Talking Gloves: Low-Cost Gesture Recognition System for Sign Language Translation

Hina Shaheen
Department of Electrical Engineering
Institute of Space Technology
Islamabad, Pakistan
E-mail: hinas436@gmail.com

Tariq Mehmood
Department of Electrical Engineering
Institute of Space Technology
Islamabad, Pakistan
E-mail: tariq47@msn.com

***Abstract*—Sign language is used by speech and hearing-impaired persons to convey their message to other people. It consists of different sets of movements of fingers and hands. Each motion and bending of fingers has its own meaning. Often this sign language is not understood by everyone, which produces a communication gap. To bridge this gap, Talking Gloves are introduced. The system is based on sensor gloves which convert the sign language to speech. The gloves read the motion and orientation of both hands through Accelerometer and Flex sensors sewed within. All the sensors' data is processed and multiplexed wirelessly through bluetooth. A respective sound file is played by the audio module upon matching the sensors' values of the gestures.When no sign is made, the system has the capability to switch to its sleeping mode which enables it to save the power. The system design uses a simple algorithm that directly maps gestures via lookup process, thus avoiding complex computations. The aim is to develop a portable, reliable and an inexpensive system. Therefore, the system uses less expensive electronics which are easily available in the local market, making the system affordable for everyone.**

***Keywords*—Sign Language Translation, Sensor Gloves, Gesture Recognition, Arduino, Flex Sensors, Accelerometer**

I. Introduction

Deafness or hearing-impairment is the loss of ability to hear normally whether permanent or unstable. It can be caused by environmental and genetic factors as well [1]. According to WHO estimates, 360 million people worldwide are suffering from hearing loss and this could increase to 900 million by 2025[2]. The deaf population in Pakistan is over 0.2 million [3] and is usually under-reported due to the societal factors. The disabilities in household members are considered as stigma and threat to family's social status. In a study conducted [4], it was found that hearing impairment students have a hard time adjusting with the other hearing classmates. They don't feel belongingness and hence get admissions in special education institutions while lack of sign language interpreters in schools is one of the reasons for frustration observed in students. Deafs in Pakistan have low paid jobs just because of the communication barrier. Communication problems have caused them isolation from the society. Deaf use sign language as a medium of communication with the world. Sign language is a complex set of gestures which includes facial expressions, hand movements, bending of fingers and arms position. Most of the signs are made from hand movements. Sensing these motions, many systems for sign language translation have been made. Most of the work has been done to translate American Sign Language (ASL), British Sign Language (BSL), Vietnamese, Arabic, Chinese and others but less work is done in Pakistan Sign Language (PSL). Hence, the system proposed in this paper focuses on the translation of Pakistan Sign Language but can also be modified to translate any.

The paper is organized in such a way that Section II provides the reviewed literature, Section III explains the problem statement, Section IV introduces the proposed system, Section V gives the experimental results and Section VI provides the concluding remarks along with the future applications

II. Literature Review

Gesture recognition is a complicated field. It is mostly being achieved through computer vision (web camera and depth sensors [5], [6]).Gesture recognition using sensor gloves has been done through various methods. Their applications are vast ranging from Biomedical, Design and Manufacturing, Virtual Reality, Robotics to Sign language translating. A survey paper for the applications of sensor gloves and their classification is presented in [7].A gesture recognition based Human-Computer Interaction control system is developed [8] via LabVIEW to control a robot wirelessly through hand gestures. An improved PSO-SVM (Particle Swarm Optimization) classification algorithm of hand-gesture recognition is proposed to increase the precision and efficiency of gesture recognition. The

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gesture sample data is collected using sensor gloves which has five bending sensors and then processed and optimized using PSO algorithm. Inertial motion sensing glove [9] was designed to detect movement of the entire limb. 3 axis accelerometer sensors were used on each finger, wrist, and arm. Precise hand gesture modeling was done by using the sensor gloves with RGB camera for vision-based gesture recognition. The approaches of Hidden Markov Model (HMM)[10] and parallel HMM were used for sensor fusion modeling. Another sensor-computer based hybrid Inertial sensor glove system was developed [11]. The system tracks hand movements using inertial measurements and the real-time data is fed to a machine learning algorithm for gesture recognition based on LDA (Linear Discriminant Analysis) to reduce classification complexities. In [12] the data was captured using a camera mounted on the hat to give the vision-based system a mobility factor and accelerometers on the wristbands. Accelerometer data provides additional information to the camera captured data. However, the results were too noisy because of the webcam used in order to make the whole system relatively cheap.

Sign language translation through gesture detection can be achieved using various tools [13], [14], [15]. A tremendous amount of work has been done in computer-based image/video gesture recognition but there are differences in tools and environment used between implementations [16], [17], [18]. Many Hybrid approaches have also been used for solving this problem. An approach of translating Indian Sign Language is proposed in [5] using leap motion controller. It is a small device consisting of a 3D noninvasive sensor which allows the user to capture their hand gestures and finger motion on the computer. It can report discrete position and motion of fingers and hand. Multilayer Perceptron Neural Network (MPNN) was used for gesture recognition and classification. An ARM9 processor-based Chinese sign language translation system [19] was designed consisting of sensor modules, voice and text display modules. The data from modules are processed in ARM9 processor and the gesture is recognized by matching the characteristic value of the hand. The system is portable, scalable and of high efficiency but the only negative is the cost and size of ARM9 which makes the system not feasible to carry all the time. Another system [20] was made using a 7-sensor glove of 5DT company. This glove had 5 optical fiber for each finger and thumb to measure the flexion by detecting the light loss due to the bending of a finger and another sensor for tilt and rotation of the hand. Artificial neural networks were used to recognize the data from sensor gloves and converted into text and speech. But this system is overall expensive. Arabic Sign Language translation system was developed [21] using the two CyberGloves, two trackers and support vector machine to translate Arabic Sign language. Implementing the system through Principal Component Analysis (PCA), the recognition rate of 99.6% is obtained but the whole system costs more than 30K$.

Vision-based systems have the limitations in practical life due to the lighting conditions for the camera and the mobility issue for PC based systems.The image of signing the person is captured, processed and then translated. This type of solution requires the whole computer system every time the person wishes to communicate. With the availability of various sensors, it is possible to make a portable system applicable in the practical life. A project called Talking Hands [22] was designed based on Arduino UNO to translate Indian Sign Language. In this design, flex sensors on each finger of both hands were placed in order to detect the bending of fingers and accelerometers were used to calculate the orientation of hands. For all the combined values of sensors, a predefined database was present in the mobile based application which converts the text to speech according to the sign. An Arduino Mega based smart glove system [5] consisting of 5 flex sensors on each finger and accelerometer on top of the hand, was designed that captures the hand gestures and converts it into text for display on embedded LCD and Smartphone. In [16]a two-hand sign language translation system have been developed based on AT Mega 328 micro-controller. The system is divided into primary and secondary subsystem consisting of flex sensors, contact switches, and the whole system is connected through BLE (Bluetooth Low Energy) module. The signed gesture is processed in the primary subsystem with the help of a Dual-mode Intelligent Agent and is displayed on LCD. A single hand glove based system is developed in [23] to translate the Pakistan sign language. Flex sensors are used to measure the bending of finger and thumb and accelerometer for the orientation of hand. Principal Component Analysis [24] then used for feature extraction and recognition of gestures. The detected gesture is displayed as text on the waist belt. The processing was done by Arduino Mega 2560.

III. System Design and Implementation

A. Hardware Design

The block diagram of the proposed system is shown in Fig.1. It comprises of following four major modules:

1) Data Acquisition Module
2) Signal Conditioning and Processing Module
3) Data Transmission and Reception Module
4) Audio Module

1) Data Acquisition: The system is comprised of both hand sensor gloves that is the gloves will be able to translate both single and double-handed gestures. The gloves will track angular position, rotation of hands and

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Fig. 1. Block Diagram of The Proposed System

bending of fingers.These motions are read through the use of multiple sensors stitched within the gloves as shown in fig 2. Following sensors are used to read the

Fig. 2. Sensor Gloves Model

aforementioned hand motions.

Flex Sensors: Bending of fingers are read from the flex sensors. The resistance of sensor changes as it bents. The bending of fingers creates variations in resistances and these variations are transformed into voltages by using flex sensors in voltage-divider configuration as shown in Fig. 3. Flex sensors are attached to every finger and thumb of both hands so in a total of 5 flex sensors are sewed on each glove.

MPU6050 (Accelerometer and Gyroscope): MPU6050 is a small size chip of 6 DOF. It has both accelerometer and gyroscope built in. Rotation of hand is read from the accelerometer data while angular movement is tracked by the gyroscope shown in Fig 4.The data form both accelerometer and gyroscope is

Fig. 3. Flex Sensor in VDR Configuration

of 16 bits which are processed by the controller to detect the motion of hands.

Fig. 4. MPU6050 Gyroscope Sensor

2) Signal Conditioning and Processing: Signal conditioning is required for the flex sensors to correctly obtain the data at desired voltage levels. For this purpose, operational amplifiers are used in buffer configuration as shown in Fig.3. Now, all the data from flex sensors and MPU6050 chip is processed in a micro-controller. The micro-controller selected is Arduino Pro Mini which is operated at 3.3V at 8MHz. It is a small size 0.7x1.3" controller board, which makes the whole system portable and introduce higher mobility to the user. The controller board is based on ATMega328P micro-controller. Arduino Pro Mini is attached to the wrist of each hand to process the raw values from the gyroscope, accelerometer and flex sensors. The raw data is processed and transformed into the meaningful ones.

3) Data Transmission and Reception: The processed data from one hand is multiplexed with the other via Bluetooth. HC-05 Bluetooth module is used for wireless communication because of its low price and high performance. The data receiving controller will also act as a master controller. This Bluetooth module is interfaced with the Arduino Pro Mini through UART pins (Tx, Rx) and operates at 3.3V. Bluetooth modules were configured so that no other Bluetooth module connects to them. Both Receiver and Transmitter Bluetooth was bind using AT commands. While gesturing, the data from the slave gets transferred to the master for further processing and recognition of the gesture.

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4) Audio Module: Micro SD Card module along with the portable MP3/MP4 speaker makes the whole audio module of the system. When all the data has been processed. Master controller will then match the processed data with the database stored in the SD Card and with respect to the matched value, a sound file is played. Audio files are converted into PCM unsigned 8bit/8000Hz mono .wav format file. The conversion was done because Arduino controllers easily process the .wav files.

Finally, all of the above modules are powered with the 3.7 V 1000 mAh Li-Ion battery with the charging module and low battery level indicator using TP4056 module.

B. Experimental Setup

Ten volunteers were hired from the university campus in order to collect the sensors data variations according to the various hand sizes and shapes. The participants did not possess any muscular disorder that could affect the gestures. The volunteers were requested to perform each sign, as shown in fig 5, for approximately 20 seconds and the neutral position is also observed regardless of the hand orientation.

(a)

(b)

Fig. 5. (a) Alphabets and Numeration in Pakistan Sign Language (PSL) (b) Neutral Position

All the data were recorded using Data Acquisition application PLX-DAQ as shown in fig 6. Values of flex sensors from F1 to F5 and rotation of hands were recorded during the experiment. The data were saved in text MS Excel Sheet for the processing and easy visualization through the graph.

B	C	D	E	F	G	H	I
Time	Acc	Gyro	F1	F2	F3	F4	F5
1	+ve Y direction	CCW	0.28	0.21	Open PLX DAQ UI		0.21
2	+ve X direction	CW	0.28	0.22			0.21
3	+ve X direction	CW	0.28	0.21	0.22	0.26	0.21
4	+ve X direction	Still	0.28	0.21	0.22	0.26	0.21
5	+ve X direction	Still	0.28	0.21	0.22	0.26	0.21
6	+ve X direction	Still	0.28	0.22	0.22	0.26	0.22
7	+ve X direction	Still	0.28	0.21	0.22	0.27	0.21
8	+ve X direction	Still	0.28	0.21	0.22	0.26	0.22
9	+ve X direction	Still	0.28	0.21	0.22	0.27	0.21
10	+ve X direction	CCW	0.26	0.22	0.22	0.27	0.22
11	+ve X direction	CCW	0.26	0.21	0.22	0.27	0.21
12	+ve X direction	CW	0.27	0.21	0.22	0.27	0.21
13	+ve X direction	CW	0.28	0.21	0.22	0.27	0.21
14	+ve X direction	CW	0.29	0.21	0.23	0.26	0.22
15	+ve X direction	CW	0.28	0.22	0.22	0.27	0.22
16	+ve X direction	Still	0.28	0.21	0.23	0.27	0.21
17	+ve X direction	Still	0.28	0.22	0.23	0.27	0.22
18	+ve X direction	Still	0.28	0.22	0.22	0.27	0.22
19	+ve X direction	Still	0.28	0.22	0.23	0.27	0.22
20	+ve X direction	Still	0.28	0.22	0.23	0.27	0.22

Fig. 6. Sensors value of sign 'A' recorded in PLX-DAQ

IV. Methodology

A. Flexion

As stated in the sections above, flex sensors and accelerometer are used to record the bending of fingers and orientation of hand respectively. Flex sensors change its resistance when it bends. This variation is changed into voltages through voltage divider configuration and further digitized with the ADC of the microcontroller. The ADC is of 10bit resolution. It will map input voltage from 0 to 3.3 volts into integer 1 to 1023. The increase and decrease in the 10bit value points depend on the increase and decrease in the resistance of flex sensor. By doing a simple calculation, the integer value can be converted into the actual voltage as shown in (1). The values are further normalized between [0,1] for easier analysis.

$$Volts = ADCvalue \times \frac{V_{ref}}{1023} \tag{1}$$

B. Orientation of hands

The orientation of hand is derived from the accelerometer and gyroscope data.The accelerometer and gyroscope module is interfaced with the controller and its raw values are obtained from its buffers and then processed by the controller to get the information of orientation of hands. The range of Accelerometer and Gyro is selected to be +/- 2g and +/-250°/sec respectively. The values are then scaled between -1 to +1 as (2) and (3).

$$a_i = a_i/16384; \tag{2}$$

$$g_i = g_i/131; \tag{3}$$

Where i = x,y,z

Hence pseudo code for indicating orientation becomes;

if a_i> 0.5, orientation is positive in i^{th} axis

else if a_i< -0.5, orientation is negative in i^{th} axis

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C. Movement of hands

Movement of hand is defined as the clockwise, counterclockwise and Still position as shown in fig 7. This movement is detected by the Gyro values as

if gyx >10, Hand is moving in the counterclockwise direction

else if gyx < -9.0, Hand is moving in a clockwise direction

else if gyx > -9.0, Hand is Still

D. Gesture Mapping

Sensors' data from both hands are multiplexed through bluetooth modules. All the flex sensors data are converted into decimal values according to each gesture. For the similar values of both hands, data from accelerometer and gyroscope are used for differentiating the gestures. Average values of each sensor are computed and matched with the gesture made. For similar values, accelerometer and gyroscope values are taken into the account. Gesture recognition is performed via lookup data.

Fig. 7. Flow diagram of System

Fig 7 shows that how the program is executed. It contains initialization, analog to digital conversion, recognition via lookup process and matching with an audio database stored in the SD Card. When no sign is made for 5 minutes, it is detected as a neutral condition and then the system goes into the sleep mode enabling its power saving mode and can be activated again by reset switch.

The accuracy for each gesture is calculated as (4)

$$\%Accuracy = \frac{N - F}{N} \times 100 \tag{4}$$

Where;

F= total number of times, gesture is false identified

N=Total number of times gestures signed

V. Results and Discussion

The system was implemented and tested with the sample gestures as depicted in Fig 8. It depicts the sign for Alphabets from A to E. The proposed system has a short initialization time to set up the bluetooth connection which is 2s approx and is able to process a recognition in approximately 0.4s. To detecting alphabets with dynamic motions such as 'J' and 'Z', the angle of rotation and flexion values are observed while due to the higher similarity in 'V' and 'U', their mismatch rate was high as compared to other signs. In order to rectify this problem, a contact sensor comprising of simple copper foil is attached to the side of fingers which enabled the system to easily differentiate between both alphabets. Fig 9 shows the graphical representation of

Fig. 8. (a) Gesture test for Alphabet 'A' (b) Gesture test for Alphabet 'B' (c) Gesture test for Alphabet 'C' (d) Gesture test for Alphabet 'D' (e) Gesture test for Alphabet 'E'

flexion values of the signed Alphabets. 20 trials per each Signed alphabet and number produced the efficiency of 93.4%. These values are averaged for the corresponding gesture in order to make a lookup table.

Fig 10 depicts the accuracy percentage of each gesture signed and tested. This accuracy was calculated on the basis of each gesture signed 20 times. It was observed that some gestures are not correctly identified because of the nearly equal values of the sensors and similar hand positions such as 'A', 'C' and 'E', 'M' and 'N', 'S' and 'T', '0' and 'O'.

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(a)

Fig. 9. (a) Flexion value for Alphabet 'A'

Fig. 10. Accuracy for each signed alphabet and number

VI. Conclusion

The proposed system translates the Pakistan Sign Language to speech with the help of various sensors such that the flex sensors, accelerometer, gyroscope and contact sensor. The system achieved the efficiency of 93.4% with alphabets and numbers and is expected to vary with more gestures and database. The wireless communication and small size modules make it an autonomous, portable and a user-friendly system. Keeping in view, the economic condition of deaf community in Pakistan, the system is made from cheap and inexpensive modules without compromising the system performance. It can be modified to the extensive vocabulary of Sign Language so that the deaf community can easily communicate with other people. The system also aims to use in various fields such as biomedical, controlling mechanisms in industries and virtual reality.

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