A Framework for Hand Gesture Recognition based on fusion of Flex, Contact and Accelerometer Sensor

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***Abstract*— This paper presents a framework for hand gesture recognition using information received from Flex, Contact and 3 axis accelerometer sensor. A final decision is made on the basis of matching the sensor values with the already stored values for each sign in the database. Experimental results for 26 American Sign Language Recognition demonstrate the functionality and effectiveness of the framework. An accuracy of 100% is achieved for recognizing the ASL alphabets.**

Keywords*— *Sign Language Recognition, Microcontroller, Flex Sensor, Accelerometer Sensor, Contact Sensor

I. Introduction

Human Beings communicate and know each other through thoughts, ideas. The best way to present your idea is through speech. Some people don't have the power of speech; the only way to communicate with others is through sign language. The problem with sign language is that it is confined to the people who are also deprived of the power of speech. These people are often termed as deaf and dumb. We can say that it is limited to the same set of persons that cannot speak. Technology has reduced this gap through systems that converts sign language into speech. These systems can be broadly classified in two types based on the mechanism they use to convert sign language into speech. These are glove based system and vision based system. Every country has its own sign language for the deaf and dumb. This paper recognizes American Sign Language using data gloves. There had been several attempts in the past to recognize hand gestures. These hand gestures may be static or dynamic. Static hand gestures are fixed with respect to time while in dynamic hand gestures movement of some portion of the hand is involved with respect to time.

In Glove based systems, a person sign's while communicating are transferred to the computer using gloves worn on hands. The real time sign is compared with the database that contains all the signs added initially to the system. After matching with the correct sign, the data is transferred to text to sound converter system where the data is converted to sound. A lot of research has been done in this field using various sensors to recognize hand gestures [1-14].

In vision based systems a camera is used to track the persons hand and then based on feature extraction, template matching a decision is taken. It is more complex then glove based mechanism.

The main contributions of this paper that significantly differ from others are as follows: 1) proposing a framework of hand gesture recognition using fusion of flex, accelerometer and contact sensors; 2) data segmentation is done with the help of data received from accelerometer sensor, that is, change in hand position with respect to time and 3) conducting ASL recognition experiments with A-Z alphabets comprising of both static and dynamic gestures and creating a prototype of the system to evaluate our proposed methods.

The remainder of this paper is organized as follows. Section II presents the methodology for hand gesture recognition. Section III provides the results and discussions for ASL alphabets to examine the proposed methodology in continuous Sign Language Recognition. The conclusions and future work are given in Section IV.

II. METHODOLOGY

A. American sign language

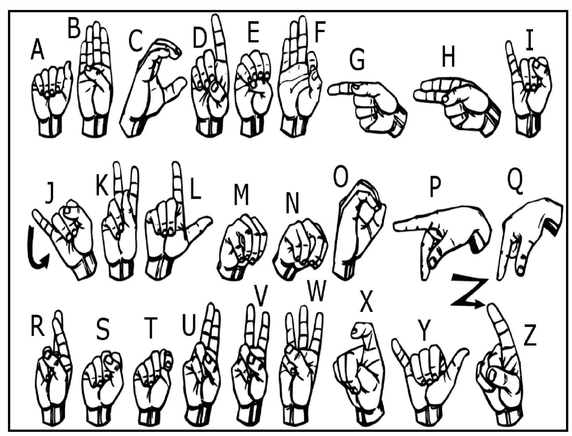

Figure 1: American Sign Language

In this project a glove is designed as a sign language translator fitted with sensors that can interpret the 26 English letters in American Sign Language (ASL) as shown in Figure 1. Different approaches have been used till now for the sign language recognition. Some of them are based on only flex sensors and some uses only accelerometer. For better results and accuracy we have used three types of sensors which are explained in the following block diagram.

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B. Basic block diagram

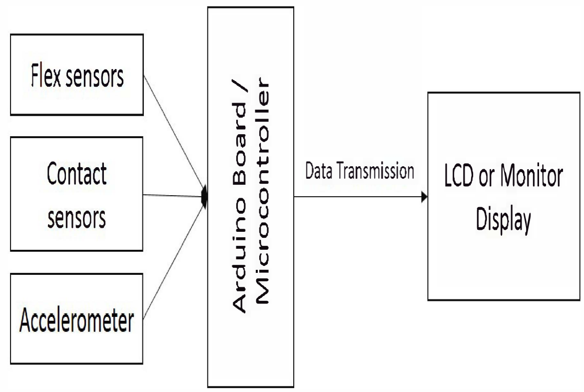

Figure 2: Block Diagram of the System

The Basic Block Diagram of the project as shown in Figure 2 uses three sensors :flex sensors, contact sensors and accelerometer. The device sensors mounted on a glove maintaining the structural rigidity so that the sensors can be worn and taken off without harming the calibration of the sensors. These sensors generates different voltages for different hand movements and send them to the microcontroller. The ADC ports on the microcontroller convert these analog values to digital values. These digital values are further used in decision making process. Further, the receiver i.e. the computer has the serial monitor that displays the letter on the screen.

The three types of sensors used and their significance:

Flex sensor - Flex sensors are sensors that change in resistance depending on the amount of bend on the sensor. They convert the change in bend to electrical resistance – the more the bend, the more the resistance value. They are usually in form of a thin strip from 1” – 5” long that vary in resistance. Here the flex sensors are used as a variable resistance in the circuit working on the principle of a potentiometer which gives different voltage as output on varying the resistance. Here the flex sensors are used to measure the bend of the fingers.

Contact sensor - Contact sensor can be two metal plates with a pull down resistance which returns a high value to microcontroller when two metal plates are connected. These sensors are placed in between the fingers to check whether the two fingers are connected or not.

Accelerometer - This project uses the MPU-6050 sensor which contains an accelerometer and a gyroscope in a single chip. It is very accurate, as it contains 16-bits analog to digital conversion hardware for each channel. Therefor it captures the x, y, and z channel at the same time. The sensor uses the I2C-bus to interface with the Arduino. It contains both accelerometer and gyroscope, but only accelerometer is sufficient for this project. It is used to determine the orientation of the hand. Its major role is to recognize the dynamic alphabets J and Z.

C. Glove layout

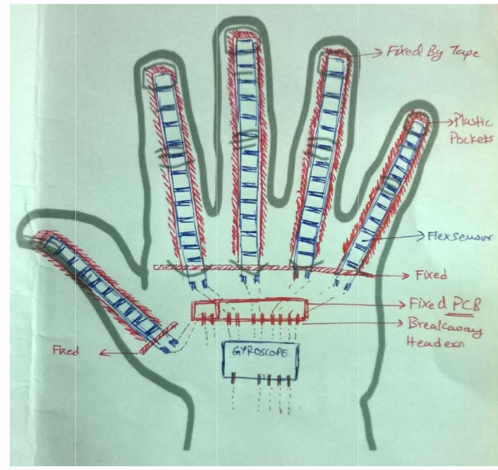

Figure 3: Glove Layout

We decided the structure of the glove on the basis of number of flex sensors that had to be placed on each fingers first. After deciding the placement of the flex sensors we decided the placement of contact sensors between, on the circumference and along the length of the fingers. The gyroscope/accelerometer module was placed on top of the palm first and then decided to be place on top of the hand. The components to be placed on glove were given a thorough run through individually on the basis of their strength, flexibility, agility and stress bearing capacity i.e. the maximum limits that we can push it to and then accordingly they were packaged in sealed envelopes and placed onto the glove as shown in Figure 3.

A Regular sized Glove was taken which could fit most of the hands. The flexibility of the glove had to be low as the highly flexible glove produced a wide range of fluctuations in its values i.e. they were more sensitive to changes in the readings with the flex sensors. One more quality was required that the strength of the cloth had to be such that it could bear the weight of all the components that had to be placed on it, stitched on it and taped onto it. Thus accordingly a thick glove was then selected whose cloth gave us the right combination of Strength and Flexibility. We sliced few plastic pockets and enclosed the flex sensors in it. Then those pockets/ sleeves were stitched thus covering flex sensors from dust and humidity. Now the placement of contact sensors was a tricky one. They had to be placed along the length of the fingers and that too in between each of them. We took foil papers and molded them into the required shapes and then the molds were then taped onto the sides, on the circumference and along the length of the fingers and the thumb. The accelerometer module was placed on the top of the hand on the glove. The flex sensors and the contact sensors were then soldered with connecting wires the accelerometer module was then soldered with connector pins and connecting wires were then used to join. The glove and the arm band bearing the microcontroller and extension board are connected such that they can be disconnected anytime from each other. The final layout of the glove with different sensors is shown in Figure 4.

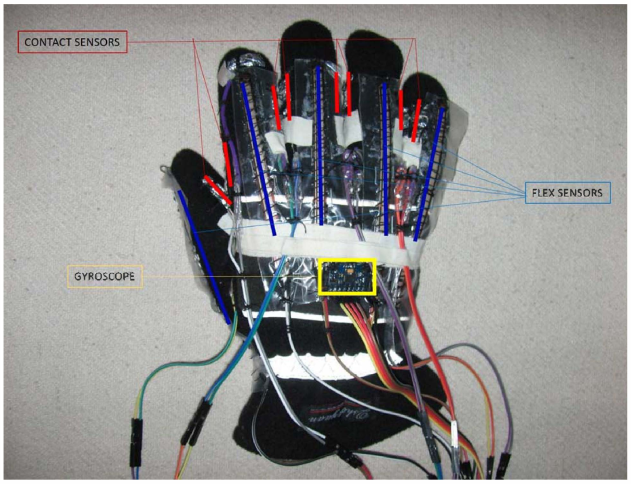

Figure 4: Final Glove Layout

D. *Logical approach*

The Flowchart to recognize the alphabets of ASL is shown in Figure 5. It works on the simple principle that when the device is powered on, the sensors are calibrated. Then the microcontroller acquires the readings from the sensors. The values are matched with a database stored. If the values matches the given letter that is formed, the character is forwarded to the display unit and the result is displayed and the program stops the process for once else if the character is not matched then the process still goes on and is in the loop till a character is matched from the database. The Interactive Development Environment IDE is from Arduino which has this specialty that the code is looped inside so this gives us the advantage that once the code detects and matches the letter the code is looped again and the work continues.

The microcontroller Atmega 644 receives 13 values from 3 sensors: 5 from flex sensor, 3 from accelerometer sensor one for each X, Y and Z axis. These 8 values are fed to the ADC port of the microcontroller which converts these analog values to corresponding 10 bit digital values. The remaining 5 values are from contact sensors are digital and are connected to I/O port of the microcontroller. Static hand gestures can be easily recognized with the help of flex and contact sensor. In order to recognize dynamic hand gestures accelerometer sensor is used that differentiates static gestures from dynamic gestures with a change in hand movement.

Data segmentation is done using the technique described in [10].

$$V(t)= |x_{t+1}- x_t| + |y_{t+1}- y_t| + |z_{t+1}- z_t| \quad (1)$$

Equation 1 is used to identify when hands are in static position, using change in hand velocity V, according to the above equation. Values of x,y and z are the data received from the 3 axis accelerometer sensor.

$$S(t)= \sum |x_{i,t+1}- x_{i,t}| \quad (2)$$

Equation 2 denotes data received from flex and contact sensor, so I varies from 0 to 9. Intersection of both the threshold will be a keyframe.

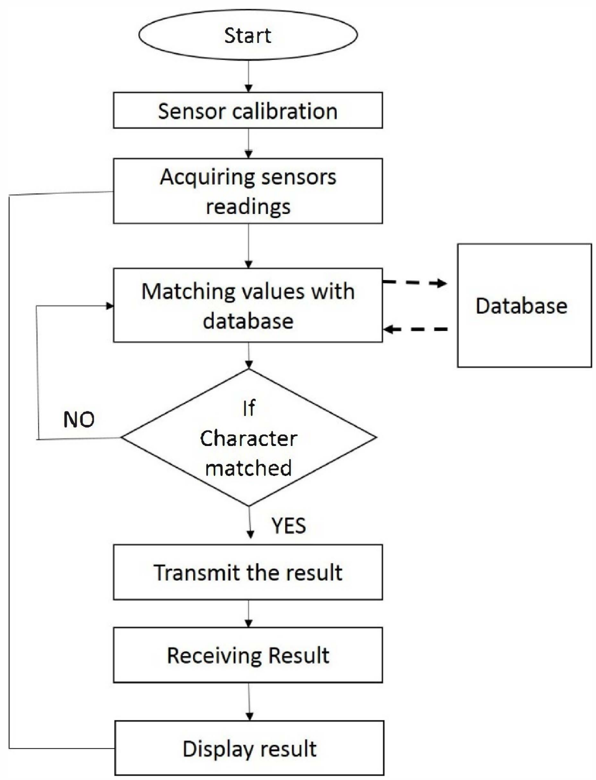

Figure 5: Flowchart of the system

E. *Ambiguities in alphabet signs*

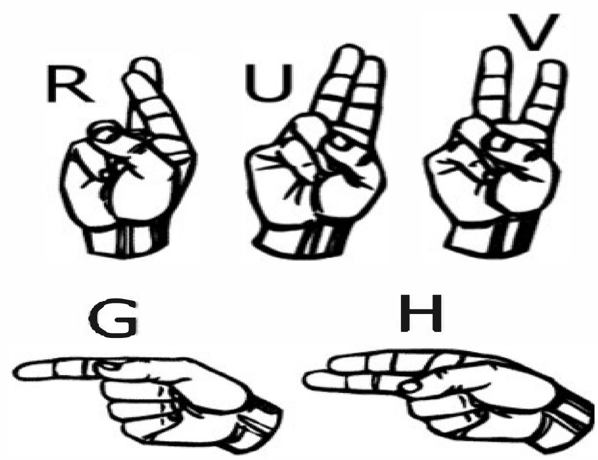

Figure 6: Ambiguities in ASL

There were several ambiguities that were found in the process of development of the letters' code. The ambiguities as shown in Figure 6 proved as a challenge to our design and it pushed our model even further beyond its maximum detection range. To resolve ambiguities we had to incorporate not only new algorithms but also new hardware. The ambiguities were resolved initially at the test phase but still when we designed the final hardware the issue of sensitivity cropped in thus posing an even greater challenge to the design of our project.

The similarity between the basic contacts or rather the design of the letter using hands is somewhat similar and the structural similarity poses the problem of making the letters from hand a bit more precisely so as to find a proper range for the entire English Alphabets.

The similarity between letter G and letter H and the similarity between letter R, letter U and letter V was removed out of picture using the contact sensors. The contact sensors helped classify the different structure of the letters.

Having sorted the static letters from each other the dynamic letters posed a problem, for which we used an accelerometer sensor that allows us to detect the dynamic letters instantaneously within a fixed time frame set by us.

III. RESULTS AND DISCUSSIONS

TABLE 1: ASL recognition using Flex sensors

Character to be detected	Equivalent 10 bit voltage value for Thumb	Equivalent 10 bit voltage value for Index finger	Equivalent 10 bit voltage value for Middle finger	Equivalent 10 bit voltage value for Ring finger	Equivalent 10 bit voltage value for Little finger	Character detected
A	560	336	371	385	342	A
B	520	490	495	515	515	B
C	525	425	430	450	405	C
D	505	500	400	425	370	D
E	485	350	383	411	350	E
F	517	370	492	512	516	F
G	560	497	376	399	342	D
H	540	504	498	430	342	H
I	530	360	400	410	480	I
J	530	360	400	410	480	I
K	550	501	499	408	364	H
L	590	500	380	407	360	L
M	512	380	410	440	377	E
N	520	370	400	416	370	E
O	519	378	405	430	360	O
P	543	495	427	400	360	P
Q	566	445	377	397	353	Q
R	514	470	486	412	365	H
S	515	343	383	400	350	S
T	540	380	410	425	360	S
U	519	501	499	408	364	H
V	519	501	499	408	364	H
W	513	508	497	510	356	W
X	494	405	395	414	367	X
Y	584	353	388	403	500	Y
Z	505	500	400	425	370	D

TABLE 2: ASL recognition using Flex and Contact Sensors

Character to be detected	Equivalent 10 bit voltage value for Thumb	Equivalent 10 bit voltage value for Index finger	Equivalent 10 bit voltage value for Middle finger	Equivalent 10 bit voltage value for Ring finger	Equivalent 10 bit voltage value for Little finger	High or Low value for determining contact in between tips of Index finger and Middle finger	High or Low value for determining contact in between Little and Ring finger	High or Low value for determining contact in between Ring finger and Middle finger	High or Low value for determining contact in between Index finger and Middle finger	High or Low value for determining contact in between Index finger and Thumb	Character detected
A	560	336	371	385	342	LOW	HIGH	HIGH	HIGH	HIGH	**A**
B	520	490	495	515	515	LOW	HIGH	HIGH	HIGH	LOW	**B**
C	525	425	430	450	405	LOW	HIGH	HIGH	HIGH	LOW	**C**
D	505	500	400	425	370	LOW	HIGH	HIGH	LOW	LOW	**D**
E	485	350	383	411	350	LOW	HIGH	HIGH	HIGH	LOW	**E**
F	517	370	492	512	516	LOW	HIGH	HIGH	LOW	LOW	**F**
G	560	497	376	399	342	LOW	HIGH	HIGH	LOW	LOW	**D**
H	540	504	498	430	342	LOW	HIGH	LOW	HIGH	LOW	**H**
I	530	360	400	410	480	LOW	LOW	HIGH	HIGH	LOW	**I**
J	530	360	400	410	480	LOW	LOW	HIGH	HIGH	LOW	**I**
K	550	501	499	408	364	LOW	HIGH	LOW	LOW	LOW	**K**
L	590	500	380	407	360	LOW	HIGH	HIGH	LOW	LOW	**L**
M	512	380	410	440	377	LOW	LOW	HIGH	HIGH	LOW	**M**
N	520	370	400	416	370	LOW	HIGH	LOW	HIGH	LOW	**N**
O	519	378	405	430	360	LOW	HIGH	HIGH	HIGH	LOW	**O**
P	543	495	427	400	360	LOW	HIGH	LOW	LOW	LOW	**P**
Q	566	445	377	397	353	LOW	HIGH	HIGH	LOW	LOW	**Q**
R	514	470	486	412	365	HIGH	HIGH	LOW	LOW	LOW	**R**
S	515	343	383	400	350	LOW	HIGH	HIGH	HIGH	LOW	**S**
T	540	380	410	425	360	LOW	HIGH	HIGH	LOW	LOW	**T**
U	519	501	499	408	364	LOW	HIGH	LOW	HIGH	LOW	**H**
V	519	501	499	408	364	LOW	HIGH	LOW	LOW	LOW	**V**
W	513	508	497	510	356	LOW	LOW	LOW	LOW	LOW	**W**
X	494	405	395	414	367	LOW	HIGH	HIGH	LOW	LOW	**X**
Y	584	353	388	403	500	LOW	LOW	HIGH	HIGH	LOW	**Y**
Z	505	500	400	425	370	LOW	HIGH	HIGH	LOW	LOW	**D**

TABLE 3: ASL recognition using Flex, Contact and Accelerometer Sensor

Character to be detected	Equivalent 10 bit voltage value for Thumb	Equivalent 10 bit voltage value for Index finger	Equivalent 10 bit voltage value for Middle finger	Equivalent 10 bit voltage value for Ring finger	Equivalent 10 bit voltage value for Little finger	High or Low value for determining contact in between tips of Index finger and Middle finger	High or Low value for determining contact in between Little and Ring finger	High or Low value for determining contact in between Ring finger and Middle finger	High or Low value for determining contact in between Index finger and Middle finger	High or Low value for determining contact in between Index finger and Thumb	Equivalent 16 bit voltage value for X axis of accelerometer	Equivalent 16 bit voltage value for Y axis of accelerometer	Equivalent 16 bit voltage value for Z axis of accelerometer	Character detected
A	560	336	371	385	342	LOW	HIGH	HIGH	HIGH	HIGH	1630 0	*	*	**A**
B	520	490	495	515	515	LOW	HIGH	HIGH	HIGH	LOW	1650 0	*	*	**B**
C	525	425	430	450	405	LOW	HIGH	HIGH	HIGH	LOW	1600 0	*	*	**C**
D	505	500	400	425	370	LOW	HIGH	HIGH	LOW	LOW	1600 0	*	*	**D**
E	485	350	383	411	350	LOW	HIGH	HIGH	HIGH	LOW	1600 0	*	*	**E**
F	517	370	492	512	516	LOW	HIGH	HIGH	LOW	LOW	1600 0	*	*	**F**
G	560	497	376	399	342	LOW	HIGH	HIGH	LOW	LOW	*	1500 0	*	**G**
H	540	504	498	430	342	LOW	HIGH	LOW	HIGH	LOW	*	1550 0	*	**H**
I	530	360	400	410	480	LOW	LOW	HIGH	HIGH	LOW	1600 0	*	*	**I**
J	530	360	400	410	480	LOW	LOW	HIGH	HIGH	LOW	1600 0	*	*	**J**
K	550	501	499	408	364	LOW	HIGH	LOW	LOW	LOW	1600 0	*	*	**K**
L	590	500	380	407	360	LOW	HIGH	HIGH	LOW	LOW	1600 0	*	*	**L**
M	512	380	410	440	377	LOW	LOW	HIGH	HIGH	LOW	1600 0	*	*	**M**
N	520	370	400	416	370	LOW	HIGH	LOW	HIGH	LOW	1600 0	*	*	**N**
O	519	378	405	430	360	LOW	HIGH	HIGH	HIGH	LOW	1600 0	*	*	**O**
P	543	495	427	400	360	LOW	HIGH	LOW	LOW	LOW	*	*	1350 0	**P**
Q	566	445	377	397	353	LOW	HIGH	HIGH	LOW	LOW	*	*	1400 0	**Q**
R	514	470	486	412	365	HIGH	HIGH	LOW	LOW	LOW	1600 0	*	*	**R**
S	515	343	383	400	350	LOW	HIGH	HIGH	HIGH	LOW	1600 0	*	*	**S**
T	540	380	410	425	360	LOW	HIGH	HIGH	LOW	LOW	1600 0	*	*	**T**
U	519	501	499	408	364	LOW	HIGH	LOW	HIGH	LOW	1600 0	*	*	**U**
V	519	501	499	408	364	LOW	HIGH	LOW	LOW	LOW	1550 0	*	*	**V**
W	513	508	497	510	356	LOW	LOW	LOW	LOW	LOW	1600 0	*	*	**W**
X	494	405	395	414	367	LOW	HIGH	HIGH	LOW	LOW	1600 0	*	*	**X**
Y	584	353	388	403	500	LOW	LOW	HIGH	HIGH	LOW	1600 0	*	*	**Y**
Z	505	500	400	425	370	LOW	HIGH	HIGH	LOW	LOW	1600 0	*	*	**Z**

TABLE 4: Success Rate and Accuracy of the Proposed System

Character	Number of time the character experimented	Success rate
A	10	100%
B	10	100%
C	10	90%
D	10	90%
E	10	90%
F	10	100%
G	10	100%
H	10	100%
I	10	90%
J	10	90%
K	10	80%
L	10	100%
M	10	80%
N	10	80%
O	10	90%
P	10	90%
Q	10	100%
R	10	100%
S	10	90%
T	10	90%
U	10	80%
V	10	80%
W	10	100%
X	10	90%
Y	10	100%
Z	10	80%

The experiments were conducted in four parts

- Flex sensor only
- Flex and Contact Sensor
- Flex, Contact and Accelerometer Sensor
- Repeated 10 times to determine the average success rate.

Result of ASL recognition using Flex sensor is shown in Table 1. With Flex sensors we can recognize 16 alphabets correctly only out of 26 giving success rate of 61.54%. This is due to the ambiguity with some alphabets and dynamic gestures that cannot be recognized correctly with the help of flex sensors only. Using the combination of flex and contact sensor ambiguity can be avoided. The result using the combination of flex and contact sensor is shown in Table 2. From Table 2 we can say that we can recognize 22 alphabets out of 26 with the help of combination of flex and contact sensor giving success rate of 84.61%. Still dynamic gestures cannot be recognized using the above combination of sensors. In Table 3 we can see that the dynamic characters are also recognized correctly using the combination of flex, contact and accelerometer sensor giving success rate of 100%.

Table 4 discusses the experiment in which each ASL alphabet was tried 10 times and the success rate of each is shown. Average success rate of 91.54% is achieved.

TABLE 5: COMPARISION OF OUR APPROACH WITH OTHERS

Technique Used	**Static/Dynamic**	**Success Rate**	**Single/Double Hand**	**Sensors Used**	**Remarks**
Kinematic Chain Theory [11]	Static	100%	Single Hand	3 axis accelerometer	Only 3 gestures were considered
Extended Kalman Filter and Dynamic Time Warping [1]	Dynamic	92.3%	Single Hand	Inertial and Vision sensor	For numerals only
Bayes Linear Classifier and Improved Dynamic Time Warping [2]	Dynamic	95%	Single Hand	3 axis accelerometer and 4 SEMG (Surface Electromyography)	19 predefined gestures were considered.
Multilayer Perceptron Feed Forward Neural Network with Back propagation [3]	Dynamic	94%	Single Hand	Flex and 3 axis accelerometer	For American sign Language.
KNN Classifier [4]	Dynamic	100%	Single Hand	Flex Sensor	Only Four gestures were considered.
Sign Sequence and Template Matching without Training [5]	Dynamic	100%	Single Hand	3 axis accelerometer	Only Seven gestures were considered.
3 level dynamic Bayesian Network [6]	Dynamic	88.6%	Single Hand	Three motion sensor (gyroscope and accelerometer sensor)	10 activities like sitting, standing, walking, etc were considered.
Intrinsic Mode	Dynamic	93%	Single Hand	5 channel Surface	For Greek Sign

Entropy [7]				Electromyography and 3 axes accelerometer	Language
Hierarchical Hidden Markov Model [8]	Dynamic	100%	Single Hand	Inertial and 3 axis accelerometer	Only 5 gestures were considered
Hidden Markov Model [9]	Dynamic	95.3% for words 72.5% for sentences	Single Hand	3 axis accelerometer and Multichannel electromyography	72 Chinese Sign Language(CSL) words and 40 CSL sentences
Elman Back propagation Neural Network [10]	Dynamic	94.4%	Single Hand	Flex Sensor and Accelerometer	Thai Language
Our Approach (Template Matching)	Dynamic	100%	Single Hand	Flex, Contact and Accelerometer sensor	American Sign language.

The experiments were conducted using Atmega644 microcontroller with 16MHz clock.

IV. CONCLUSION AND FUTURE SCOPE

We were able to recognize ASL alphabets with 100% accuracy if we use the combination of flex, contact and accelerometer sensor. When the experiment was conducted 10 times the average success rate was 91.54%. The time between two ASL alphabet recognition is 500 ms. This time can be reduced by increasing the clock rate. Data from sensors are received in parallel while the program running on the microcontroller is sequential. So with the use of parallel programs or threads time can still be reduced or the system can be used in real time. The present work only includes recognition of ASL alphabets that can be further extended for ASL words and sentences. The system can further be added with the capability of transmitting the data wirelessly. This can be accomplished by using the Xbee Module. This paper demonstrates the recognition of ASL alphabets using single hand that can be extended to double hand. The Project currently uses the serial monitor of the Arduino IDE that displays the output of the glove formation on the computer screen. Text to sound converter IC may be used to speak the alphabets and words. The system may be added with voice talkback using an Android App that can spell out or communicate the data or the signs being developed by the user simultaneously.

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