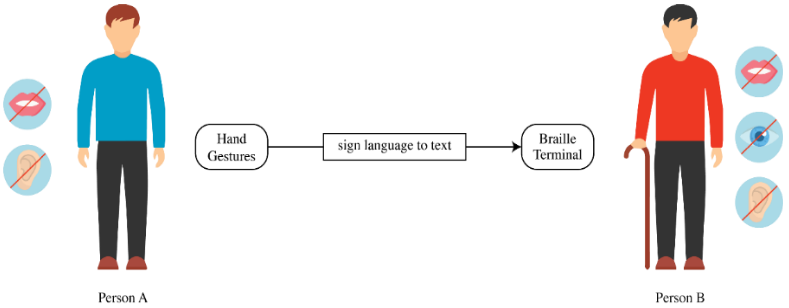


Figure 6. Communication between two differently abled people.

As the proposed design contains three main parts, Hand Gesture Recognition system, Braille system and the Speech Recognition system, each part needs to be discussed separately.

2.1 Hand Gesture Recognition System

Methodology can be divided mainly into 3 parts for the ease of explaining the Hand Gesture Recognition process as follows,

1. Collecting the data and storing them in directories.
2. Training the model.
3. Live prediction of the hand gestures.

Methodology flowchart in Figure 7 further describes the procedure involved in the design methodology from image capturing to the live prediction of hand gestures.

Figure 7. Methodology flowchart for HGR system.

.

Collecting the data and storing them in directories.

Sign language recognition is a complex and frequently undervalued problem involving numerous streams of asynchronously integrated multi-modal articulators (hand shape, orientation, movement, upper body, and face). This step involves, creating the database required for the testing and training of the model. This will collect webcam photos using the OpenCV library, generating one or more datasets based on input, putting them in folders, and pursuing them based on classes. Figure 8 shows the capturing of testing images related to the number 1.

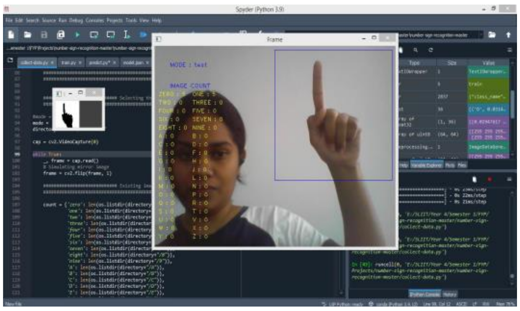


Figure 8. Capturing images.

Those images were subjected to grey scaling, resizing and binary thresholding. After prepossessing, the images were saved in the created destination folder. Addition or removal of the alpha channel, channel reversal, conversion to or from 16-bit RGB color (R5:G6:B5 or R5:G5:B5), and conversion to or from grayscale are all examples of transformations carried out within the RGB space using the Eqs (1) – (2),

$$\mathrm{RGB[A]to\ Gray: Y} \leftarrow 0.299 \cdot \mathrm{R} + 0.587 \cdot \mathrm{G} + 0.114 \cdot \mathrm{B} \tag{1}$$

$$\mathrm{Gray\ to\ RGB[A]: R} \leftarrow \mathrm{Y}, \mathrm{G} \leftarrow \mathrm{Y}, \mathrm{B} \leftarrow \mathrm{Y}, \mathrm{A} \leftarrow \max(\mathrm{ChannelRange}) \tag{2}$$

The Eq (3) describe how the function converts a grayscale image to a binary image.

$$\mathrm{dst}(\mathbf{x}, \mathbf{y}) = \begin{cases} \mathrm{maxval} & \text{if } \quad \mathrm{src}(\mathbf{x}, \mathbf{y}) > \mathrm{thresh} \\ \mathbf{0} & \text{otherwise} \end{cases} \tag{3}$$

Processed dataset was used for the final prediction to increase the accuracy of the prediction. Figure 9 shows the processed image after capturing.

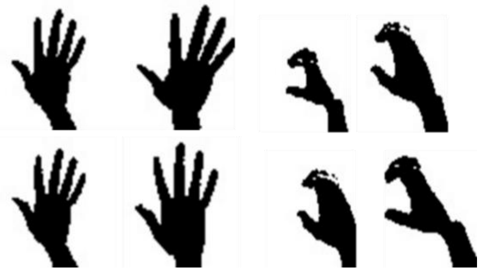


Figure 9. Processed images for the number 5 and letter C.

Training the Model

The models are trained with TensorFlow and Keras, and the Convolutional Neural Network is trained on these models. The Sequential model is employed here. This approach is utilized when the user simultaneously has one input and one output. The development of a Convolutional Neural Network is always comprised of four key steps. They are the,

1. Convolution
2. Pooling
3. Flattening
4. Full Connection

The first convolutional layer will modify the image input tensor and produce a convoluted matrix. The generated matrices will be integrated and combined into a single matrix. The 2-D convolution mathematical formulation is provided by Eq (4),

$$y[i, j] = \sum_{m=-\infty}^{\infty} \sum_{n=-\infty}^{\infty} h[m, n] \cdot x[i - m, j - n] \tag{4}$$

Where x is the input image matrix to be convolved with the kernel matrix h to produce a new matrix y representing the output picture. The indices I and j are engaged with image matrices, whereas m and n are concerned with kernel matrices. If the kernel size in convolution is 3 x 3, then the indices m and n extend from -1 to 1. The two activation functions are ReLU (Rectified Linear Unit) and Softmax. The activation is linear for input values greater than zero or more precisely as in the Eq (5),

$$R(z) = \begin{cases} z & if\ z \geq 0 \\ 0 & otherwise \end{cases} \tag{5}$$

The primary catch here is that the ReLU function does not activate all neurons simultaneously. The neurons will be deactivated only if the linear transformation's output is less than 0. Compared to the sigmoid and tanh functions, the ReLU function is significantly more computationally efficient since only a limited number of neurons are engaged.

After the convolution, the matrix is subjected to Max-Pooling to reduce its size, which aids in efficient determination. Max-Pooling is employed as the maximum pixel value. The second Convolutional Layer is added to enhance the detection efficiency. The subsequent step is to flatten the layers and connect them to create a complete neural network. The trained model should be fitted to the collected image dataset as the final step in training a CNN model. However, pre-processing must be performed to prevent overfitting. Overfitting nodes from one layer to the following results in high training and low-test accuracy.

Live Prediction of the Hand Gestures

The model will predict the gesture when it was performed inside the region of interest. The predicted gesture will be displayed on the frame real time. The final step of Hand Gesture Recognition is to output the predicted letter as a text. That text will be taken as input to the development carried out by the member 2 in this multifunctional system. Figure 10 shows the prediction window of live gesture related to the number 6.

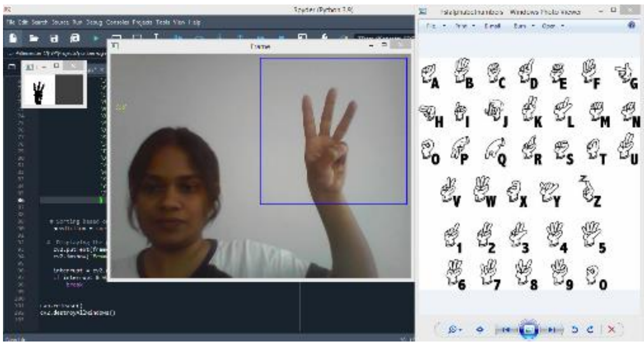


Figure 10. Predicting the live gesture for number 6.

2.2 Voice Recognition System

Here, the focus is primarily on people without disabilities in talking, listening, and hearing but unable to see (blind). The development was initiated by converting audio messages to text and displaying that on a screen.

1. ASL gestures converts to text file then it converts to selected output.
2. Braille inputs converts to text file then it converts to the selected output.
3. Voice inputs convert to the text file and then it converts to the selected output.

Text to Voice Conversion

Several APIs in Python can convert text into speech. A straightforward application called gTTS converts text input into audio that may be saved as an mp3 file. The speech can be delivered at either the speed or slow of the two available audio rates. Text to voice convention helps to convert all text comes from difference inputs to convert to mp3 audio file. It will enable the communication between,

- Deaf people– Normal people
- Blind people – Normal people
- Mute people – Normal people
- Mute people -Blind people

The text-to-speech API of Google Translate is interfaced using the Python library and CLI utility gTTS (Google Text-to-Speech). Write spoken mp3 data to stout, a file, or a byte string for additional audio editing. Alternatively, create Google Translate TTS request URLs in advance and pass them to an external software. Features of the gTTS are customizable text pre-processors that, for example, can correct pronunciation to be used to read texts of any length while maintaining accurate intonation, abbreviations, decimals, and sentence tokenism that are particular to speech.

Voice to Speech Conversion

Conversion of speech to text and display Attached to the microcontroller is a microphone module that does the conversions. Using a microcontroller, the audio signal is transformed into text form.

- Identification of the captured voice signal.
- Send the instruction to the microcontroller through the wireless connection.
- Send converted signal to the display.

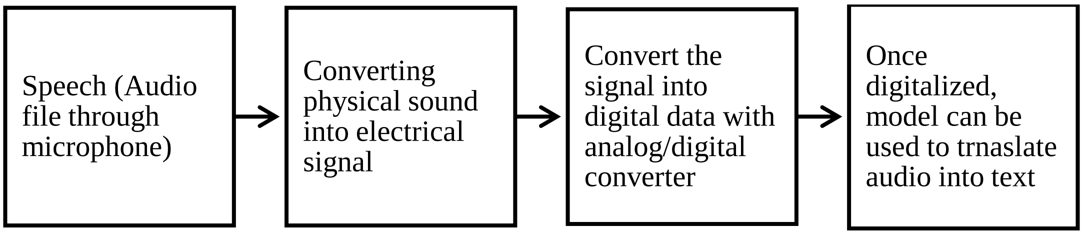


Figure 11. Overview of speech to text.

At its most fundamental level, human speech consists of nothing more than a wave of sound. These sound waves or audio signals have several properties that may be described in terms of acoustics. These characteristics include amplitude, peak, trough, crest, and trough, as well as wavelength, cycle, and frequency. These audio signals are continuous, which means that they include an infinite amount of data points. To transform such an audio signal into a digital signal that can be processed by a computer, the network must collect a discrete sample distribution that comes extremely near to simulating the continuity of an audio signal.

2.3 Braille System

Braille Input System

In this multi communication device, there is a keyboard with 8 keys on it. 1 to 6 keys represent the braille cell and each six dot locations organized in a rectangle with two columns of three dots each. There are two more additional keys and, [#] is for change the character type (example – letters to numbers) and, [TT] is for change the capital simple of the letters. The keys in this keyboard are planned to make using push buttons and add key caps with relevant numbers and icons on it. Tactile push buttons were used for braille keyboard.

Braille Output System

Blind and low-vision readers use a light touch to move from left to right across the page. To detect the raised dots, you'll want to use the softer pads of your fingers, which are more attuned to touch than your fingertips. Many people who can see can learn braille simply by looking at the letters. Although a keen sense of touch is required for reading braille, many people are pleasantly surprised at how quickly their fingers become more sensitive after some practice. 12VDC Push-Pull solenoids, as shown in the Figure 12 were used to implement this physical braille dot output. According to the relevant input, solenoids were come out and blind people can easily touch the surface and get the message. Instead of using these solenoids, 6 LEDs used on this project to demonstrate the braille output mechanism easily.

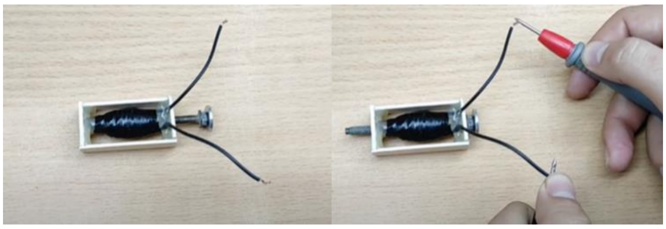
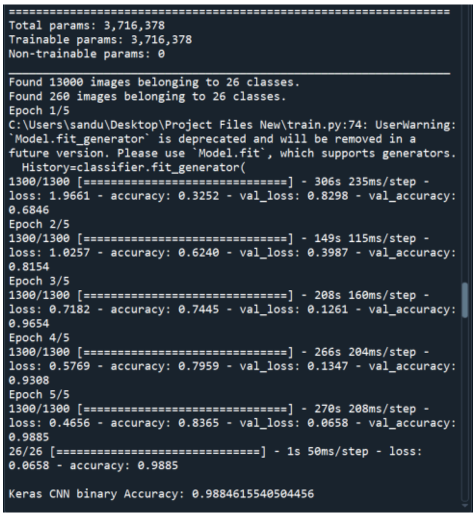


Figure 12. Pull and Push state of the Solenoid.

3 RESULTS

Figure 13 shows the summary of the classifier obtained through `classifier.summary().` At the end of the training, the model was able to obtain an accuracy of 98.85% for the Hand Gesture Recognition System for 260 test images where it could detect and predict letters of the English alphabet.



```
=================================================================
Total params: 3,716,378
Trainable params: 3,716,378
Non-trainable params: 0
_________________________________________________________________
Found 13000 images belonging to 26 classes.
Found 260 images belonging to 26 classes.
Epoch 1/5
C:\Users\sandu\Desktop\Project Files New\train.py:74: UserWarning:
`Model.fit_generator` is deprecated and will be removed in a
future version. Please use `Model.fit`, which supports generators.
  History=classifier.fit_generator(
1300/1300 [==============================] - 306s 235ms/step -
loss: 1.9661 - accuracy: 0.3252 - val_loss: 0.8298 - val_accuracy:
0.6846
Epoch 2/5
1300/1300 [==============================] - 149s 115ms/step -
loss: 1.0257 - accuracy: 0.6240 - val_loss: 0.3987 - val_accuracy:
0.8154
Epoch 3/5
1300/1300 [==============================] - 208s 160ms/step -
loss: 0.7182 - accuracy: 0.7445 - val_loss: 0.1261 - val_accuracy:
0.9654
Epoch 4/5
1300/1300 [==============================] - 266s 204ms/step -
loss: 0.5769 - accuracy: 0.7959 - val_loss: 0.1347 - val_accuracy:
0.9308
Epoch 5/5
1300/1300 [==============================] - 270s 208ms/step -
loss: 0.4656 - accuracy: 0.8365 - val_loss: 0.0658 - val_accuracy:
0.9885
26/26 [==============================] - 1s 50ms/step - loss:
0.0658 - accuracy: 0.9885

Keras CNN binary Accuracy: 0.9884615540504456
```

Figure 13. Summary of the Sequential Classifier.

Figures from 14-17 shows the final product that was developed assembling all the systems of Hand Gesture Recognition, Braille System and the Voice to Text Conversion System.

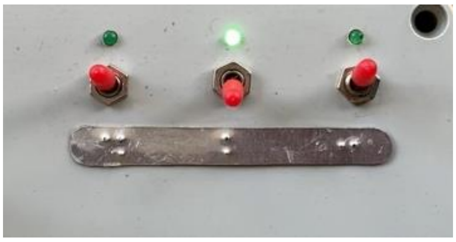


Figure 15. Switches to change the operating mode.

Figure 14. Power Supply.

Switches in the Figure 15 are used to switch between the modes of outputs. Those were the LCD display, speaker, and the braille display.

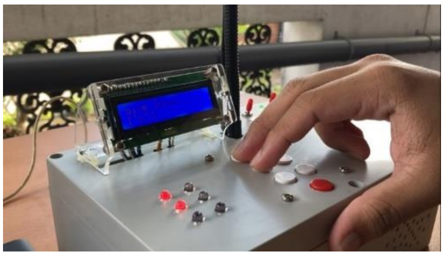


Figure 17. Braille output through keyboard and display.

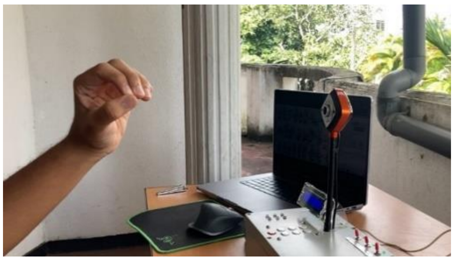


Figure 16. Hand Gesture inputs.

In Figure 16, tactile buttons are used to give the input as braille characters. In Figure 17, the hand gestures are performed in front of the camera are detected by the system and can be converted to both text through the LCD display and voice through the speaker.

4 CONCLUSION

While conducting the designing and the implementation phase, one of the major problems encountered was the need of heavy computational power when training the model; took a long time for the training process. Initially the training set was 3000 per each letter of the alphabet with a total of 78,000 images. But that had to be reduced to 13,000 images having 500 test images for each due to the long hours for training. Also, several lags were observed with the obtained output, especially with the webcam capturing the live frames. Unavailability of the required electronic components like solenoids made some hardware changes in the final product. However, all the intended objectives were successfully achieved with the development of the final product. The Hand Gesture Recognition system was completed with a higher accuracy of 98.85% and capable of detecting ASL gestures performed by the user in real-time. Furthermore, users accessing the braille mode can input braille signs using the braille keyboard and get the output through tactile braille terminal. The application development was simplified while using this tool with Python being the programming language of choice.

Also, there are various possible future developments identified while concluding the project. Major one of them being the use of dynamic hand gestures for the identification and employing Sinhala language for Hand Gesture Detection and Voice Recognition. In conclusion, the project was a success in reaching the end goal as well as bringing something useful to the society. Working on this project provided exposure to new technology areas and a vast amount of knowledge. In addition to technical skills, research and documentation were acquired as soft skills that will be useful in future endeavors.

REFERENCES

Nguyen, Chew, & Demidenko. (2015, April). Vietnamese Sign Language Reader using Intel Creative Senz3D. *Researchgate*. Retrieved December 22, 2022, from https://www.researchgate.net/publication/282311300_Vietnamese_sign_language_reader_using_Intel_Creative_Senz3D

Symeonidis. (2000, August 23). Hand Gesture Recognition Using Neural Networks. Retrieved December 22, 2022.

(2015, May 4). A novel approach for communication among Blind, Deaf and Dumb people. *IEEE Xplore*. Retrieved December 22, 2022, from https://ieeexplore.ieee.org/abstract/document/7100321

(2020, June 6). Wearable Assistive Tactile Communication Interface Based on Integrated Touch Sensors and Actuators. *IEEE Xplore.* Retrieved December 22, 2022, from https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9076597

López, F., & Tejedor, J. (2000). Augmented Service for Deaf People Using a Text to Sign Language Translator. *Academia.edu*. Retrieved December 22, 2022, from https://www.academia.edu/16702795/Augmented_Service_for_Deaf_People_Using_a_Text_to_Sign_Language_Translator

Wibowo, S. (2008). Hand Gesture Recognition: Sign to Voice System (S2V). *Academia.edu.* Retrieved December 22, 2022, from https://www.academia.edu/47956318/Hand_Gesture_Recognition_Sign_to_Voice_System_S2V_

(2008, March). Dynamic Hand Gesture Recognition for Human Computer interaction; A Comparative Study. *Academia.edu*. Retrieved December 22, 2022, from https://www.iaeng.org/publication/IMECS2008/IMECS2008_pp388-393.pdf

What Is Braille? (2012). The American Foundation for the Blind. Retrieved December 29, 2022, from https://www.afb.org/blindness-and-low-vision/braille/what-braille

libbraille.org. (2018, December 6). How Alphabets and Numbers Are Written In The Script? *libbraille.org*. Retrieved December 29, 2022, from https://libbraille.org/how-alphabets-and-numbers-are-written-in-the-script/

(2011). What Is Braille? Retrieved December 29, 2022, from https://www.lvib.org/what-is-braille/

(2012, August 25). Solenoid 101: What is a Solenoid? | *TLX Technologies*. Retrieved December 29, 2022, from https://www.tlxtech.com/articles/solenoid-101-what-is-a-solenoid

Kumar. (2019, September 26). An Introduction to Solenoids. What Is a Solenoid- Its Working Principle and Types | *Circuit Digest*. Retrieved December 29, 2022, from https://circuitdigest.com/article/what-is-solenoid-its-working-principle-and-types

Research on the Effects of Voice to Text Applications When Used as Part of the Writing Process. *IEEE Conference Publication | IEEE Xplore*. Retrieved December 29, 2022, from https://ieeexplore.ieee.org/document/7235820

A new technique for speaker-independent isolated word recognition. (2002, April 14). *IEEE Conference Publication | IEEE Xplore*. Retrieved May 22, 2022, from https://ieeexplore.ieee.org/document/196546

An automatic speech recognition system on DSP board. (2017, July 13). *IEEE Conference Publication | IEEE Xplore*. Retrieved May 31, 2022, from https://ieeexplore.ieee.org/document/7973913

Python Speech Recognition Module - A Complete Introduction. (2021, May 19). *AskPython.* Retrieved June 29, 2022, from https://www.askpython.com/python-modules/speech-recognition.