Prosthetic Hand for Typing

ECE 445 Design Document

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1) Introduction

1.1 Objective

In the 21st century, computers are essential in our society for working, learning, and absorbing information with 90% of U.S. adults using the internet **[1]**. Typing is fundamental to using a computer and current affordable prosthetics cannot be used for typing, so the user has to type with just one hand. This severely reduces efficiency and makes it hard for people with prosthetic arms to work on a computer. While the prosthetics industry is constantly evolving and making revolutionary products, current prosthetics are expensive and not readily available to the public **[2]**. Our goal is to create an affordable solution that improves the typing experience for people with only one hand. We will create a prosthetic hand that allows the user to type by tapping buttons with their feet.

We propose a solution that consists of two main components: a prosthetic hand, and foot buttons that can be used to send signals that control the fingers on the hand. The foot buttons and prosthetic hand will communicate using Bluetooth protocol to ensure low latency and good responsiveness. Each time the user taps one of the foot buttons, the corresponding finger on the prosthetic hand will rotate downward and press a key on the keyboard.

The prosthetic hand will be made out of a lightweight metal such as aluminum to ensure that it is easy to move, while still remaining durable and able to mechanically withstand hundreds of hours of usage. The four servos will be mounted adjacent to each other, and we will use bevel gears to change the angle of rotation. An axle will be placed above the motors to allow the bevel gears to rotate in a vertical motion. Attached to each vertical bevel gear will be a metal finger that has a rubber stopper on the end. The servos will be controlled by a microcontroller that will also serve as a communication bridge between the buttons and the hand.

There will be four foot buttons to control the four fingers on the prosthetic hand. There is no need for five buttons and fingers because the thumb is generally used for the space bar, which the user can use their other hand to press. The buttons will be mounted to a base and will be spaced out evenly, so the user does not accidentally press the wrong button. The buttons will act as sensors and will be connected to a microcontroller on the foot button system that will send a Bluetooth signal to the microcontroller on the prosthetic hand.

1.2 Background

For patients without health insurance, a prosthetic hand typically costs no less than $5,000 for a purely cosmetic arm, up to $10,000 for a functional prosthetic arm that ends in a split hook, and up to $20,000-$100,000 for an advanced myoelectric arm, controlled by muscle movements with a functioning artificial hand **[3]**. These costs are reduced for patients with health insurance, but the overall price still remains in the thousands. Even the most expensive prosthetic hands offer only predefined gestures, so BrainCo's recent announcement of a prosthetic hand that works with brain waves and muscle signals allowing the user to train the prosthetic to perform an unlimited number of gestures is a huge stride in the industry **[4]**. The prosthetic hand is reported to cost between $10,000 to $15,000, which is much cheaper than competing prosthetics. This prosthetic would give users the ability to type along with other functionality, but still comes at a high price. Our design does not aim to compete with an advanced prosthetic hand such as the one that BrainCo has created, but serve as an affordable tool for typing. Ottobock's Electrohand 2000 shows how limited functionality prosthetic arms can still cost thousands of dollars. The Electrohand only supports thumb movement, yet boasts a nearly $5000 price tag **[5].** Hands like these are primarily used by children, as myoelectric hands are more expensive to manufacture. Our design hopes to enable children to find a passion for computers through an improved typing experience.

Figure 1. Electrohand 2000 Highlighting Limited Functionality.

1.3 Visual Aid

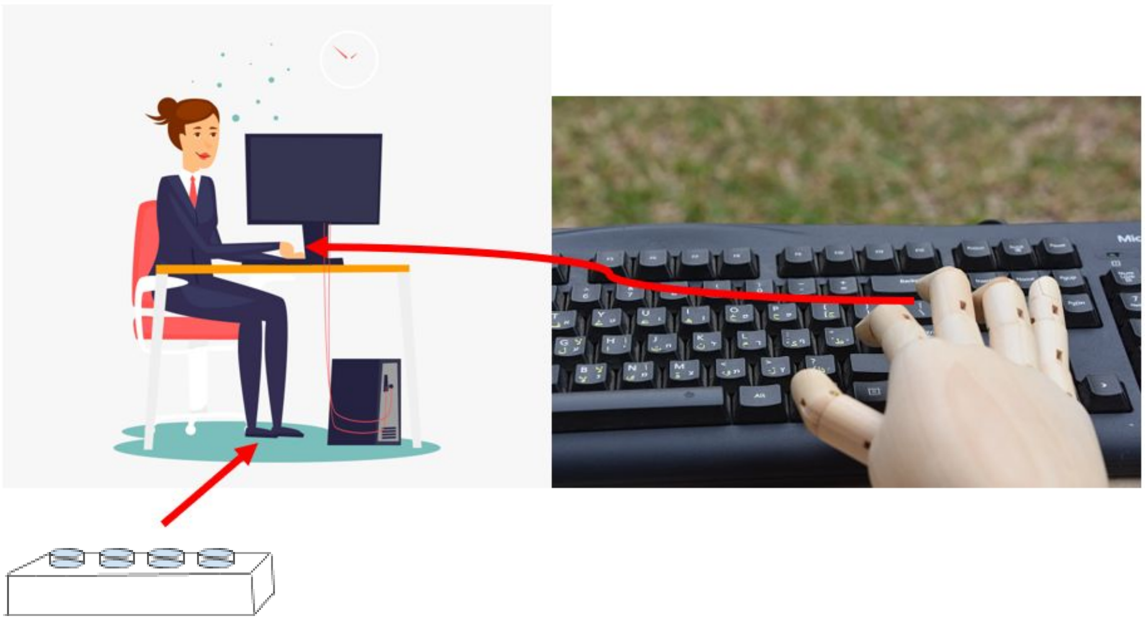

Figure 2. Visual Aid of Locations of the Prosthetic Hand and Foot Button System

1.4 High-level Requirements List

- The final design must be affordable and should cost less than $1000 to manufacture.
- The foot-to-finger response time should be less than 0.25s, so the user can comfortably type without noticeable delay.
- A user should achieve a typing speed greater than 25 words per minute when using the system. We want users to be able to type faster than they would be able to with just one hand. The average typing speed for someone with two hands is 41 words per minute **[6]**. When we tested ourselves with one hand, our team obtained an average of 25 words per minute.

2) Design

2.1 Block Diagram

The prosthetic hand and foot buttons are the two systems of the device. Both systems will have a battery charger, battery, microcontroller and Bluetooth module. The prosthetic hand will have four servo motors and the foot button system will have four buttons. There are only four servos and buttons because the user is expected to use their thumb on their functioning hand to press the spacebar, so a thumb on the prosthetic hand is unnecessary and will only add to the weight of the hand. The parts we are planning to use total under $300, so the cost to manufacture the device will be well below the $1000 requirement. The Bluetooth module of the foot button system will send an 8-bit signal to the Bluetooth module of the prosthetic hand. This signal determines which servo motor will be rotated to initiate a key press. Bluetooth classic transfers data at 0.7-2.1Mbps [7] and the device only needs to transfer eight bits at a time, which will take much less than 0.25s. The servo motors will be attached on top of the hand and connect to a gear and axle system that will move the fingers to press the keys. This motion will be rather quick as the fingers should be hovering over the keyboard and will not require a large angle of rotation to make the press.

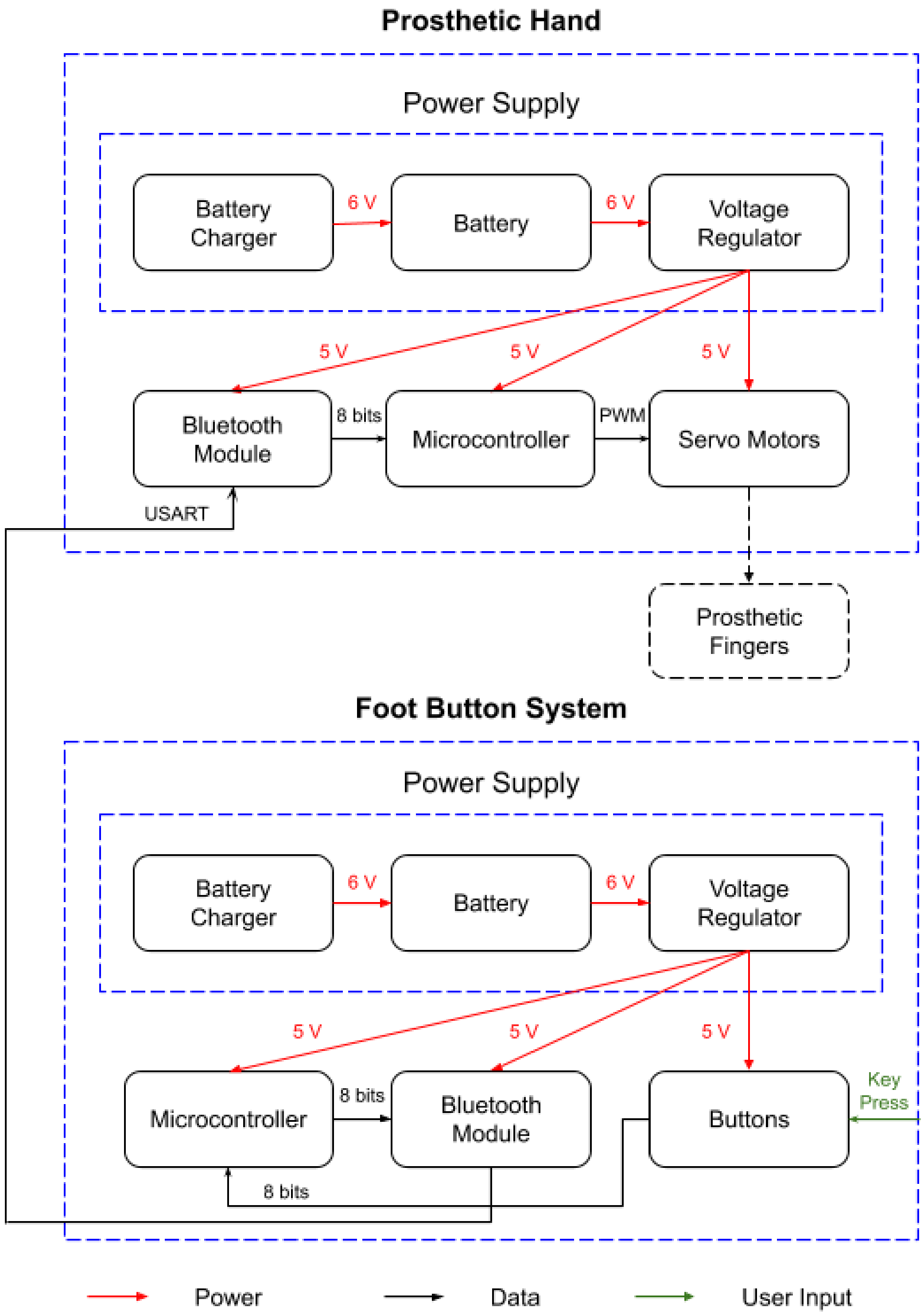

Figure 3. Block Diagram of the Prosthetic Hand and Foot Button System

2.2 Physical Design

Figure 4 (shown below) is what the mechanical components of the prosthetic hand will look like when put together. The vertically-aligned bevel gears allow the servo motors to be placed side-by-side and minimize the amount of space used. Each servo motor has a width of 19.81mm, so all four together will take up about 80mm when we account for space between each servo motor. The average male adult has hands with a breadth of 3.5 inches, while for females it is about 3.1 inches **[8]**. The prosthetic hand will have similar dimensions to the average hand because 80mm is about 3.15 inches. We want people using the device to feel as if they are typing with two hands, so a prosthetic hand of comparable size to average hands is ideal. At the tip of the finger, we will attach rubber stoppers to allow for easy keypresses.

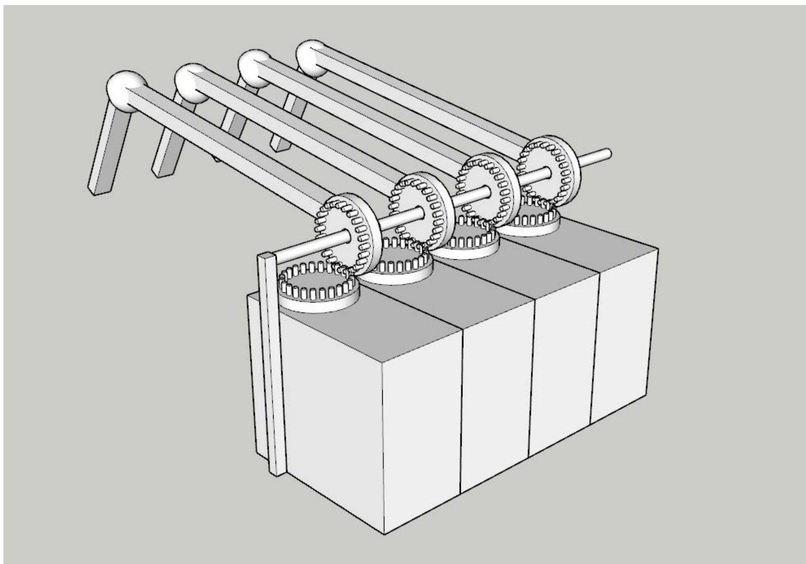

Figure 4. 3D Model of the Mechanical Components of the Prosthetic Hand

Figure 5 (shown below) displays the design of the foot button system. Since the buttons need to be spaced out, we are aiming for a design that is 24” x 6” x 2”. Each button will have a diameter of two inches for easy pressing. We will use momentary push buttons to capture the press from the user.

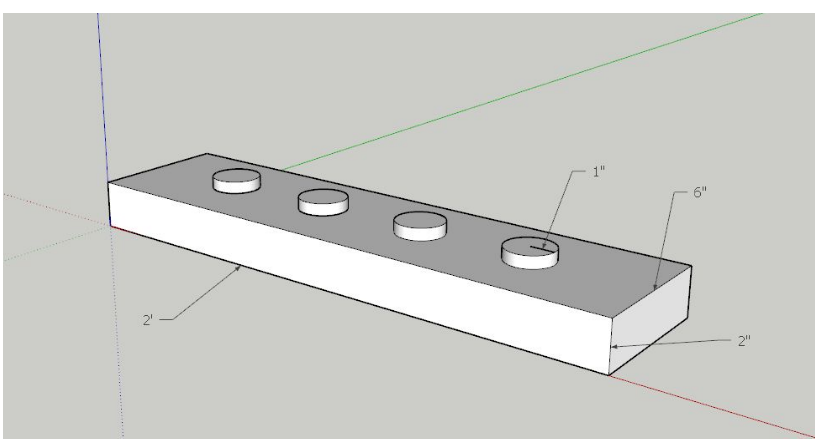

Figure 5. 3D Model of the Foot Button System

2.3 Power Supply

2.3.1 Battery Charger

A battery charger will be used to charge each 6V battery of the prosthetic hand and foot button system. The chargers will be powered by a wall outlet and should be able to fully charge a battery in 3-5 hours.

Requirement	**Verification**
1. Can charge the battery to 6V +/- 5% in under five hours.	1. A. Connect the battery to the charger and set a timer for five hours; B. Remove the battery and use a DMM to verify the voltage of the battery is 6V +/- 5%.

2.3.2 Battery

For each system, we will use a 6V 2000 mAH NiMH rechargeable battery. For the prosthetic hand and foot button system, the 6V battery will feed into a voltage regulator that will step down the voltage to the 5V needed to operate the servo motors, buttons, Bluetooth modules, and microcontrollers. The microcontroller requires 4.5 to 5.5V to run at its max clock speed of 20MHz, so 5V should work well. The servo motors have a current drain of 160mA at 4.8 V; if all four servos are running at the same time, the total current drain from the servos would be 640mA. Logically, at most two servos will be operating at a time, so the current drain will be closer to 320mA. The microcontroller draws between 20 to 80mA and the Bluetooth module has an operating current of 30mA, so the absolute maximum total current drain for the prosthetic hand will be about 750mA/hr. Since we want our hand to operate for at least three hours at a time, the batteries should have between 1110 to 2250mAH of charge.

Requirement	**Verification**
1. Outputs 6V +/- 5%; 2. Stores at least 1100mAH of charge.	1. Connect the battery to a DMM to ensure that the voltage is 6V +/- 5%; 2. A. Connect the positive terminal of the battery to a voltage source of 6V and negative terminal to ground; B. Discharge the battery at 370mA for three hours; C. Use a DMM to ensure that the voltage remains at 6V +/- 5%.

2.3.3 Voltage Regulator

The voltage regulator for the prosthetic hand and foot button system will step down the voltage from 6V to 5V for the microcontroller, Bluetooth module, servos and buttons.

Requirement	Verification
1. Provides 5V +/- 5% from a 6V source;	1. A. Connect a power supply to the voltage regulator and feed in 6V; B. Measure the output voltage using an oscilloscope to see if it stays within 5V +/- 5%;
2. Maintains thermal stability below 125℃.	2. Use an IR thermometer to see if the voltage regulator stays below 125℃.

2.4 Prosthetic Hand

2.4.1 Microcontroller

We will be using the same microcontroller for both of our systems, which is the ATmega328P from the Arduino Uno. The microcontroller will be connected to both a Bluetooth module and the four servo motors. It will run a program to send PWM signals to the corresponding servo motors whenever the HC-05 Bluetooth module receives a signal from the foot button system.

Requirement	Verification
1. Must support USART at a minimum of 16 bytes/second to communicate with the HC-05 Bluetooth module;	1. Connect the HC-05 Bluetooth module to the ATmega328P chip and use the Arduino serial monitor to send 16 bytes of data per second and verify correct transmission of data between modules;
2. Must send a 5V amplitude PWM signal to correctly control servo motors.	2. A. Connect oscilloscope to the digital pins and program microcontroller to send PWM signals to those pins; B. Check oscilloscope to verify that PWM signals are accurate.

2.4.2 Bluetooth Module

The Bluetooth module we will be using is the HC-05, which will give the ATmega328P Bluetooth capability. The HC-05 on the prosthetic hand will be the slave, and will receive 8-bit signals from the master on the foot button system. Bluetooth is capable of 0.7-2.1Mbps data transfer rates, which far exceed our requirements.

Requirement	**Verification**
1. The module must be able to receive at least 16 8-bit message bursts per second via USART protocol.	1. A. Connect the HC-05 Bluetooth module to the ATmega328P and establish link; B. Send this HC-05 module 16 messages per second for 10 seconds, monitoring Arduino serial port to ensure successful retrieval of all messages.

2.4.3 Servo Motors

There will be four HS-311 servo motors mounted to the prosthetic hand, each one controlled by the microcontroller. The servos will rotate a set angle whenever the Bluetooth module on the ATmega328P receives a signal from the foot button system. We chose the HS-311 servos because they are reliable and have a travel time of .107°/µsec **[9]**, so they will be able to rotate the 30° required to push a button in about 300µsec.

Requirement	**Verification**
1. Must be capable of a 30° revolution within 250ms of receiving a PWM signal;	1. Use a signal generator to generate PWM signals of increasing duty cycle and record the corresponding servo revolution angles;
2. Must be capable of four 30° revolutions per second.	2. Once we have mapped a duty cycle to angle relationship, send four instructions to rotate the servo +30°, -30°, +30°, -30°, evenly sent over half of a second and ensure that it follows instructions accurately.

2.4.4 Prosthetic Fingers

The prosthetic fingers will be manufactured by the machine shop. In Figure 4, we show an example of how the fingers will be designed. Using bevel gears to change the axis of rotation, we will place the servos adjacent to each other. The fingers will be made of a lightweight aluminum material and will have two parts connected by a ball joint socket. The purpose of this joint is to allow the finger positions to be modified slightly to account for differences in keyboard sizes. While most keyboards have keys that are 20mm apart, our prosthetic fingers assure that the users will be able to type with any keyboard.

Requirement	**Verification**
1. Must be capable of pressing keys without damaging keyboard;	1. Use a force meter to verify the force of finger motion is less than the mean keystroke press of 12.9 N **[10]**;
2. Finger tips must stay in position when a key is pressed (ball joint socket should be sturdy).	2. After fastening the socket, use a force meter to apply 12.9 N of force in each direction of the finger and see if the finger moves.

2.4.5 Circuit Schematic

Figure 6 (shown below) is a circuit schematic for the prosthetic hand. The circuit has a 6V battery feed into a 5V voltage regulator that powers an ATmega328P, an HC-05 slave module and four servo motors.

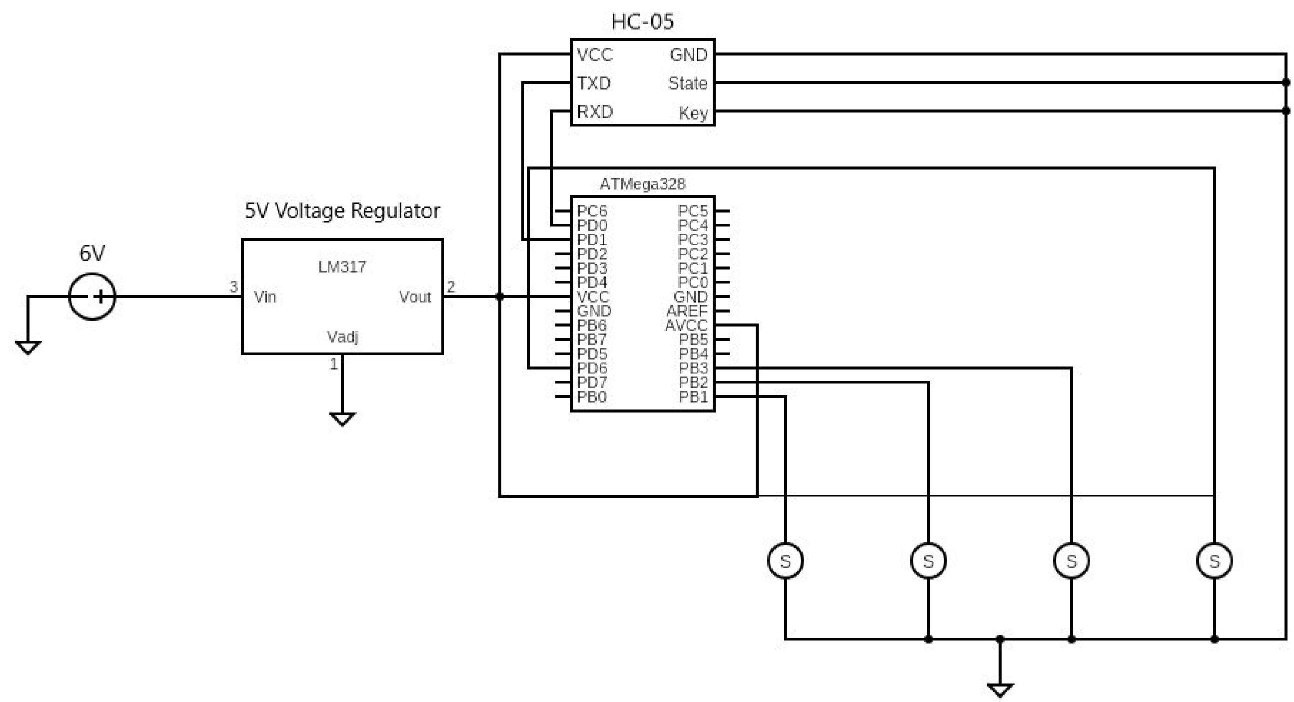

Figure 6. Circuit Schematic for the Prosthetic Hand

2.5 Foot Button System

2.5.1 Microcontroller

We will be using the same microcontroller for both of our systems, which is the ATmega328P from the Arduino Uno. The microcontroller will be connected to the Bluetooth module and four buttons. The ATmega328P will receive signals from the buttons when they are pressed. It will run a program that determines which button has been pressed and send a signal to the prosthetic hand using the HC-05 Bluetooth module.

Requirement	**Verification**
1. Must support USART at a minimum of 16 bytes/second to communicate with the HC-05 Bluetooth module;	1. Connect the HC-05 Bluetooth module to the ATmega328P and use the Arduino serial monitor to send 16 bytes of data per second and verify correct transmission of data between modules;
2. Must detect up to four presses of each button per second.	2. A. Connect the four buttons to four of the digital pins and open the Arduino serial monitor; B. Press each button four times within one second and confirm that the microcontroller is detecting all button presses correctly.

2.5.2 Bluetooth Module

The HC-05 Bluetooth module is the same one we will be using on the prosthetic hand, but this one will serve as the master and send 8-bit signals to the slave on the prosthetic hand whenever one of the buttons is pressed.

Requirement	**Verification**
1. The module must be able to send at least 16 8-bit message bursts per second via USART protocol.	1. A. Connect the HC-05 Bluetooth module to the ATmega328P and establish link; B. Send 16 8-bit messages per second from this HC-05 Bluetooth module for 10 seconds, monitoring the Arduino serial port to ensure successful retrieval of all messages.

2.5.3 Buttons

We will be using pushbutton switches placed on the surface of the foot button system. To indicate when a button has been pressed, an 8-bit signal is sent to the microcontroller on the foot button system. The buttons in our cost analysis are 30mm in diameter. To achieve bigger buttons, we will create button caps that are two inches in diameter and attach them to the buttons.

Requirement	**Verification**
1. Must be comfortably pressable with feet;	1. Measure the diameter of the button to verify it is at least two inches;
2. Must not be able to accidentally press two buttons with the same foot.	2. Press the button to make sure it can be done without hitting another button by mistake.

2.5.4 Circuit Schematic

Figure 5 (shown below) is a circuit schematic for the foot button system. The circuit has a 6V battery feed into a 5V voltage regulator that powers an ATmega328P, an HC-05 slave module and four buttons.

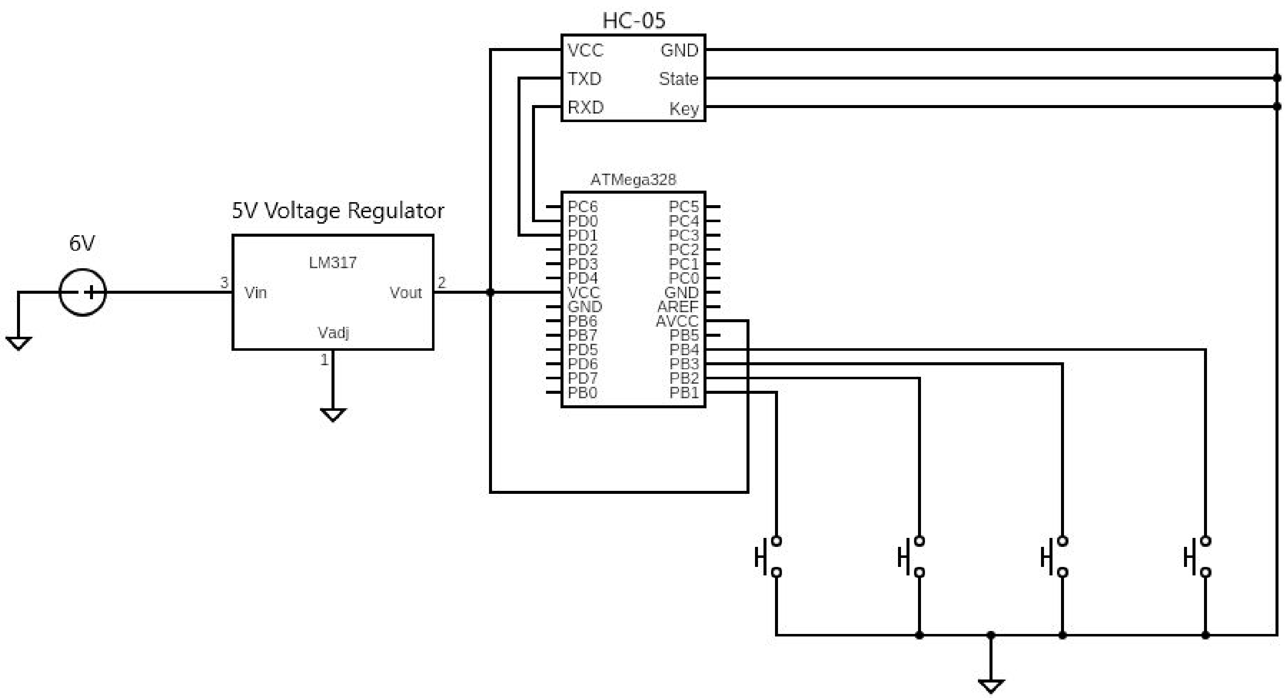

Figure 7. Circuit Schematic for the Foot Button System

2.6 Software

The flowchart below outlines the program that the ATmega328P of the prosthetic hand will run whenever the slave HC-05 of the prosthetic hand receives an 8-bit signal from the master HC-05 of the foot button system. The ATmega328P is responsible for determining which of the four servo motors need to be actuated based on the 8-bit signal received by the slave HC-05 on the prosthetic hand. The 8-bit signal indicates which button was pressed so the prosthetic hand can actuate the correct servo motor that rotates the finger to press the key.

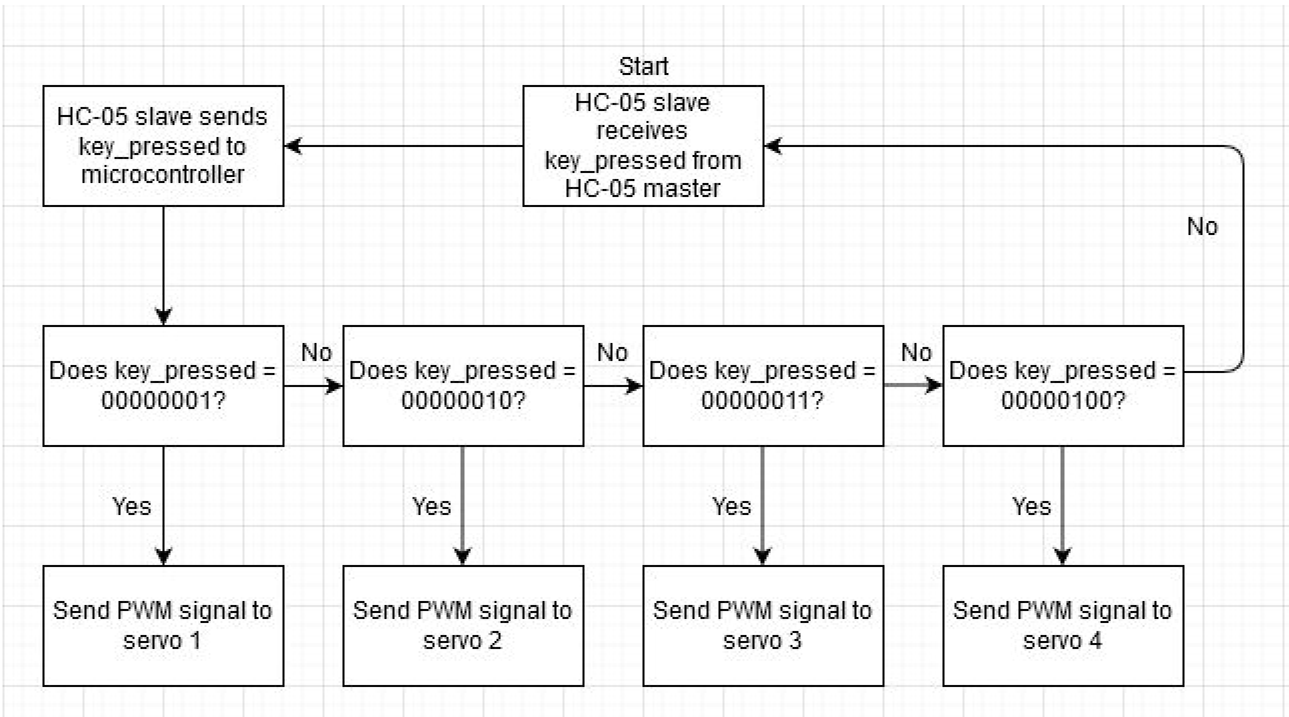

Figure 8. Flowchart for the Microcontroller Code of the Prosthetic Hand

The flowchart below outlines the program that the ATmega328P of the foot button system will run. The ATmega328P is responsible for determining which of the four buttons have been pressed. An 8-bit signal corresponding to the servo that should be actuated is sent from the master HC-05 on the foot button system to the slave HC-05 on the prosthetic hand.

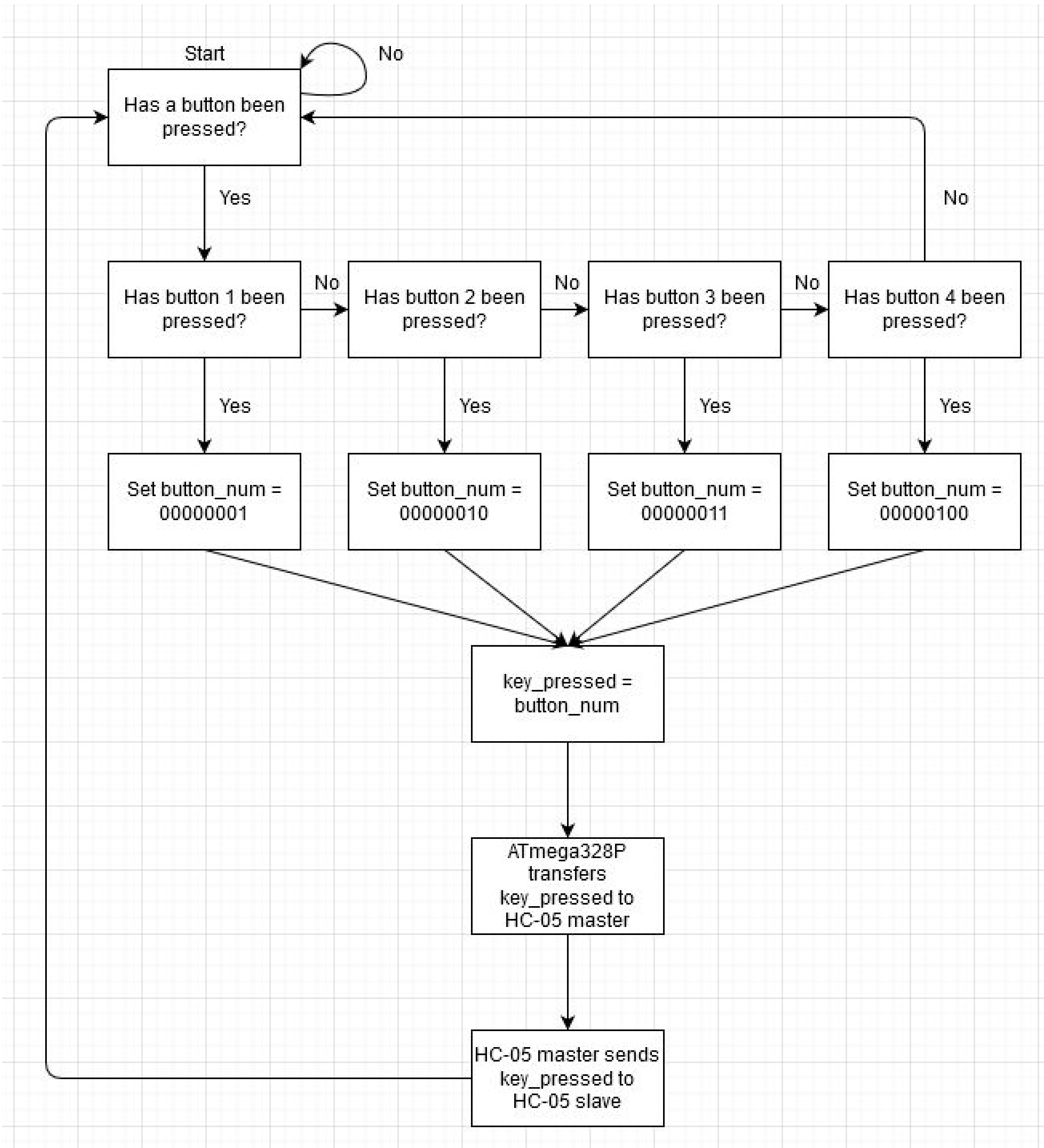

Figure 9. Flowchart for the Microcontroller Code of the Foot Button System

2.7 Tolerance Analysis

The most critical part of our project is not one of the systems, but rather the interfacing between the hand and foot systems. Since we are using Bluetooth to communicate between the systems, we are worried about latency between the buttons and the servo motors because high latency would make our product very difficult to use, if not impossible. We are confident that our HC-05 Bluetooth module will be fast enough to communicate with each other.

Our Bluetooth modules communicate using 8-bit asynchronous signals. After researching our Bluetooth module and microcontroller, we found an ICACAT journal that states the HC-05 Bluetooth module is capable of speeds around 3Mbps **[11]**, which means that we could send approximately 375,000 bytes of data per second from the foot button system to the prosthetic hand. While we do not anticipate to ever approach this capacity, it should be enough to support our communication system which will be sending a maximum of 12-16 signals per second.

While the Bluetooth communication capacity far exceeds our requirements, we will also be limited by our Bluetooth module-microcontroller interface. Our Bluetooth module will be communicating with the microcontroller chip using USART protocol at a 9600 baud rate. A 9600 baud rate translates to approximately 960 bytes of data per second **[12]** (due to the fact that Bluetooth transfers a start and stop bit - meaning 10 bits per message). This significantly bottlenecks our bandwidth from the maximum capacity of Bluetooth, but this means we should still have the capacity to send signals for 960 button actuations each second without any data loss.

Even though both the Bluetooth and the interfacing capacity is beyond our requirements, the actual data rates will be lower than the maximum capacity in practice. In order to fully verify that the Bluetooth controllers are fast enough for our prosthetic arm and foot button system, we will have to unit test the Bluetooth modules per our R&V tables.

3) Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

We estimate the cost of labor for three people will be around $37,500 assuming a reasonable salary of $50/hour, while working 10 hours/week for 10 weeks. We have an ongoing discussion with the machine shop and will receive machine shop labor hours in the near future.

$$3 \cdot \frac{\$50}{hour} \cdot \frac{10\ hours}{week} \cdot 10\ weeks \cdot 2.5 \ = \ \$37,500$$

3.1.2 Parts

Description	**Manufacturer**	**Part #**	**Quantity**	**Cost**
6V Battery	Tenergy	11106	2	$9.99 x 2 = $19.98
Battery Charger	Tenergy	1025	2	$20.99 x 2 = $41.98
Voltage Regulator	Microchip Technology	MCP1726T-5002E/MF	2	$0.68 x 2 = $1.36
Arduino Uno R3	Arduino	A000066	1	$18
ATmega328P	Microchip Technology	ATMEGA328P-PU	1	$2.08
HS-311 Servo	Hitec RCD Inc.	HRC31311S	4	$12.94 x 4 = $51.76
HC-05 Bluetooth Module	HiLetgo	HC-05	2	$12.59
Pushbutton Switch	Adafruit Industries LLC	3491	4	$2.50 x 2 = $5.00
Ball Joint Socket	Sunex	1800	4	$8.99 x 4 = $35.96
Bevel Gear	Dilwe	B07MCCNT9N	4	$4.89 x 4 = $19.56
Rubber Stopper	UIUC Machine Shop	N/A	4	$0
Total				$208.27

3.1.3 Sum of Costs

Sum of Costs = Labor Cost + Parts Cost = $37,500 + $208.27 = $38,708.27

3.2 Schedule

Week	Rahul	Vaidas	Rohil
03/02	Design Review Order Parts	Design Review Order Parts	Design Review Order Parts
03/09	Design PCB for foot button system Order PCB Put in machine shop order	Design PCB for prosthetic hand Order PCB Put in machine shop order	Design PCB for foot button system Order PCB Put in machine shop order
03/16	Assemble prosthetic hand system	Assemble power supply system	Assemble foot button system
03/23	Wire prosthetic hand to power supply and develop code for prosthetic hand	Establish Bluetooth communication between modules	Wire foot button system to power supply and develop code for foot button system
03/30	Test servo motors for optimal actuation angle for typing	Test Bluetooth connection for accuracy and latency	Test foot buttons and create button caps for optimal user pressing
04/06	Testing and debugging prosthetic hand	Debugging Bluetooth communications	Testing and debugging foot button system
04/13	Work on presentation and practice demo	Work on presentation and practice demo	Work on presentation and practice demo
04/20	Mock Demo	Mock Demo	Mock Demo
04/27	Final Demo	Final Demo	Final Demo
05/04	Presentation Final Paper	Presentation Final Paper	Presentation Final Paper

4) Discussion of Ethics and Safety

While we do not anticipate many safety hazards during this project, we have identified possible sources of danger that we need to keep in mind while working on the project. They include the overheating of servo motors that are being used to drive the fingers, the malfunction of servo motors causing mechanical dysfunction of the fingers which may harm the user of the prosthetic hand, and the improper discharge of batteries being used to power the controllers for our motors and foot buttons. Another potential safety hazard is the material of the prosthetic hand. We plan on using a lightweight metal like aluminum for the hand, which can be sharp or conductive and can cause injury if used carelessly. We can help mitigate some of these dangers by adding a plastic coating or encasing for the hand, which will both insulate the user from the electronics on the hand, as well as make the hand look more aesthetically pleasing.

We have met with the machine shop, and have come up with a design for the hand that will minimize the potential risks to the user. In order to avoid the risk of electric shock, we will only be using 6V to power our entire system - 5V per microcontroller and 6V to drive the servo motors attached to the hand. By keeping our maximum voltage at 6V, we should never overdrive the servos and avoid most mechanical issues that could arise from servo malfunction. Also, by keeping the voltage relatively low, there should never be enough current in our system to harm the user of the hand. Keeping the voltage low will also help with regulating heat in the system and keeping the hand at a safe operating temperature.

In terms of ethical issues that we might encounter, we do not believe there are not many applicable guidelines from IEEE **[13]**, but these are the most relevant:

1. *to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, and to disclose promptly factors that might endanger the public or the environment;*
9. *to avoid injuring others, their property, reputation, or employment by false or malicious action;*

Some of the ethical guidelines from ACM **[14]** are far more relevant to our project choice, such as:

1.1 *Contribute to society and to human well-being, acknowledging that all people are stakeholders in computing.*
3.7 *Recognize and take special care of systems that become integrated into the infrastructure of society.*

We believe that if we maintain proper caution during the assembly of the hand, we can mitigate the chances of causing harm to the users and their property, and avoid the ethical issues involving harm to the user entirely. Additionally, we will vigorously test the functionality of the prosthetic hand so that we do not accidentally break any keyboards. We assume full responsibility for the product that we put out, and will therefore take every possible step to mitigate the potential for our product to be abused.

We recognize that our product will be used mainly for the improvement of daily life for prosthetic users, and believe that the very spirit of our project echoes the underlying principles behind these codes. We also believe that our project has the potential to become incorporated into the lives of countless amputees and other members of society, and will therefore make every effort to make our product ethical and secure. Through rigorous testing and refinement of our design, we hope to achieve a product that will give prosthetics users more functionality and help make computers more efficient for them.

5 Citations

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