

## PROTOTYPING OF A SIGN LANGUAGE ROBOTIC HAND USING LOCAL MATERIALS

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### ABSTRACT

People living with disability constitute a significant percentage of the world population. For many people with disabilities, assistance and support are prerequisites for participating in societal activities. This research work developed a hardware prototype of a robotic hand for sign language communication with persons living with hard of hearing disability (deaf and/or dumb). The prototype has three basic modules: input unit, control unit and the robotic hand. The input unit is designed as an Android-based mobile application with speech recognition capabilities while the control unit is ATMEGA 2560 microcontroller board. The robotic hand is constructed using locally available materials (bathroom Slippers, expandable rubber, straw pipe, and tiny rope) together with three servo motors and designed to look and perform movements similar to a human hand. The prototype was evaluated quantitatively in terms of empirical accuracy and response time. It was also evaluated qualitatively by thirty-five (35) users, including two sign language experts, who completed questionnaires to rate the prototype on a 5-point Likert scale in terms of five parameters: functionality, reliability, ease of use, efficiency and portability. An accuracy of 78.43% with an average response time of 2seconds was obtained from empirical experiments. Statistical analysis of user responses showed that 97%, 68%, 77%, 80% and 83% of users rated the system as above average for functionality, reliability, ease of use, efficiency, and portability, respectively. The robotic hand effectively communicates American Sign Language which includes English Alphabets, numbers (1-9) and some selected common words, which can be demonstrated with a single hand for hard of hearing persons. The prototype can be improved by extending the single robotic hand to a full robotic body with two hands.

**Keywords:** Android, Communication, Deaf, Disability, Dumb, Hardware, Mobile App, Robotics, Sign Language, Speech Recognition.

### 1. INTRODUCTION

Disability refers to an individual limitation or restriction of an activity as a result of impairment

(Srivastava & Kumar, 2015). It is a physical or mental impairment which limits an individual's movement, senses or activities (Kuyini et al., 2015). People living with disabilities constitute a significant percentage of the world population. Several efforts have been made to provide assistance for people with disabilities. For instance, an advocate helps to support intellectual impairment person, a person can hold those that are blind to direct their way and a sign language interpreter is used to communicate with hard of hearing persons (World Health Organization (WHO), 2021).

Sign language interpreters are professionals whose job is to accurately translate a spoken language, such as English, into special gestures understood by the hard of hearing persons. Sign language primarily consist of hand gestures which uses visually transmitted sign patterns to convey meaning. It is the combination of hand shapes, orientation and movement of hands, arms or body, and facial expressions (Adeyanju et al., 2021). There are many settings where a sign language interpreter is needed, including medical, legal, educational, religious, performing arts, social and political (Jose et al., 2013). However, there are few sign language professionals and this can lead to difficulties in communication with the deaf and hard of hearing persons. This work develops a Robotic Hand that can enable simple communication in sign language with hard of hearing person when an expert interpreter is not readily available.

## 2. THEORETICAL BACKGROUND

Communication is an important human characteristic. In order to maintain relationships, humans must communicate with each other (Ben-Nun, 2015). Human spoken and pictorial languages can be described as a system of symbols (sometimes known as lexemes) and the grammars (rules) by which the symbols are manipulated (Eunson, 2012; Hinde & Hinde, 1972; Payrató, 2009). Verbal or oral communication is one in which information is transmitted by word of mouth and a piece of writing while Non-verbal communication is the process of communicating through sending and receiving wordless messages. Such messages can be communicated through gesture, body language or posture, facial expression and eye contact, or formally as a sign language (Hans & Hans, 2015; Wahyuni, 2018). American Sign Language (ASL) is the most common of the different variants of sign language and often used as a lingua franca organized hard of hearing persons community (LeMaster & Monaghan, 2005). Figures 1 and 2 show the denotation of the basic English alphabets and numbers (1-10) in ASL, respectively.

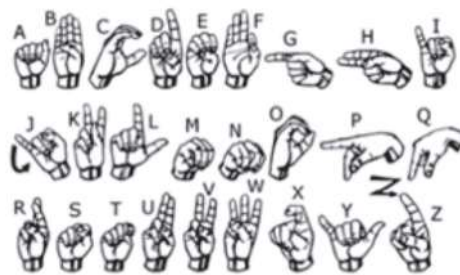


Figure 1: Chart of the manual alphabet in American Sign Language (Maliki et al., 2017)



Figure 2: Numbers 1-10 in American Sign Language (Tennant & Brown, 1998)

Several systems have been developed to aid in communication of sign language with the hard of hearing persons. El-Darymli et al. (2006) introduced a Speech to Sign Language Interpreter System (SSLIS) that translate uttered English speech into a video equivalent in ASL. Sphinx 3.5 was used as the speech recognition engine as well as for translation. The input speech is first captured and translated to text; the text is matched on a word-by-word basis with an ASL database which contains a prerecorded video signs with one video clip for each basic word. The sequence of videos is then displayed as the equivalent sign language for the speech. A drawback is that nothing is shown for any word not found in the database. A similar text to Indian Sign Language (ISL) translation system was designed to assist the hard of hearing to access public information in common places like railway, bank, and hospitals (Dasgupta & Basu, 2008). The system takes English sentence as input, performs syntactic analysis, and generates the corresponding ISL structure. Since ISL does not have any written form, it uses Lexical Functional Grammar formalism for representing the ISL syntax. The output is also represented as a sequence of pre-recorded video streams.

Foong et al. (2009) designed a Voice to Sign (V2S) Language Translation System for Malaysian Deaf People. The project used template-based recognition in which the system is firstly trained with speech pattern based on some generic spectral parameter set. These parameter set is then stored as template in a database. The system performs the recognition process through matching the parameter set of the input speech with the stored templates to finally display the sign language in video format.

Othman & Jemni (2011) in their work developed a statistical machine translation from English text to ASL system. The system is based on Moses tool with some modifications and the results are synthesized through a 3D avatar for interpretation. The input text is translated to gloss, a written form of ASL, then passed to the WebSign plugin to play the sign. Another machine translation system was proposed by (Hamandi et al., 2015) that translates English text into ASL. The proposed system takes in English text and produces ASL. A large dictionary of ASL words each with a corresponding video was used for this task.

A Robotic Hand to teach Sign Language was designed and previously implemented (Maliki et al., 2017). The InMoov robot, an open-source design, was used as the base for the work. Servo motors were used in the robotic arm assemblies to drive the fingers and wrist rotations. My Robot Lab (MRL) was used in the initial assembling and programming of the robot while Raspberry Pi was used to do the initial programming of the robotic arm. The developed was not evaluated in any form and makes it impossible to be used as a benchmark for similar systems. Our research work builds an improved version of this robotic hand but using materials readily available in the local environment within Nigeria such as bathroom rubber slippers, straw pipe and tiny rope. Their work is further improved with an extensive evaluation of the constructed Robotic hand using quantitative and qualitative techniques that can serve as a benchmark for future similar works.

### **3. MATERIALS AND METHODS**

The sign language robotic hand is designed around a microcontroller programmed to accept textual input from a mobile application on the Android platform. The robotic system has four modules: power supply, input unit, control unit and the robotic hand. Figure 3 shows the functional relationships between the system modules.

The power supply steps down a 220-240V AC supply and converts it to a 5V DC; this unit supplies electrical power to the control unit which then powers the robotic hand. The input unit is an android

based mobile application developed using Massachusetts Institute of Technology (MIT) App Inventor 2 (MIT, 2019). Input is sent as serial data through Bluetooth to the microcontroller in the control unit which is connected to a HC-05 Bluetooth module on the development board. The control unit consists of a development board with an Arduino ATmega 2560 microcontroller, double sided fiberglass Printed Circuit Board (PCB) strip board, 10K ohm variable resistor, 220 ohm resistor, male/female connectors, and a HC-05 bluetooth module. The Robotic Hand was implemented using cost effective local materials including “Dunlop” bathroom rubber slippers, straw pipe and tiny ropes. Servo motors were used as actuators for movement of the fingers. The Robotic Hand was designed to resemble that of humans and is able to perform similar movements of the fingers.

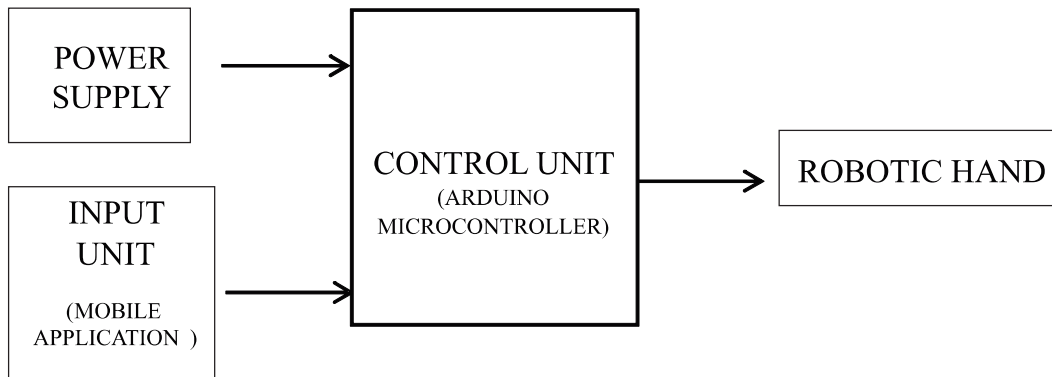


Figure 3: A block diagram of the system

### 3.1 System Design

This section briefly discusses the design of each unit within the robotic system.

#### 3.1.1 Power Unit Design

For this project, a 5V/12V 3A Raspberry Pi 3 power adapter was used, as the microcontroller and other components requires a 5V DC to operate properly. The power adapter converts a 220/240V AC into 5V and 12V DC. Figure 4 shows the schematic circuit diagram of a typical power adapter. This adapter gives two DC outputs, 5V and 12V. It consists of a step-down transformer, four diodes, eight capacitors and one voltage regulator each for the DC outputs.

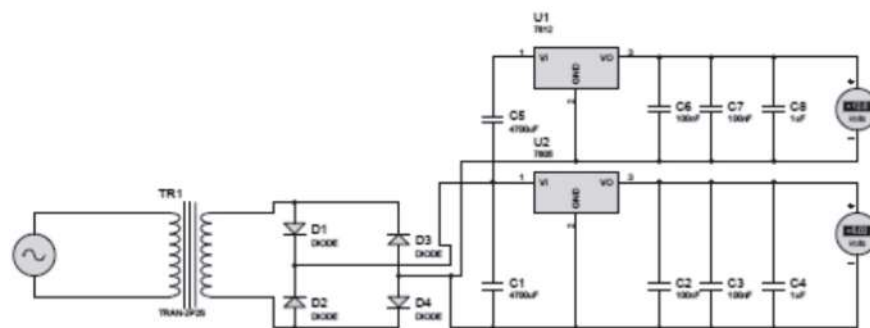


Figure 4: The schematic diagram of a 5V power source

#### 3.1.2 Input Unit Design

The input unit is designed as a mobile application through which a textual value to be signed is selected. Figure 5 shows the use case diagram for the designed mobile application. The app will provide functionalities related to the six requirements shown including connecting and

disconnecting from the Bluetooth module, selecting a sign category (alphabets, numbers and common words) and sign, as well as sending the sign for display in ASL by the Robotic hand.

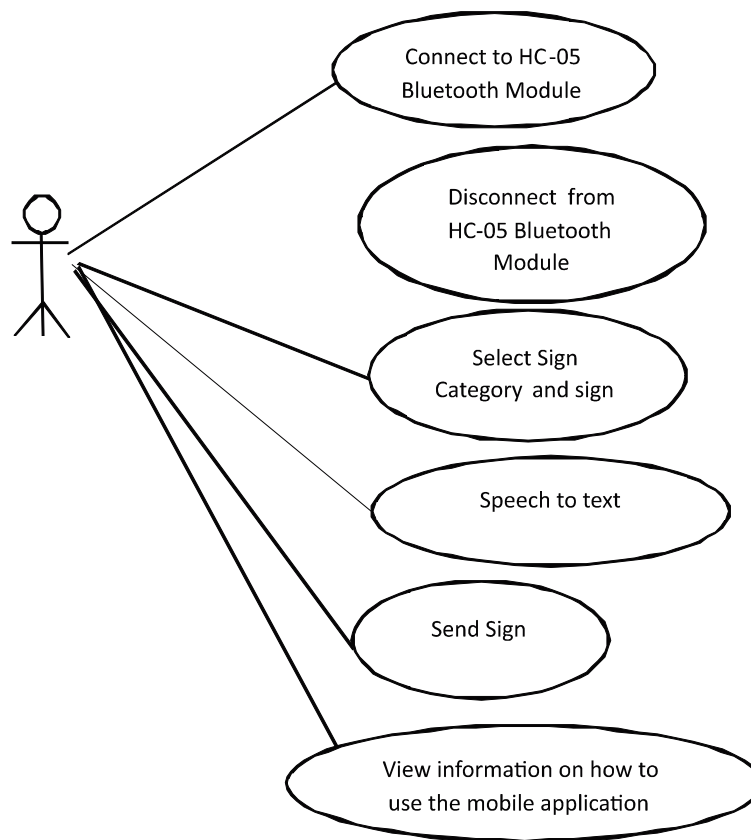


Figure 5: Use Case Diagram for the Input Unit to the Robotic Hand

The words or phrases that can be demonstrated with just one hand are limited in sign language; sixteen of these words and/or phrases were included in our design as shown in Table 1. The app also has a facility that allows for interaction using speech which is then converted to text before being sent. Lastly, it has a help menu that contains information on how to use the robotic system.

Table 1: Common words and phrases signable with one hand in the robotic hand design

AIRPLANE	ALSO	CAN	DON'T KNOW
FIGHT	FINE	FLY	I LOVE YOU
NEED	NO	OLD	THAT
UNDERSTAND	WHY	YES	YOU

### 3.1.3 Design of the System Control Unit

This unit controls the Robotic Hand when textual input is received from the input unit through Bluetooth. It consists mainly of an Arduino ATmega 2560 microcontroller and a HC-05 Bluetooth module. The microcontroller stores the configurations for predefined ASL text that can be signed with one hand including numbers (1-9), alphabets and selected common words. Figure 6 shows the schematic pin diagram of the microcontroller.

The microcontroller has 54 digital input/output pins, of which 14 can be used as Pulse Width Modulation (PWM) outputs, 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal

oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The Arduino Mega can be powered via the USB connection or with an external power supply. The board can operate on an external supply of 5 to 20volts. It has 256 KB of flash memory for storing code, of which 8 KB is used for the bootloader, 8 KB of SRAM and 4 KB of EEPROM. Each of the 54 digital pins operate at 5 volts and can be used as an input or output, using pinMode() , digitalWrite(), and digitalRead() functions. Each pin can provide or receive a maximum of 40mA and has an internal pull-up resistor (disconnected by default) of 20-50k Ohms.

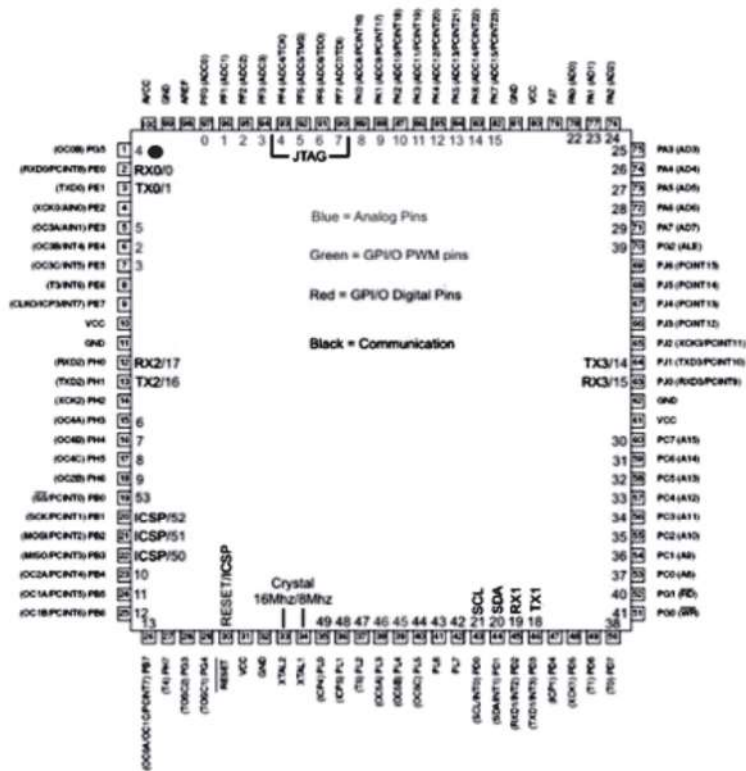


Figure 6: Schematic diagram ATmega 2560 Microcontroller

### 3.1.4 Design of Robotic Hand

The Robotic Hand was designed such that the position of each finger does not affect the movement of other fingers. It has a palm and five fingers with a tilt and pan to control the wrist of the hand; each finger consists of three segments except the thumb which was two segments. Figures 7 and 8 shows the design sketches diagram for the Robotic Hand and Tilt and pan, respectively.

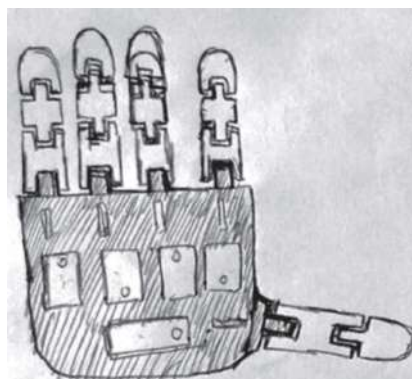


Figure 7: Design sketch of the Robotic Hand



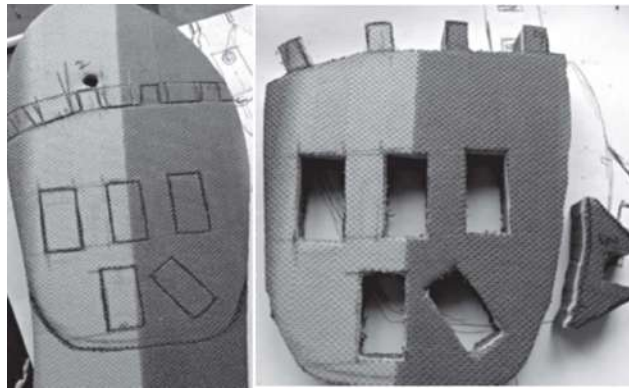


Figure 10: Shaping the Robotic Hand palm from bathroom rubber slippers

In addition to the shaping out, the position for each of the five sg90 servo motors, to control the five fingers, was indicated and where four fingers will be fixed with the thumb attached on the side. In other to make the Robotic Hand resemble that of humans, each finger of the Robotic Hand has three segments except the thumb that has two segments. The segments for each finger are joined using expandable rubber. Servo motors were fixed into their position and a tiny straw pipe was glued in the front of each finger for easy passage of the rope attached to each servo motor for movement of the fingers when the motors rotate. Figure 11 shows the constructed fingers with and without the servo motors.

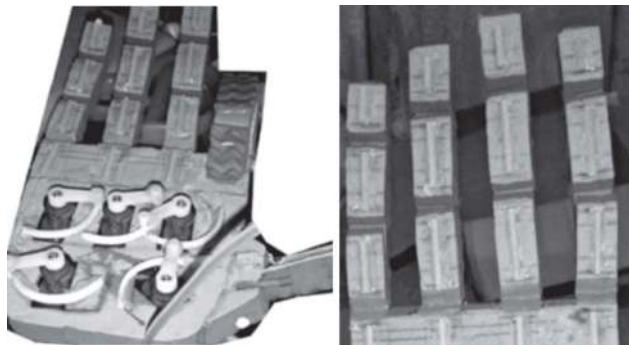


Figure 11: Robotic Fingers constructed from local materials and servo motors

A tilt and pan which consist of two Mg90s servo motor in it was fixed beneath the constructed hand for controlling the movement of the Robotic Hand wrist. A conduit pipe with a length of 20m was fixed below the tilt and pan while the other end of the pipe was fixed on a U-shaped servo rack which consist of MG996r servo motor screwed in between the U-servo rack to control the movement of the Robotic Hand forearm as shown in Figure 12.

Three different specifications of servos were used in assembling the robotic hand. The servos were carefully selected to perform the different angles of motion required for different parts of the arms and hands. There were specific differences in the torque requirements to move different parts of the Robotic Hand that required proper sizing and consideration of actuators. Table 2 shows the specifications of the servo motors used in the constructed robotic hand.

Table 2: Servo Motors and Specifications

	sg90	Mg90s	MG996r
<b>Max. Torque</b>	2.5kg/cm	2.2kg/cm	11kg/cm
<b>Speed</b>	0.1s/60°	0.1s/60°	0.17s/60°
<b>Mass</b>	9g	13.4g	55g

The completely constructed Robotic Hand was fixed on a double side pallet box screwed on a flat smooth wood.

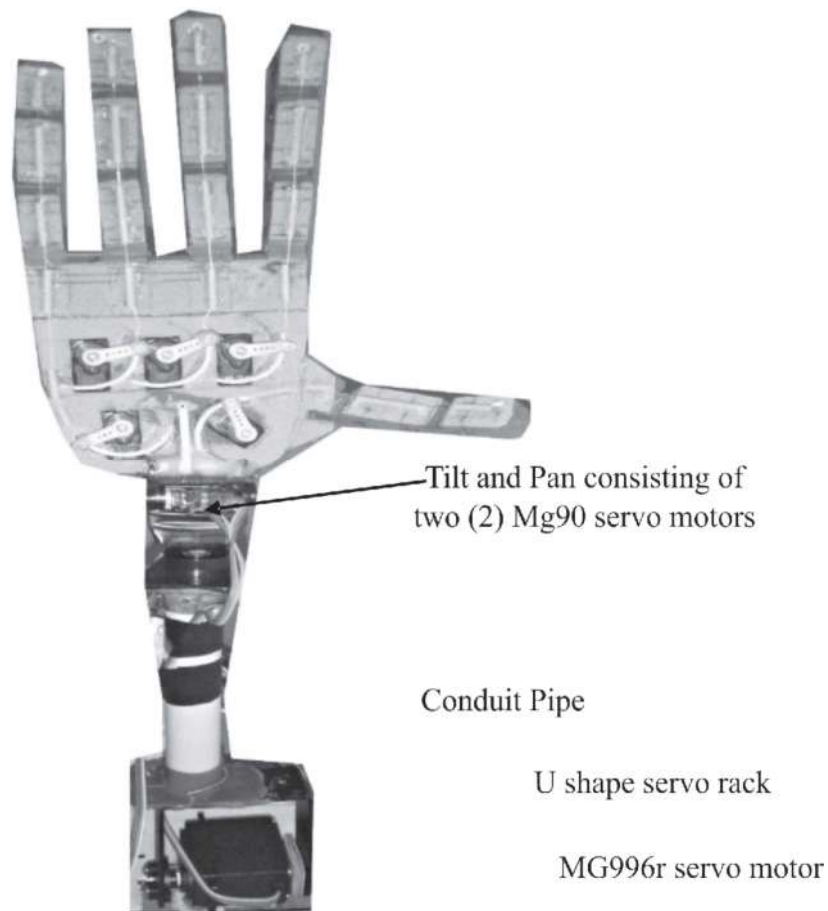


Figure 12: The Robotic Hand with wrist and forearm

### B. Implementation of the Control Unit

The control unit comprises of an Arduino ATmega 2560 microcontroller, development board, male header, female SIL header, LED, 12V DC adapter, 220 Ohm resistor, 103 10K variable resistors, HC-05 bluetooth module and a Liquid Crystal Display (LCD) screen. The microcontroller, bluetooth module and resistors were setup on a breadboard and interconnected to the control, power, and ground pins of servo motors on the Robotic Hand using jumper wires. After a successful components layout and testing on the breadboard, the components were then transferred to the double-sided fiberglass PCB Veroboard and connections soldered permanently on the development board.

The connection of the eight servo motors (5 on the fingers, 2 on the wrist and 1 on the forearm) used for the Robotic Hand was through the set of female headers soldered permanently on the PCB Veroboard. The servo motors male headers jumper wires for the ground, power and control were connected on the female headers soldered on the board. The servo motors control pins used for Pulse Width Modulation (PWM) to control the servo motors rotation within angle  $0^{\circ}$  to  $180^{\circ}$  depending on the fixed position of each finger servo motors on the Robotic Hand palm. The minimum and maximum rotation value for each servo was connected on pin A0-A7 on the microcontroller through a male header that is used to extend the pin to the Veroboard.

The HC-05 bluetooth module was used to establish wireless serial connection between the mobile app and the Robotic Hand. It was connected on a female header soldered on the Veroboard mounted on microcontroller. The female header consists of six pins whereby only four of the pins were used by the Bluetooth module for connection. The four pins used are RX, TX, Ground and VCC. The TX3 (pin

14) and RX3 (pin 15) of the microcontroller was extended using a male header to the Veroboard with a female header used to complete the extension of the pin on the Veroboard. The power and ground were from the 12V DC plug adapter. Figure 13 shows the connections on the Veroboard within the control unit while Figure 14 shows the completely implemented robotic hardware system.

The text to be printed on the LCD is textual value of the sign communicated by the Robotic Hand which was sent through the developed mobile application for the system to the control unit (microcontroller) and received by the HC-05 Bluetooth module. Once the textual value of the sign sent has being communicated, the LCD is cleared and waits for user to send another value.

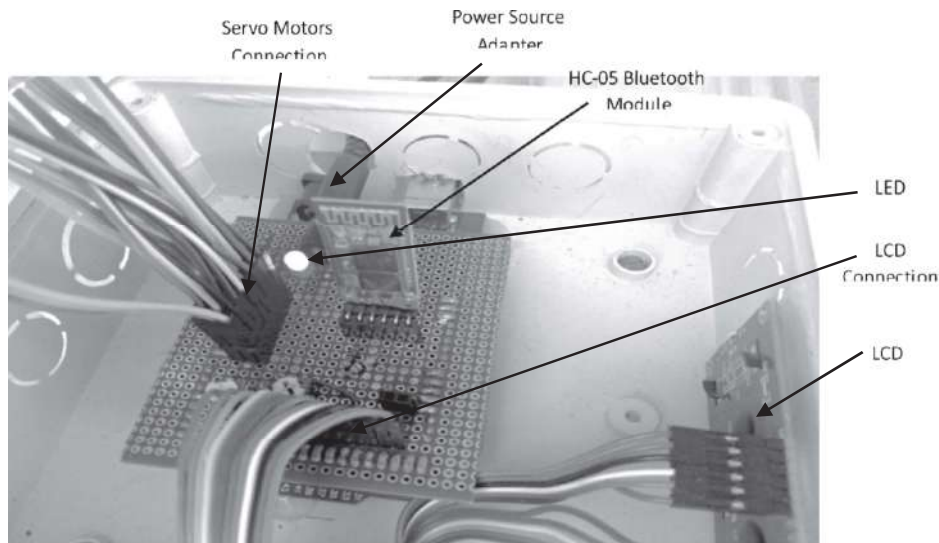


Figure 13: Connections on the Veroboard within the Control unit

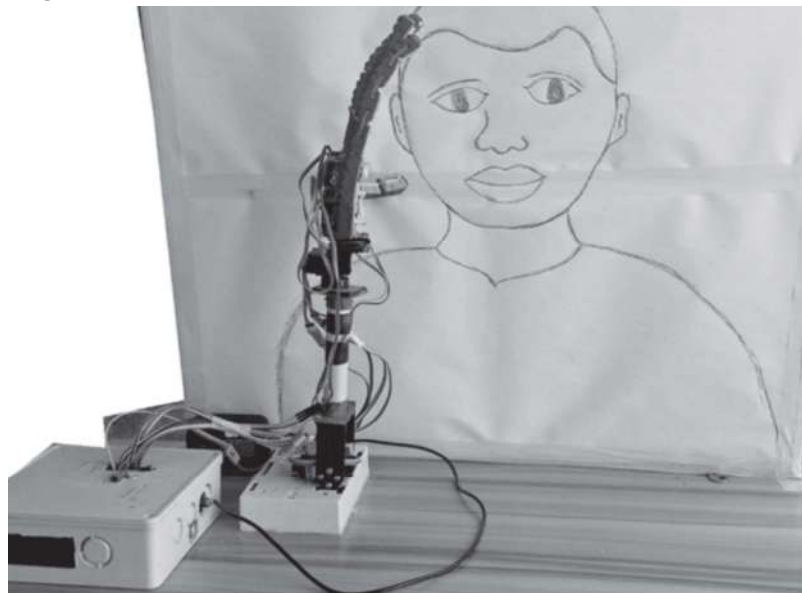


Figure 14: The complete Robotic Hand for Sign Language Communication

### 3.2.2 Software Implementation

The software implementation comprises the programming of Arduino ATmega 2560 microcontroller and development of an android based mobile application for the system.

#### A. Programming ATmega 2560 Microcontroller

A modular approach was employed in writing the software for the microcontroller. This made it easier

to check for errors and debug the program. Arduino IDE version 1.8.3 was used, because of its multifunctional abilities which includes a Text Editor, Compiler, Linker, and Loader and Testing. Figures 15 and 16 show code snippet for declaration of the eight (8) servo motors used in the Robotic Hand and how rotation position value of the servo motors is being assigned for numbers 1-9 to be correctly signed.

```

my_robot_hand_code
30 Servo panky;
31 Servo ring;
32 Servo middle;
33 Servo index;
34 Servo thumb;
35 Servo wristPitch;
36 Servo wristYaw;
37 Servo elbow;
38
39 int servoPin[8] = {A0, A1, A2, A3, A4, A5, A6, A7}; // 1
40 int potPin = A11, potValue, angle; // Declaration of
41 String msg; // get sign text through mobile applicati

```

Figure 15: Servo Motors Declaration Code Snippet

```

54 //DECLARING ASL NUMBERS FROM 1-9
55 //Associating servo rotation value for each ASL numbers
56 int one[8] = {135, 15, 75, 175, 110, 15, 5, 120};
57 int two[8] = {135, 15, 175, 175, 110, 15, 5, 120};
58 int three[8] = {135, 15, 175, 175, 10, 15, 5, 120};
59 int four[8] = {25, 175, 175, 175, 115, 15, 5, 120};
60 int five[8] = {25, 175, 175, 175, 10, 15, 5, 120};
61 int six[8] = {175, 175, 175, 175, 115, 15, 5, 120};
62 int seven[8] = {25, 20, 175, 175, 115, 15, 5, 120};
63 int eight[8] = {25, 175, 50, 175, 115, 15, 5, 120};
64 int nine[8] = {25, 175, 175, 77, 115, 15, 5, 120};
<<

```

Figure 16: Assigning servo motors rotation value to sign text

**B. Implementing an Android based Mobile Application for the Robotic Hand**

MIT App Inventor 2 was used to develop the mobile application used in the input unit. Textual input of the sign to be performed by the Robotic Hand is sent to the control unit through the HC-05 Bluetooth module. The mobile application developed for the Android platform and can be installed on any smartphone with an Android operating system.

The mobile application has four main menu items/ buttons (Start, About, Help and More) as shown in Figure 17. The Main Menu interface is the first screen/interface to be display to the user when the mobile application is launched.

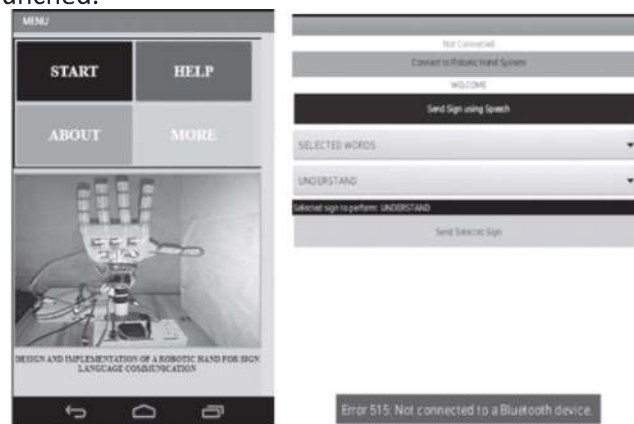


Figure 17: Screenshots from the Input unit mobile application for the Robotic Hand

The Start button allows a user to connect to the HC-05 bluetooth module to be able to send a textual value (sign) as serial data to the microcontroller for the Robotic Hand to perform the sign. This menu item also has a functionality that allows for interaction using speech which is then converted to text before being sent. The speech recognition feature can reduce the time taken to look for the text sign on the interface to communicate with hard of hearing persons.

The Help button gives the user information about how to use the mobile app to send textual input as sign to the Robotic Hand and how the Robotic hand works. The About button gives brief information about the persons involved in the project. The More button gives the user information about the list of numbers, alphabets, and selected words/ phrases that can be performed by the Robotic hand. The software was built into an Android Package (APK) for easy installation on Android smartphones.

### 3.3 System Demonstration

The robotic hand was developed to communicate ASL Alphabets, numbers (1-9) and some selected words to hard of hearing persons. The robotic hand can also be used to teach basic signs to normal people who have no idea about sign language. Figure 18 shows the demonstration of the robot to show the ASL for an alphabet (Y), a word (You) and a phrase (I love you).

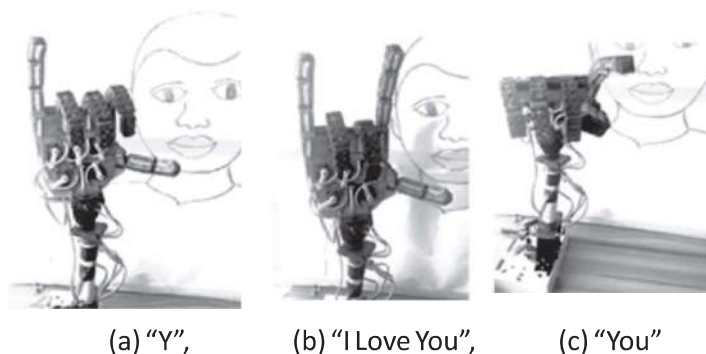


Figure 18: The Robotic Hand System showing the American sign language for different texts

The robotic hand was able to mimic possible movements of human hand as much as possible and communicated the equivalent sign corresponding to the textual input sent through the developed mobile application to the control unit. It was observed that there were slight differences in the movement of the robotic hand for some signs being performed due to the inability to exactly model the degrees of freedom and movement that exist between human fingers.

## 4. EVALUATION RESULTS AND DISCUSSION

The developed prototype of a robotic hand for sign language communication was evaluated using empirical and qualitative methods. The empirical evaluation measured the robot's response times and accuracy while the qualitative evaluation allowed user to evaluate the prototype on a 5-point Likert scale in terms of functionality, reliability, ease of use, efficiency and portability.

Empirical evaluation of the robotic prototype shows that the average response time of the system was 2seconds; this implies that the microcontroller was able to process the textual value sent through the developed mobile application in few seconds (2seconds) and assigned the rotation value for each servo motors for the movement of the robotic hand and for the robotic hand to perform the equivalent sign corresponding to the sign text sent or spoken speech. An average accuracy of 78.43% was obtained based on the number of signs demonstrated correctly by the robotic hand as shown in Table 3. All numbers and words/phrases programmed were correctly signed by the robot. However, the performance on alphabets was less impressive at about 58%. This was mainly due to inability to exactly model the degrees of freedom and movement that exist between human fingers. For

instance, alphabet “J” requires movement of the finger not just bending it while “R” requires crossing two fingers which were impossible in our design of the fingers.

Table 3: Accuracy results from Empirical Evaluation

	<b>Total Signed</b>	<b>Total Expected</b>	<b>% Accuracy</b>	<b>True Positives</b>
<b>Numbers</b>	9	9	100.00	1-9
<b>Alphabets</b>	15	26	57.69	A,B,C,D,E,F,G,H, I,L,O,V,W,X,Y
<b>Words/ Phrases</b>	16	16	100.00	As shown in Table 1
<b>Total/ Average</b>	40	51	<b>78.43</b>	

For qualitative evaluation, a total number of thirty-five (35) users which included two (2) ASL experts were used to rate the performance of the system on a 5-point Likert scale in terms of functionality, reliability, ease of use, efficiency and portability. Functionality indicated that the system was effectively able to do the tasks for which it was designed, reliability meant that the system did not fail or had a level of fault tolerance throughout the period of operation, Ease of use meant it was not difficult to learn to use the system, Efficiency dealt with response time while Portability means that the system can be carried around with little or no difficulty.

Table 4 shows the collated values for each evaluation parameter from the 35 respondents. Analyses shows that over 97% of users rated the system functionality as very good or excellent while about 66% rated the system similarly based on reliability. For ease of use, efficiency and portability, 77%, 80% and 83% of the users rated the system as above good, respectively.

Table 4: Responses from qualitative evaluation of the Robotic system

	<b>Excellent</b>	<b>Very good</b>	<b>Good</b>	<b>Fair</b>	<b>Poor</b>
<b>Functionality</b>	17 (48.57%)	17 (48.57%)	1 (2.86%)	0 (0%)	0 (0%)
<b>Reliability</b>	10 (28.57%)	13 (37.14%)	11 (31.43%)	1 (2.86%)	0 (0%)
<b>Ease of use</b>	13 (37.14%)	14 (40.00%)	8 (22.86%)	0 (0%)	0 (0%)
<b>Efficiency</b>	13 (37.14%)	15 (42.86%)	6 (17.14%)	1 (2.86%)	0 (0%)
<b>Portability</b>	17 (48.57%)	12 (34.29%)	4 (11.43%)	1 (2.86%)	0 (0%)

## 5. CONCLUSION AND FUTURE WORK

People living with disabilities, particularly the hard of hearing, might require assistance when communicating with others. Sign language interpreter have been used to provide some form of communication assistance to the hard of hearing but such professionals are quite few. The prototype of a robotic hand presented in this paper was designed and implemented to communicate sign language to hard of hearing persons. It can also to be used to teach basic American sign language to interested persons. One significant contribution to knowledge is the tangible use of local materials, such as bathroom slippers, expandable rubber, straw and tiny rope, in the construction of the robot. Empirical and qualitative evaluation of the prototype indicate a very good performance in demonstrating sign language for selected numbers, English alphabets and words/ phrases. There is the need to improve the performance of the robotic hand by increasing the degree of freedom of the

fingers on the hands. Another robotic hand can also be added to make it two hands since sign language is typically performed using two hands. Thus, a full body robot with two hands using tangible local materials, to perform substantial sign language communication is highly recommended for future work.

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