Project Proposal

Team 30

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Contents

1 Introduction

American Sign Language (ASL) serves as an important mode of communication for the Deaf and hard-of-hearing community. In ASL, proficiency is judged not on vocabulary, but on the execution of hand poses and gestures. As such, effective instruction requires a clear visual demonstration and, more importantly, immediate feedback so that learners build gestures with severe inaccuracies. As it stands, the current educational methods fall short of providing the nuanced, 3-D spatial feedback that is essential for mastering ASL. This feedback gap is acutely felt in learning environments such as high school classrooms, where a single instructor is responsible for making corrections and guiding numerous students. The resulting inefficiency can lead to student frustration and poor retention that translates into a systemic barrier to inclusive ASL education.

1.1 Problem

In today's time, the methods for learning American Sign Language (ASL) in structured educational settings fail to really provide the immediate, spatial feedback that is needed for accurate gesture development. Students primarily rely on classroom observation, supplemental videos and websites, which lack the 3D perspective necessary to truly replicate the hand positions and unique movements. This lack of perspective leads to developing incorrect signs, poor retention and an increasing feeling of frustration. This feedback gap is widened in high school classrooms where a single teacher must divide their attention among 20-30 students with varying proficiency levels, truly making individualized correction strenuous and even impossible during practice sessions.

As such, these teachers are faced with the challenge of remediating ingrained errors in students rather than helping them proactively guide progress, which reduces the effectiveness of the ASL course. This inefficiency represents a significant resource constraint in the form of a teacher's time in the classroom. With over 100,000 students receiving services for hearing disabilities in the United States public schools, the systemic inability to scale good quality ASL instruction that is individualized is a large barrier to inclusion. The problem here is an absence of tools that deliver the essential feedback required to obtain mastery eventually, which ultimately puts strain on students and teachers.

1.2 Solution

We are creating a tendon-driven bionic hand that is capable of performing all of the letters of the alphabet in the American Sign Language, designed as an interactive and cost efficient tool. At a high level, the robotic hand will contain 5 movable fingers and a wrist that will move in order to achieve the ASL letter positions. Additionally, we will create a separate glove that is worn by a person, which will capture finger flex data and wirelessly transmit that to the robotic hand, where it will then assume that position. This will be used to train the physical robot to demonstrate the accurate letter gestures, allowing a learner to mimic the poses of the hand.

This is divided into 2 overarching subsystems: Robotic Hand and Glove sensors. Starting with the robotic arm, it is built around 3D printed parts, including the fingers, wrist, palm, and part of the arm. Each finger joint is actuated using a nylon string (acting as a tendon) which will be pulled via a servo motor. Each finger will also have an elastic cord that will provide the necessary restoring force for the finger to return. The brain of the robotic hand will be the ESP32 microcontroller which will be placed on our custom designed PCB which manages power and commands/logic into simple PWM signals for the servos. Moving on to the Glove sensor, it is just an ordinary winter glove fitted with flex sensors for each finger joint. This glove will have its own ESP32 on its custom PCB that will be mounted on the glove. The values from the flex sensor will be read and then sent via Bluetooth to the main robotic hand.

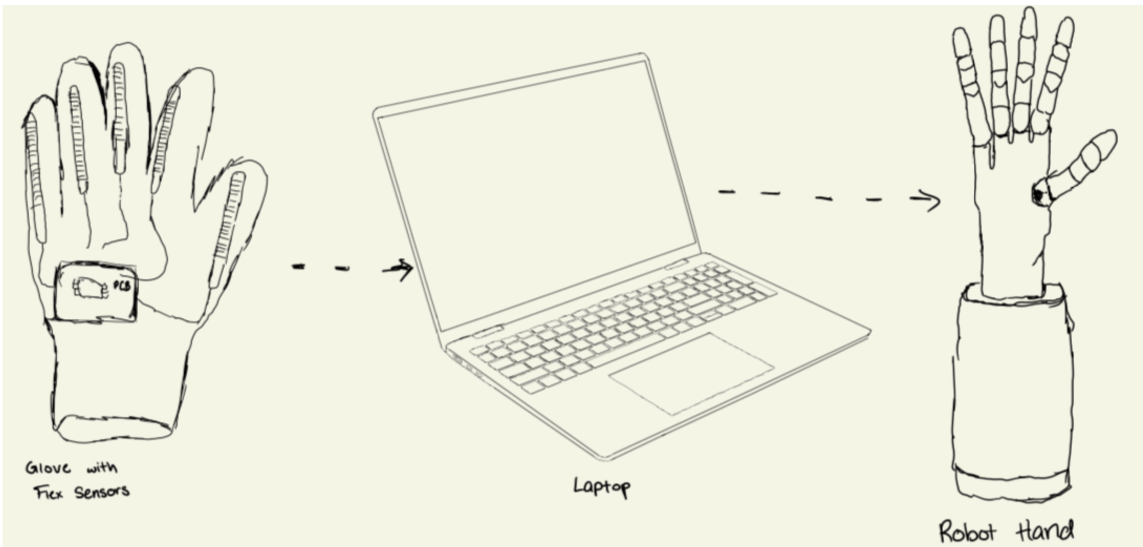

Figure 1: Visual Aid of Training Process

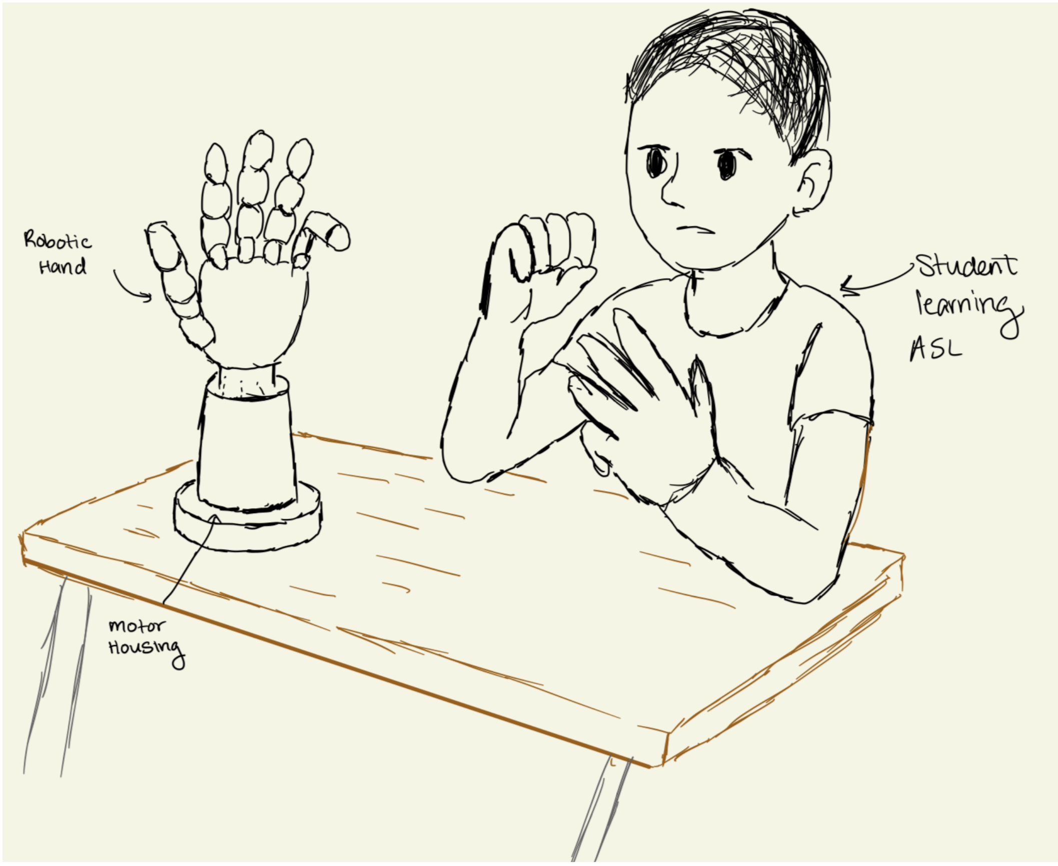

Figure 2: Visual Aid of Product being used in context

1.3 High-Level Requirements

We understand that being able to perform complete sign language can be very challenging due to physical limitations. Thus, we will be focusing on the technical aspects of the project and aim to perform basic movements with the robotic arm.

- The robotic hand should sign simple letters of American Sign Language which do not require complicated movements (e.g. A, B, D, F, U, W)
- Any words or letters signalled should be able to be recognized by at least 3 testers
- The device should be able to sign letters in succession 6 times
- The robotic hand must be able to replicate the signs that were performed from the glove at 85% accuracy

2 Design

2.1 Block Diagram

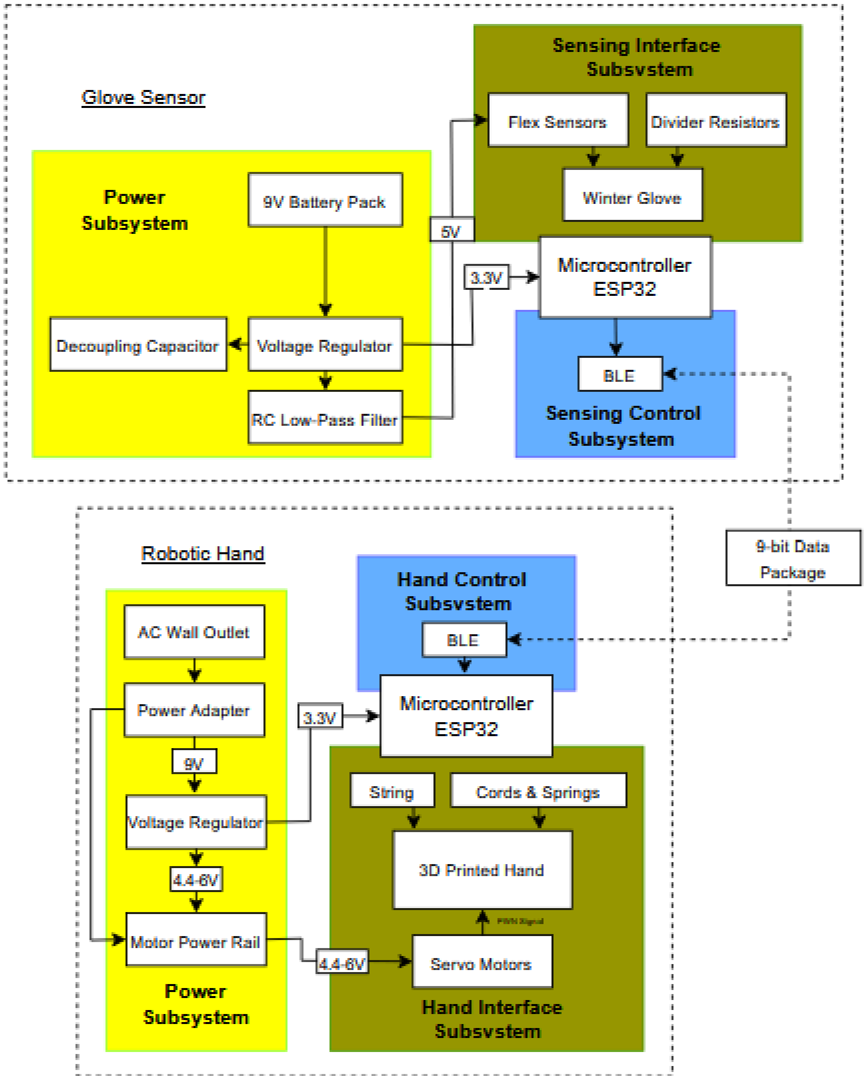

Figure 3: System Block Diagram

2.2 Hand Control System

This system is the core execution unit of our project. By managing the real-time control logic and the actuation process, this unit translates the motion data received from the glove system into repeatable and precise mechanical motion of our robotic hand. Our Hand Control System is divided into three subsystems. The Mechanical Subsystem, the Hand Control Interface Subsystem, and the Power Subsystem manage control signal generation, mechanical actuation, and regulated power distribution, respectively.

2.2.1 Mechanical Subsystem

This system is the control unit for the hand that will manage receiving the data from the glove control unit. It will receive data wirelessly and generate PWM signals to control the servo motors accordingly. This subsystem enables the robotic hand to replicate the signs that were performed from the glove at 85% accuracy.

Components

- ESP32 Microcontroller
- Bluetooth Low Energy module

Interfaces

- Wireless input: Receives data packets from the Bluetooth Low Energy from the glove's ESP32
- Servo Output: Gives a PWM control signal for each separate pin to the servo motors where each of these signals must be around 50hz.

Critical Requirements

- The ESP32 must maintain a stable BLE connection, receiving sensor data at a minimum rate of 10 Hz.
- The control firmware must translate received sensor integers into servo PWM commands with a total latency of less than 100 ms from packet receipt to PWM update.

2.2.2 Hand Control Interface Subsystem

This subsystem will convert the rotation of the servo motors into the precise finger flexing and extension through the tendon mechanism. The subsystem physically executes the signs, and its precision and repeatability are required to replicate the 6 simple letters and be recognized by the testers.

Components

- Nylon String
- Elastic Cords + Springs
- 3D Printed Hand Components
- Servo Motors + Spools + Winches

Interfaces

- Control and Power input: It will receive the PWM signals and 5V power for the servo motors.

Critical Requirements

- The tendon system must be placed with minimal slack to allow the servo motors to rotate less than 10 degrees before causing any finger movement.
- The restoring force must generate sufficient force to fully extend each finger against gravity when the servo releases the tension.

2.2.3 Power Subsystem

The system manages the power consumption. It will provide stable and regulated power at the appropriate voltage levels to all of the electronic components and servos in the robotic hand. It provides the necessary power for continuous operation, which supports the requirement for the hand to sign letters in succession 6 times. Here we are getting power from a wall outlet in order to make it easier to manage power consumption in our design.

Components

- Power Adapter (9V, 1A)
- Motor Power Rail (4.4 - 6V)
- Voltage Regulator (3.3V)
- AC Wall Outlet

Interfaces

- Power input: AC Wall Outlet through a power adapter that provides 5V DC
- Motor power output: 5V rail capable of supplying enough current to supply power to 9 servos
- Controller Power Output: A 3.3V regulated rail to supply the 500mA of current to power the ESP32

Critical Requirements

- The Motor Power Rail must maintain a voltage of between 4.75-5.25V when all the servos are connected to the power supply to prevent the servos from stalling
- The 3.3V Voltage Regulator must provide a stable power supply to ensure the microcontroller is sufficiently powered.

2.3 Glove System

This system is the core sensing and training unit of our project. By capturing the user's finger and joint movements through flex sensors mounted on a wearable glove and translating them into electrical signals, this unit allows the user to train our robotic hand to mimic their hand movements. Our Glove System is divided into three subsystems. The Sensing Detection Subsystem, the Sensing Control Subsystem, and the Power Subsystem manage user hand movement data collection and conversion of this data into usable signals, transmission of the glove motion data, and regulated power distribution, respectively.

2.3.1 Sensing Detection Subsystem

This subsystem captures the user's joint and finger movements and translates these data into electrical signals to train the robotic hand by bending the fingers accordingly.

Components

- 9x Flex Sensors
- 9x Divider Resistors
- ESP 32 Microcontroller

Interfaces

- Data Output: Sends the 9 analog voltage signals to the ADC pins on the ESP32 microcontroller.

Critical Requirements

- Each flex sensor and divider resistor must be calibrated to utilize some of its dynamic range
- The physical mounting of the flex sensors must make sure that the axes that they bend are aligned with the finger to knuckle joint

2.3.2 Sensing Control Subsystem

This system will deliver accurate glove motion data to the hand control system for pose reproduction by correctly managing the wireless transmission and the processing of sensor data. This system enables a real-time and low-latency wireless link that allows for the robot hand to mimic immediately.

Components

- ESP32 Microcontroller
- Bluetooth Low Energy module

Interfaces

- Data input: Receives the nine analog voltages from the sensing subsystem
- Wireless output: Transmits the digital data packets via BLE to the robotic hand's mechanical control subsystem

Critical Requirements

- The ESP32's analog to digital converter must sample all nine sensor channels at about 100hz to accurately capture the movements
- The firmware must transmit the sensor data packets at a consistent rate to ensure smooth, real-time control of the hand.

2.3.3 Power Subsystem

This subsystem is responsible for providing a low-noise and stable power supply to the sensing and communication electronics. This will ensure that there will be accurate sensor readings,which is required for the system to reach 85% accuracy.

Components

- 9x RC Low-Pass Filters
- Battery Management System
- 9V Battery Pack
- Voltage Regulator (5-3.3V)
- Decoupling Capacitors (0.1 µF + 10–100 µF bulk)

Interfaces

- Power input: 9V Battery Pack
- Filtered power output: 3.3V power supplied to the ESP32 and the flex sensor through voltage divider circuits.

Critical Requirements

- The 3.3V Voltage Regulator must provide a stable power supply to ensure the microcontroller is sufficiently powered.
- Each of the low-pass filters on the sensor lines must have a cutoff frequency to suppress the noise without distorting the actual finger movement signal

2.4 Risk Analysis

The block posing the greatest risk and technical difficulty is the sensor to actuation block, which includes the complete data pipeline from the sensing subsystem to the hand control interface subsystem. This includes the readings from the flex sensors, wireless transmission, microcontroller processing and the final mechanical actuation. This block is responsible for the actual training function and presents many risks because the system requires precise mapping between the resistance values, the actual readings and the PWM signal to the servos. Any noise or mechanical issues will compound errors, leading to incorrect hand signs

To mitigate these risks, we will place the following tolerances forthe components within this block:

The resistance vs the amount of bend in the flex sensors must be similar for all 9 flex sensors. The servo motors must be able to achieve and hold the commanded positions with about a 4-degree leeway. The total latency from the glove to observing movement in the robotic hand must be within 300 milliseconds.

3 Ethics and Safety

With a project of such scope attempting to interact and benefit the deaf and hard-of-hearing community, there are many ethical and safety considerations that must be made. While working on the project, there are things that should be thought of as fundamental obligations, such as hazard mitigation and inclusive design, in order to set up for success.

3.1 Ethics

A primary ethical consideration is being able to honestly represent the capabilities and the scope of the system as mentioned in the IEEE code of ethics. The goal of this project is to be a tool/supplement, and so we need to be honest and transparent and clearly outline the capabilities so as not to mislead users, in accordance to IEEE Code of Ethcis Section 6. Additionally, a large ethical concern surrounding this entire project is the areas of accessibility and inclusivity. The entire goal of the tool is to help bridge the gap and reduce communication barriers in society. We will have multiple testers and people looking at the project in order to provide accurate feedback and avoid single-source bias, which aligns with ACM code 1.2 to avoid harm. Another aspect of the project is that it involves wireless data transmission through Bluetooth from the sensor glow. Even though the data being transferred does not involve any personally identifiable information, according to the ACM principles regarding privacy and responsible data handling, we should only utilize and obtain the necessary data, following the data minimization rule in ACM code 1.6. A final ethics consideration that we need to be professionally competent and rely on the engineering practices that we have learned throughout our course loads instead of blindly copying implementations from online, as required by the IEEE Code of Ethics section 2. Additionally, if we do utilize open source resources, we should reference and cite them.

3.2 Safety

There are several safety risks that can arise during the development and testing of the product. First and foremost, there are electrical hazards present due to the fact that the system will be powered via the wall outlet. In order to avoid shocks and fire risks, we will insulate exposed worries and regulate the DC power rails, and also ensure a limit on the max current. Similarly, there are mechanical hazards in the form of the servo-driven fingers pinching or snapping, and having sharp objects fly under excessive tension. To mitigate this, during testing, we will operate the servos at reduced torque values we will place a barrier in front of the robot hand. There are also thermal hazards present where several servos may heat up during long periods of operation or while running when the finger stays in place. In order to mitigate this risk, in the software, we will limit the maximum amount of time that a servo will stay on and also monitor the temperature of the servos. Now, looking at the safety considerations during use, potential misuse includes applying excessive force to the joints, trying to wear the robotic hand, and modifying the wireless connections while powered. Additionally, we will place thresholds on the servo angles so that the finger joints do not overextend.