American Sign Language Alphabet Interpreter

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1 Introduction

1.1 Objective

As it stands, there exists a communication barrier between the hearing community and the deaf, hearing impaired, and mute community. Many of those in the latter group who reside in North America rely on lipreading and American Sign Language (ASL) to communicate due to their inability to effectively produce and process audible language. Yet, relatively few members of the hearing community possess the ability to interpret American Sign Language [1]. Clearly, this inability impedes communication between hearing and non-hearing individuals. Yet, it is also enlightens us to the fact that an effective sign language translation system could allow hearing and non-hearing individuals to communicate effectively.

We endeavor to take the first step toward effortless communication between the hearing and the deaf by developing a wearable device that audibly translates the ASL alphabet into the English alphabet. While ASL contains signs for many words, there are many instances in which fingerspelling, the process of spelling a word using the twenty-six letters of the ASL alphabet, must be employed to convey meaning. Such instances include expressing a person's name, a specific place, titles, brands, types of flowers, and certain types of food. By developing a wearable device capable of audibly translating the ASL alphabet into the English alphabet, we lay the foundation for a practical American Sign Language translation system.

1.2 Background

The importance of the ability to communicate goes almost without saying. Deacon calls it "vital to a species survival" while Forbes magazine stresses its importance for professional success [2]. In fact, many consider communication to be a person's most critical skill [3]. Unfortunately, 360 million people worldwide suffer from a disabling hearing loss that makes verbal communication prohibitively difficult [4]. To overcome this disability, between five hundred thousand and two million North Americans use American Sign Language (ASL) to communicate [1]. ASL is a complete language that allows its users to communicate by gesturing their hands, adjusting their facial expressions, and modifying their posture [5]. While ASL offers deaf and hearing-impaired individuals the opportunity to communicate among themselves and with a minority of North Americans, it does not allow them to communicate easily with the majority of North Americans who, though their lips can be read, cannot interpret American Sign Language. Naturally, this inability to communicate can lead to social isolation for the deaf and hearing impaired. Sadly, psychological research performed at Brigham Young University informs us that such social isolation is associated with increased risk for early mortality [6]. Moreover, Amatzia Weisel informs us in her book *Issues Unresolved: New Perspectives on Language and Deaf Education* that the negative effect that the segregation of the deaf has on both the hearing and the deaf can be quantified in both academic and social settings [7].

Despite these consequences, relatively little progress has been made toward developing a wearable sign language interpretation system. The most noteworthy effort comes from two University of Washington students who developed *SignAloud*, a glove-based system that translates American Sign Language into audible English words [9]. Despite this product's award-winning functionality and performace, it fails to abolish the communication barrier between hearing individuals and deaf and hearing impaired individuals due to its lack of portability. Because this system relies on a nearby computer to perform the interpretation process, this product cannot be widely deployed for everyday use. A truly practical system would provide the accurate interpretation of *SignAloud* without the aid of external, cumbersome hardware.

1.3 High-Level Requirements

- The system must audibly translate all twenty-six letters of the American Sign Language alphabet into the English alphabet with ninety-five percent correctness.

- The system must be able to function properly for six continuous hours without having its batteries charged or replaced.

- The entire system must weigh less than three quarters of a pound.

2 Design

The interpreter system can be broken up into the four main parts as shown in the block diagram of Figure 1. Paramount to overall system function is the sensor module which will contain the hardware needed to describe the state of the user's hand. Data from this module will be sent to the microcontroller which will process the data and provide a serial output for the speaker module. The speaker module will serve as the output of the overall system and will announce the letter being signed. All subsystems will receive power from the power module, and the microcontroller will also illuminate LEDs to inform the user that the system is operational.

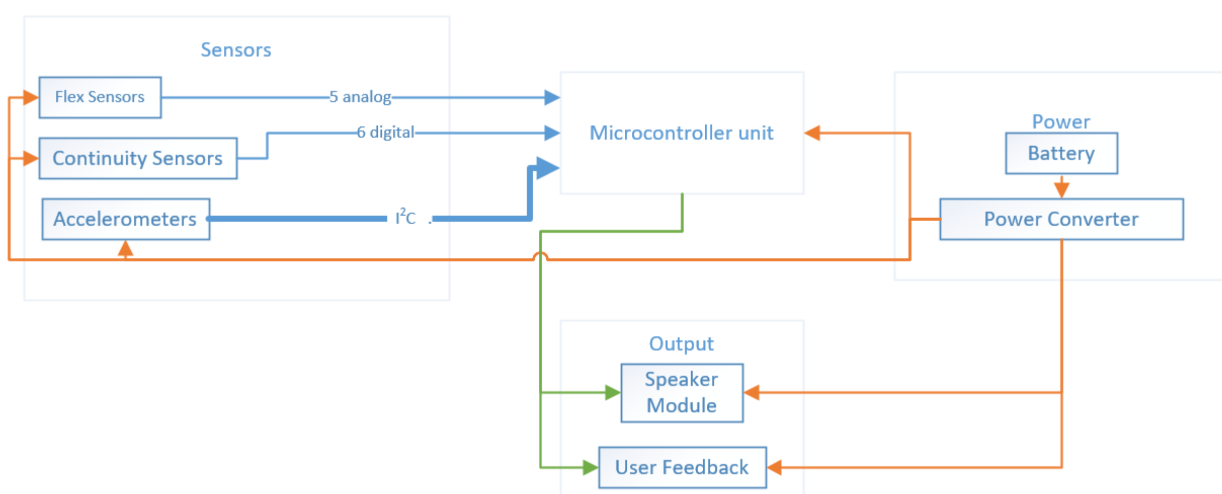

Figure 1. Block Diagram

2.1 Physical Design

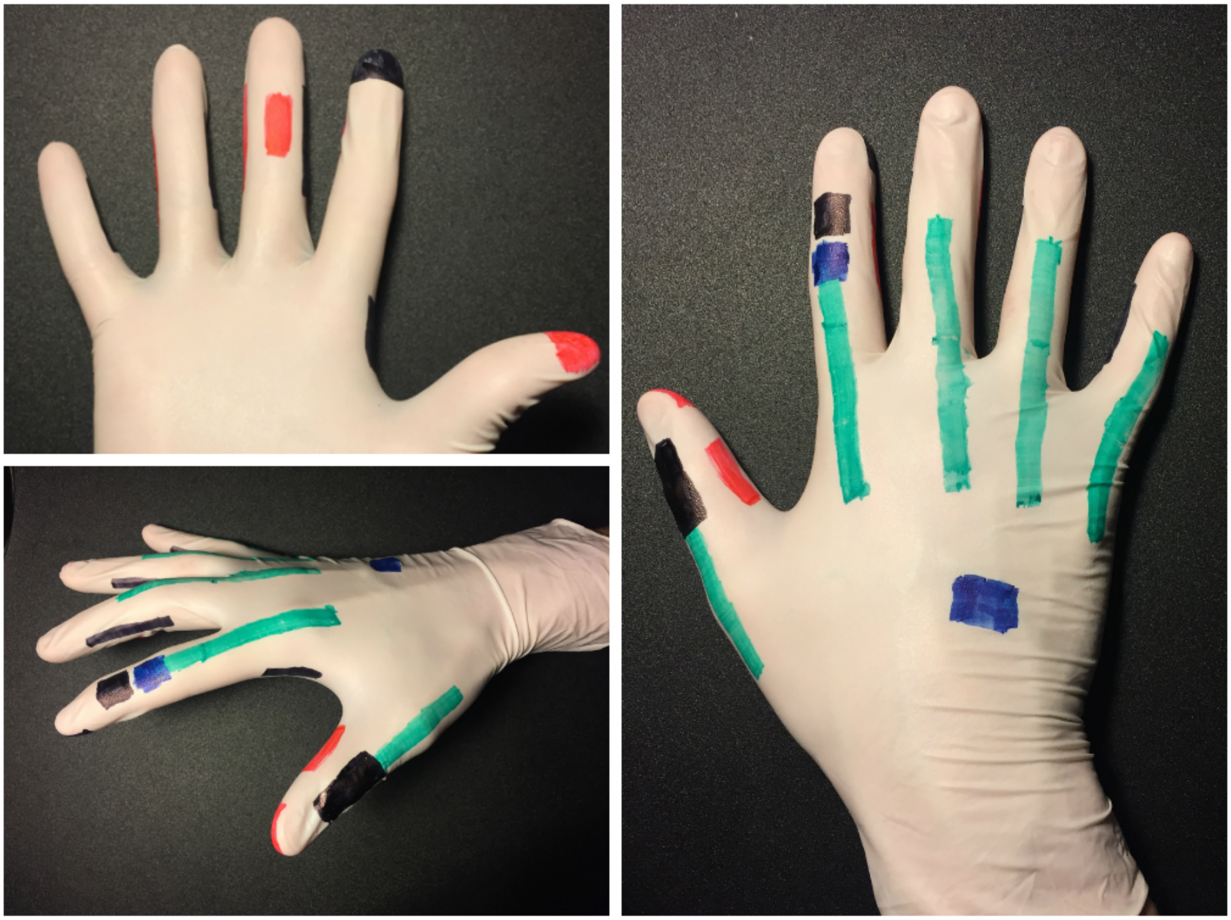

Figure 2. Proposed Sensor Configuration. The green stripes represent flex sensors, the blue squares denote accelerometers, and the red and black squares represent the high and low sides of a continuity sensor, respectively.

The variety and placement of sensors in the system will be critical to our success in distinguishing characters. Reliable character recognition will be achieved through the system's ability to consistently measure finger articulation, the orientation of the hand and the index finger, and the grouping of fingers. To fully capture the range of motion in a user's hand, a combination of flex sensors, continuity sensors, and accelerometers will be used. Our proposed configuration of these sensors is show in Figure 2.

2.2 Sensors

The purpose of the sensors subsystem is to capture enough information about the state of the user's hand to determine if the user is signing a letter of the ASL alphabet and if so which letter. The information that this system seeks to capture is the extent to which each of the user's fingers are bent, how the fingers are making contact with one another, and the orientation of both the middle digit of the user's index finger and the palm of the user's hand with respect to the surface of the earth. This subsystem receives power from the power supply module and transmits the data it collects to the microcontroller for processing and interpretation according the interface of each individual sensor as detailed below. Accurate and precise data collection and transmission by the sensor subsystem is critical to the success of the overall system because the requirement for the overall system to translate all twenty-six letters of the American Sign Language alphabet into the English alphabet with ninety-five percent accuracy cannot be achieved without reliable data on the state of the user's hand.

Requirement 1: The sensor subsystem must produce a unique data vector after quantization for each letter of the ASL alphabet.

Requirement 2: The sensor subsystem must transmit the unique data vector corresponding to each letter of the ASL alphabet to the microprocessor with 96% correctness.

2.2.1 Flex Sensor Circuits

The flex sensor circuits provide the mechanism by which to collect information on the extent to which each of the user's fingers are bent. The information is collected by measuring the output voltage of a voltage divider formed between a flex sensor and a known resistor. This subsystem is critical to the success of the overall system because without reliable data on the extent to which each of the user's fingers are bent each letter of the ASL alphabet will not be able to be uniquely identified with ninety-five percent correctness. The flex sensor circuits receive power from the power supply module and transmit information to the microprocessor across an A/D converter onboard the microprocessor. In total, there are five flex sensor circuits inside the sensor subsystem with each determining the extent to which an individual finger is bent.

Requirement 1: Each flex sensor circuit must produce voltages that differ by more than 0.1V when the flex sensors are bent with arc angles of 0°, 90°, and 180°.

Requirement 2: The standard deviation of the output voltage of each flex sensor circuit for a certain arc angle of bending must be less than 50mV.

2.2.2 Continuity Sensors

To enable the system to determine how the user's fingers are grouped together, we have strategically placed continuity sensors across the glove as can be seen in the physical diagram of Figure 2. These sensors accomplish several specific functions. Firstly, these sensors determine if adjacent fingers are in lateral contact with one another. Secondly, these sensors determine if the tip of the thumb is in contact with the inside of the ring finger, the inside of the pinky finger, or the tip of the index finger. Finally, these sensors determine if the underside of the middle finger is in contact with the top of the ring finger or the top of the thumb. In doing so, the continuity sensors serve a critical role by providing the information that allows the system to differentiate between similar signs. Without these sensors and the information they provide, the system would not be able to translate the letters of the ASL alphabet into the English alphabet with ninety-five percent correctness. Furthermore, these sensors receive power from the power supply module and transmit the information they collect to the microprocessor across a digital input pin.

Requirement 1: The difference in output voltage for detecting an open circuit and for detecting a closed circuit must be at least 1V for each continuity sensor.

Requirement 2: The worst case power dissipation in each continuity sensor must be less than 1mW.

2.2.3 Accelerometers

The purpose of the accelerometers is to detect both the orientation of the palm and the orientation of the middle digit of the index finger with respect to the surface of the earth. This information allows the system to differentiate between signs which are rotations of one another and to determine when the hand is in motion. Without these accelerometers, the system would not be able to differentiate between several sets of letters. Thus, the system would be incapable of meeting the requirement that it translate all twenty-six letters of the ASL alphabet into the English alphabet with ninety-five percent correctness. The accelerometers receive power from the power supply module and transmit the information they gather to the microprocessor across a digital read pin.

Requirement 1: The signal-to-noise ratio (SNR) for each output of the accelerometers must be greater than 5.

2.3 Microcontroller

The microcontroller will collect the data from the sensor module and will use this data to determine the letter being signed. Based on this determination, the microcontroller will then send serial data to the speaker module to audibly output the determined letter. For this project, we anticipate using the LPC1114 due to its low power consumption and ability to handle standard communication interfaces such as I^2C, and SPI. The LPC1114 also includes six analog pins which can be used to read the signals from the flex sensor circuits. The microcontroller must be able to output 3.3V from its digital pins, communicate with serial and I^2c, and be able to read analog inputs.

Requirement 1: The digital pins must be high impedance.

Requirement 2: The microcontroller must be able to sink 20mA of current at its digital pins.

Requirement 3: The microcontroller must have a 10-bit ADC for reading analog inputs.

2.4 Power

The power module will provide power to the rest of the modules. Voltage from the battery will be converted to the voltage levels necessary for the microcontroller, sensor, and output modules.

2.4.1 Battery

The power for the microcontroller, sensors, and the output modules will most likely be powered by a single 9V battery. Based on preliminary research, it appears that a single 9V battery will provide six hours of battery life under worst case operating conditions.

Requirement 1: The battery must be able to provide 200 mA at rated voltage for at least 6 hours.

2.4.2 Power Converter

The voltage will be stepped down to the 3.3V and the 5V required by the sensors, the microcontroller, and the speaker. Two buck converters will be used to step down from the battery voltage, and we require that these converters have minimal voltage ripple in order to avoid supplying the sensors and the microcontroller with voltages above their maximally allowed voltage.

Requirement 1: must be efficient enough to power the output module, speaker module, and sensor module for at least 6 hours.

Requirement 2: The two power converters must be able to supply 3.3V and 5V at 0.2A with a ±10% voltage tolerance.

2.5 Output

The output module will audibly announce the letter being signed in English and will provide the user with feedback on the interpreter's operation.

2.5.1 Speaker

Once the sign is interpreted by the microcontroller, the microcontroller will communicate with the speaker module. We anticipate using the speakjet chip to convert the ASCII string data generated by the microprocessor to an analog voice signal read by the speaker. The microcontroller will communicate with the speakjet chip via serial communication. The output of the speakjet will go to an amplifier unit which must be able to raise the speaker volume to at least 50db for normal room conversation.

Requirement 1: The speaker must be able to output 50db of audio.

2.5.2 Status LEDs

The microcontroller will also use its digital outputs to switch on status LEDs for power and hand sign reading. The status LEDs will inform the user of the current operations of the microcontroller such as whether the device is on or if there was an error in interpreting the hand sign.

Requirement 1: The status LEDs must be bright enough to be comfortably seen from a meter away.

2.6 Risk Analysis

We believe the flex sensors pose the greatest risk in our design. According to the flex sensor's specifications, the resistance tolerance is $\pm 30\%$. Therefore, between any two sensors in use on the glove, we could potentially see a 60% difference in resistance for comparable amounts of bending.

We anticipate resistance inconsistencies to be further compounded by differences in users' hand shape and size. The resistance of the flex sensor is proportional to the amount of total bend in the sensor. The placement of the flex sensor on the glove is fixed, yet a user's finger length and overall hand geometry can be quite varied. Consider the case where the user has particularly long fingers. Then there exists the possibility that the flex sensor will not capture the bend in the knuckle. Similarly, in the case that the user has an unusually small hand, there is a chance that bend from three joints would be captured.

The measurements obtained from the flex sensors are critical in providing an accurate classification. We have designed our system on the premise that we will be able to detect three discrete states of flex in each of the pointer, middle, ring, and pinky fingers and two states of flex in the thumb. In the cases proposed above, capturing one more or one less joint will likely result in significant classification error.

We believe that inconsistencies in the flex sensors is highly likely. In the worst-case, the device will be rendered useless as letters will not be recognized. Fortunately, there are no safety issues in the event of complete flex sensor failure.

Each discrete state will be defined by a range of output voltages. To mitigate the risk of inconsistent measurements in the flex sensors, we plan to incorporate a voltage divider circuit with each flex sensor. The voltage divider circuit will be tuned to the specific flex sensor it is attached to. By picking specific values of resistance in the voltage divider circuit, we can compensate for variations in the flex sensor resistance. It is our hope that this individual tuning will result in more consistent measurements across all flex sensors and thereby fingers.

3 Ethics and Safety

The greatest safety concern in our proposed design is the battery. The relatively large energy density of the batteries makes the battery pack susceptible to various thermal and electrical hazards. Sustained skin exposure to temperatures greater than 48˚C can result in third degree burns within 5 minutes [10]. As thermal buildup is an inevitable product of energy storage and discharge, we have designed our battery pack to promote air flow and convective heat dissipation to the environment. To mitigate the risks involved with short circuits, our design includes current limiting circuitry around the battery.

As with many wearable technology applications, there is an inherent requirement that numerous electrical components be coupled closely with the user's body. The effects of long term exposure of electronics positioned closely along the body is still an area of open research. In a similar vein to the potential negative effects of prolonged cell phone radiation [11], there is the potential that wearable electronics may be shown to have negative effects for long term users. In accordance with #9 of the IEEE Code of Ethics [12], to avoid potential harm to users of our product, it is important the we maintain a cautionary position on any potential adverse or harmful effects of wearable technology.

In addition to a concern for our user's safety, we also consider the safety of development a main priority. As we move through the development process, there are several potential hazards that may not be present in the final product. For example, while in development, a battery will not be used to power the device. This exposes all those working with our prototypes to a larger potential source of voltage and current. Developer and early user safety is an equally important concern to that of end user safety.

As stated in 1.7 of the ACM Code of Ethics [13], "…communication technology enables the collection and exchange of personal information on a scale unprecedented in the history…", therefore it is of notable concern to fully protect the user's privacy. A potential compromise in the security of the device could allow a malicious actor to obtain a user's entire conversation. It is critical that we preempt such a breach of privacy. As such, our design has prioritized the need for the device to be entirely self-contained. Performing all necessary data processing onboard the device and without maintaining any logs, the potential for a data leak is greatly reduced.

We strive to fulfil guidelines set forth by #3 and #7 of the IEEE Code of Ethics by representing all our technical claims honestly and willingly accepting criticism of our work. We will meaningfully credit all those who make contributions to our project.

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