GRIP

Glove for Real-time Imitation and Performance

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EEL 4914 Senior Design I
Group 21

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Section 1: Project Overview

1.1 Motivation and Background

There are many places in the world we explore despite the harsh conditions of the area. Whether it's the crushing depths of the ocean, the vacuum of space, or simple treacherous terrain, mankind has developed many different technologies to explore these places in person and remotely. With many incredible feats on our belts, there are still some limitations, specifically with remote vehicle exploration, when interaction with the environment is limited to what a machine is programmed to do. Many examples of this kind of technological interaction with exterior environments can be seen today, such as Mars rovers with collection trays and storage for specimens or remotely piloted submersibles with controllable appendages. Most of these, however, are either operated solely by the machine's protocols or are controlled by joysticks and keyboards. The Glove for Real-time Imitation and Performance (GRIP) arm project attempts to give remote operators more direct interactions with the environment they are studying. Whether it's attached to a study vehicle or in a stationary setting, by having GRIP be controlled by a human arm, more decisive movements can be made by the remote operator that can lead to better results.

Ultimately, the prototype aims to solve real world problems in a spectrum of possibilities.

1.2 Prior Related Work

There were many existing products and one project that were similar to the idea of our project. The project was for UCF senior design in 2014 and is called the Intelligent Programmable Prosthetic Arm (IPPA). This project had many of the same ideas and components that we thought of for our arm, but with a few key differences. The IPPA focuses exclusively on the hand, whereas our project is planned to be a whole arm as a stretch goal. Having a whole arm option to connect the hand to would allow our project to have more versatility than the IPPA. The IPPA also seems to be controlled by an app to make it move, where our arm will mimic the user's arm via a glove. Overall, this previous project gives a good starting point and can provide ideas for components and mechanisms that can be used to improve our design.

An advanced example was the NASA R5 also known as Valkyrie. This was a complete humanoid robot but we focused on the arms. The arms and hands have joints which use actuators to control movement. We are trying to have more advanced movement as one of our stretch goals especially in the fingers so that each one can move on its own. The R5 provides a good idea of what is needed in the hardware to make this movement possible. This is a very polished and expensive example so we may have trouble using the same exact components or methods NASA used but we might be able to find a work around using the R5 as inspiration. The full weight of the robot is three hundred pounds and the extent is full bodied and polished by experts. Our design will appear more crude than this to its full extent.

Focusing in on the glove that we are planning to have control of the arm there is a product called the Shadow Robot Dexterous Hand Series. This product mainly focuses on the hand but there is an option to add an arm. The hand is a copy of a human hand with four fingers and a thumb and is able to function with good precision. We are hoping to see how this hand interacts with the glove that controls it as we are trying to do the same thing. The communication between the hand and glove and how to have as little latency as possible will be something that this product can help with.

There are many more examples of robotic hands and arms but the three above are what we are focusing on and show that the concept is achievable and may offer solutions we have not thought about or ideas on how we may design our system. The ideas in our design remain original and cost-effective in premise. The latency is one of the biggest drawbacks that we want to improve upon. Our algorithm will be within a few seconds of delay and rotation, see the house of quality table for a visual. The shadow project was on the higher end of the projects due to higher-quality materials. Despite the simplicity of the device being a glorified arm piece, ours will include a shoulder mechanism as well.

1.3 Project Goals and Objectives

The GRIP team will have several basic and advanced goals to work towards and a singular stretch goal that will push the team to their limits. Each goal will be composed of multiple objects that must be completed in order for the goal to be achieved. Each objective will test a certain aspect of the goal being worked towards. For example, the homing sequence will have each joint of the arm reach its limit and take note of the range, with each joint's homing functionality being an objective. Each of these small objectives will work towards a bigger goal, which, once all goals are complete, will result in a device that can be felt as an extension of the user rather than a tool that they simply wield.

Table 1.1 Project Goals Overview

Goal type	Description
Basic	• Create a device with a series of sensors that will track the user's movements and translate them to GRIP, allowing it to mimic the user with high accuracy. • The hand will be able to have an open or closed grip as well as move and sustain at least 5 lbs.
Advanced	• The system will be able to sustain a low-latency connection with moderate traffic between the user's hand and GRIP, allowing the hand to move with the user with negligible delay. • The hand portion of GRIP will have articulated fingers that are bound to the user's fingers, allowing for more intricate interactions with the environment. Basic movements such as pointing and pinching will be doable.
Stretch	• Incorporate an arm attached to the hand that will be able to mimic the user's arm. • The arm's range of motion will be able to be tested by a

	computer program without the glove. ● A homing algorithm will be made to calibrate soft and hard stops for the arm, allowing use from different-sized users after the calibration sequence.

1.4 Project Features and Functions

The project will have several critical features that will function in tandem with each other. The glove itself will have a series of sensors along the upper arm that will take note of the position of the arm relative to the user being upright. The glove will send these positions wirelessly to a receiver on the bionic arm's PCB, which will then instruct it to move to the positions of the user. The glove will be powered with a battery attachment that can be changed out, along with a power switch. A calibration mode will be available to acquire the user's full range of motion before connecting to the bionic arm. Software-wise, GRIP will have algorithms in place that will keep it from moving in a way that is considered out of range, but if that fails, the arm will have hard stops for the servos in order to guarantee operation in the functional range. The GRIP arm will also have a homing sequence on power start to log its ranges.

1.5 Project Specifications

The project is split into two main components: the arm and the glove worn by the user. As such, each will have its own specifications that are tailored to its workload and design. Each part should be able to function independently of the other for testing purposes, with the ultimate goal of the glove controlling the arm being achieved once the connection between the two is made. The tables below illustrate the specs of both components separately.

Table 1.2 Arm Specifications

Parameter	**Specification**
Forearm dimension	8.3" x 3.25" x 3.25"
Upper arm dimension	9.75" x 3.25" x 3.25"
Hand dimension	6.5" x 3.5"
Arm weight	Up to 50lbs
Stand weight	Up to 70lbs
Wireless receiver	nRF24L01+pa+lna wireless module with antenna
Shoulder movement	Dynamixel XM430
Elbow movement	DS3218

Wrist movement	MG995

Table 1.3 Glove Specifications

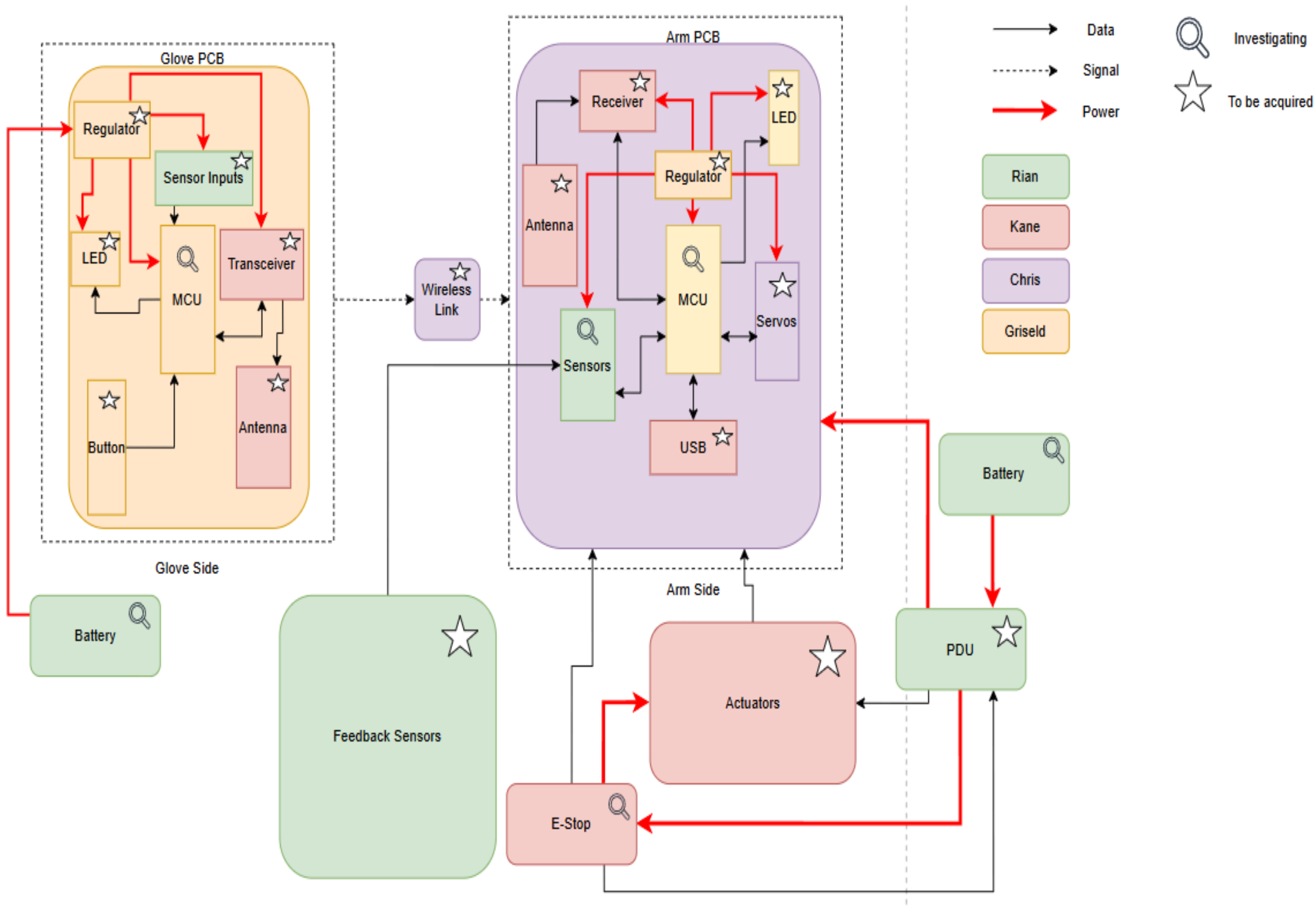
Parameter	Specification
3-axis accelerometer	ICM-20948 9DoF IMU
Wireless transmitter	nRF24L01+pa+lna wireless module with antenna
Finger potentiometer	UniMeasure ZX-PA series

Section 2: Design

2.1 Hardware Diagram

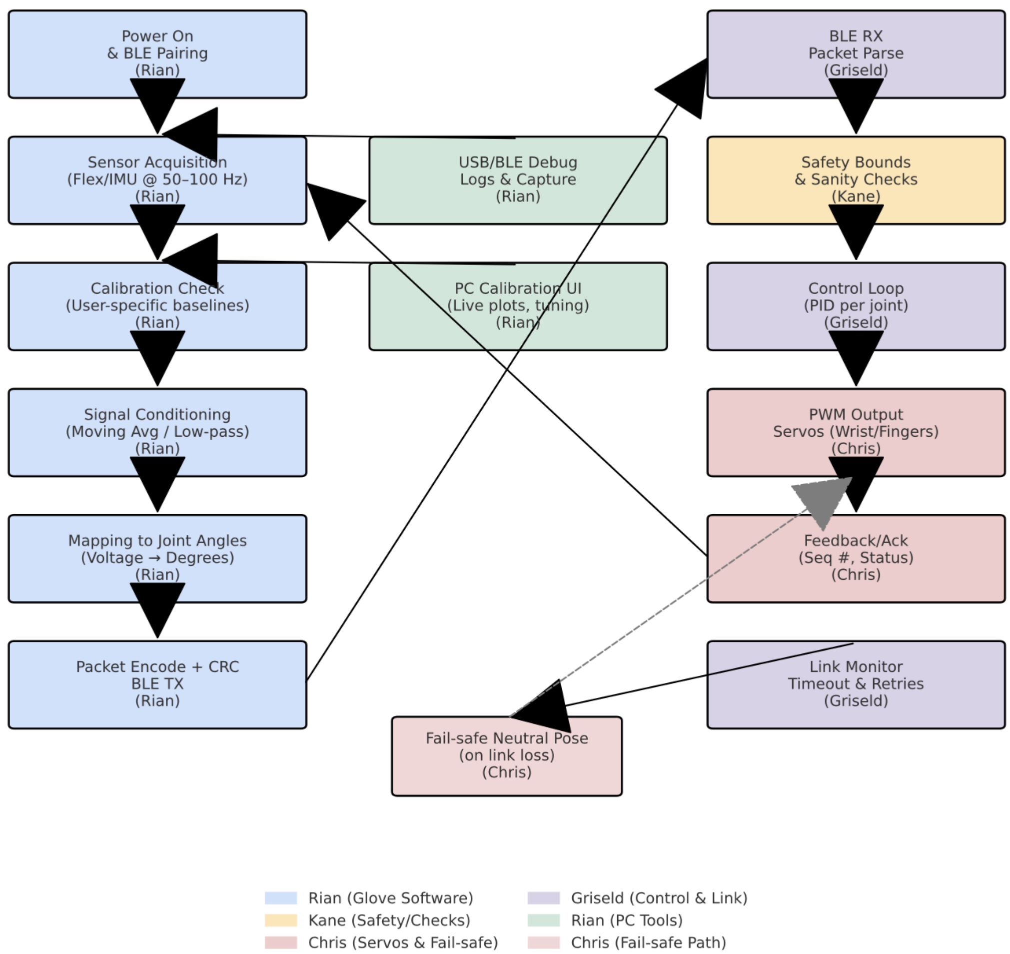
This diagram covers both the glove and the actual arm connections. We intend to implement servos to mimic joint and shoulder movement. The intention is the use of flex sensors and PCB designs that are acceptable sizes for the average human

Figure 2.1 Hardware Block Diagram



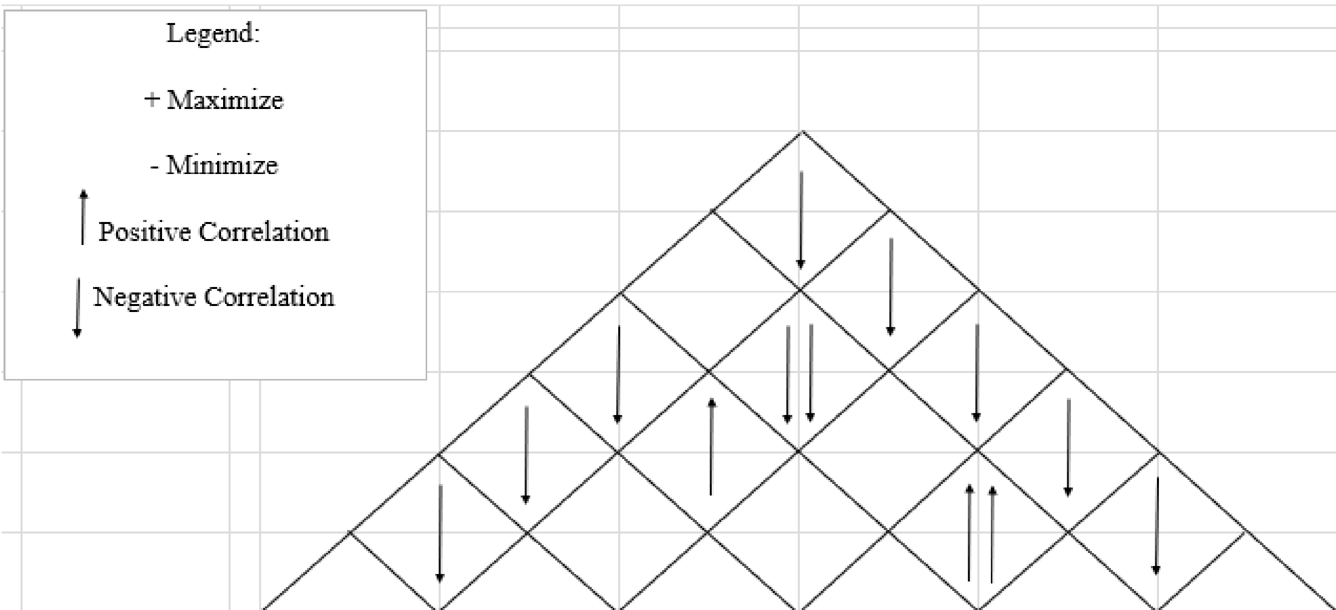
2.2 Software Design

Figure 2.2 Software Diagram



2.3 House of Quality

Figure 2.3 House of Quality



Engineering Requirements / Marketing Requirements	Direction of Desirability	Battery Life	Cost	Weight	Latency	Accuracy	Temperature
Direction of Desirability	+	+	-	-	-	+	-
Portability	+	↑	↓	↓↓			
Cost	-	↓		↓	↓↓	↓	↓
Ease of Use	+	↑	↓	↑↑	↑↑	↑	↑
Data Accuracy	+		↓		↑	↑↑	
Latency	-					↑	
Battery Life	+		↓				
Target		> 30 Min	< 1500	< 25 lbs	< 2 seconds	± 5% from reference	No Overheating

2.1.1. Data Acquisition

The C/C++ firmware for the glove's microcontroller controls the gathering of data from several sensors:

- **Flex Sensors:** A flex sensor in each finger generates analog voltages in proportion to the bending angle. These are sampled by the microcontroller's 12-bit ADC, giving fine resolution of finger motion.

- **The Inertial Measurement Unit (IMU):** used to measure movement speed, orientation, and wrist rotation. It provides three-axis acceleration and gyroscope readings.

- **Additional Sensors:** Room for expansion (e.g., pressure sensors) to detect grip force.

The frequency of sampling, which is set between 50 and 100 Hz, strikes a balance between power efficiency and responsiveness. Interrupt-driven acquisition ensures consistent timing and reduces CPU overhead.

2.1.2. Data Processing and Mapping

Sensor raw signals are prone to noise, drift, and variability. These problems are handled by the processing layer:

- **Calibration:** Flex sensor outputs are normalized for varying hand sizes and natural resting states by taking baseline readings for each user at startup.
- **Filtering:** A low-pass filter removes high-frequency noise from the IMU, while a moving-average filter smoothes out abrupt oscillations.
- **Mapping Functions:** Valuable joint angles are derived from sensor measurements. Servo angles of **0 to 90°**, for instance, are mapped to a flex sensor range of 0.5 to 3.5 V. When joint motion is not exactly proportional to voltage, nonlinear mapping functions are employed.
- **Data Packaging:** Finger angles, wrist orientation, and metadata like sequence numbers are all included in the small data packets that are created from the processed values.

2.1.3. Communication Layer

The glove uses Bluetooth Low Energy (BLE) to send packets to the robotic arm. BLE was chosen because

- Battery operation depends on low power consumption.
- Sufficient bandwidth to stream several sensor channels.
- Support for embedded microcontrollers is built in.

Packet Structure (example):

- **Header (1 byte):** Start-of-packet indicator.
- **Sequence ID (1 byte):** Used for ordering and loss detection.
- **Finger Angles (5 bytes):** One byte per finger (0–180° range).
- **Wrist Orientation (2 bytes):** Encoded yaw and pitch.
- **Checksum (1 byte):** Simple CRC for error detection.

This structure keeps packets small (~10 bytes) for efficient wireless transmission.

2.1.4. Control Output

The microcontroller of the robotic arm interprets incoming packets and uses PWM signals to drive servo motors:

- **PID Controllers:** A PID loop is used by each joint to minimize overshoot and guarantee precise positioning.
- **Safety Constraint:** Software limits keep the servos from going beyond their mechanical ranges, which is a safety constraint. Values are clipped to safe limits if data is received that is out of range.
- **Fail-Safe Procedures:** The arm returns to its neutral rest position after 500 milliseconds if no valid packet is received.
- **Servo Synchronization:** To produce organic, coordinated movement, motion is interpolated across several joints.

2.1.5. User Interface and Testing Tools

Python-written PC interfaces for GRIP offer useful development and testing capabilities, despite the system's primary function being embedded:

- **Real-Time Visualization:** Plots live sensor data for debugging.
- **Calibration Interface:** Allows manual adjustment of mapping coefficients.
- **Data Logging:** Records glove and arm movements for later analysis.
- **Wireless Debugging:** Captures BLE packets for troubleshooting communication issues.

2.1.6. Software Testing and Verification

The following tests are carried out to guarantee performance:

- **Latency Tests:** End-to-end response measured between finger movement and arm response (<100 ms target).
- **Stress Testing:** Continuous operation for 30+ minutes without overheating or communication dropouts.
- **Error Injection:** Artificially corrupted packets verify CRC detection and recovery routines.
- **Unit Tests:** Validate calibration, mapping functions, and PID controller logic.

Integration Tests: Full glove-to-arm operation across multiple users to confirm reliability.

Section 3: Budget and Financing

The budget for this project will be limited to $1000. This is a self imposed limit agreed on by the group but as the project progresses the actual cost will become clear. If we are under budget some extra funds can be used to mitigate errors and have some back up components. There are costs that are unknown such as any changes that might need to be made to the component and PCB costs. Smaller components such as the LEDs and buttons will also need to be sourced. The extra left in the budget will be useful for those situations. This budget is a draft and is subject to change.

Table 3.1 Budget

Component	Quantity	Unit Cost	Total
Controller	2	$10.00	$20.00
Flex Sensors	7	$9.42	$65.94
Servo Motors	10	$3.62	$36.20
Transceiver	1	$7.68	$7.68
Receiver	1	$4.95	$4.95
Power Source	1	$7.95	$7.95
Frame and 3-D Printed Components	1	$400.00	$400.00
Force Sensor	1	$4.95	$4.95

Section 4: Group Milestones

The GRIP team, formed at the beginning of the Fall semester, brainstormed ideas and compatibility with our timeline. Timelines below are placed based on these initial assumptions. We want concise, efficient work and to stick to these time constraints as best as we can. Since we have a multitude of hardware in the case of our project involving an arm to wear and to control, the actual design portion will take considerably longer. Senior Design I table I reflected this assumption with the dates and deadlines. As for Senior Design 2 we expect to be on schedule with these dates.

Table 4.1 Senior Design 1 Project Documentation Milestones

Task	**Timeline**	**Status**

Senior Design and Documentation		
Project Idea Brainstorm	August 28th, 2025	Complete
Project Selection	September 1st, 2025	Complete
Divide and Conquer Document (Final)	September 15th, 2025	In Progress
MCU Selection	October 6,2025	Researching
Sensor Selections	Oct 6th, 2025	Researching
60 page checkpoint	Nov 3, 2025	
Schematics Finality	Nov 3rd, 2025	Not Started
Breadboard Prototyping	Nov 17th, 2025	
PCB Layouts	Nov 28th, 2025	
120 Final Page Document	Dec 5th, 2025	
Committee Review	TBD	

Table 4.2 Senior Design 2 Documentation Milestones

Senior Design 2	Timeline	Status
Order Initial PCB	Dec 15th, 2025	Not started
PCB Assembly	TBD	Not started
Baseline Code integration	TBD	Not started
PCB redesign if needed	TBD	Not started
PCB Assembly #2	TBD	Not started
Testing and Bug Fixing	TBD	Not started
Live Demo	TBD	Not started

Appendix A

1) Ivette Carreras, Andrew Mendez, Matthew Bald, “IPPA — An Intelligent Programmable Prosthetic Arm,” *UCF ECE Senior Design*, 2015. [Online]. Available: https://www.ece.ucf.edu/seniordesign/fa2014sp2015/g05/. [Accessed: 04-Sep-2025].

2) J. M. Rogers, “R5,” *NASA*, Jul. 18, 2023. [Online]. Available: https://www.nasa.gov/technology/r5. [Accessed: 04-Sep-2025].

3)The Shadow Robot Company, “Dexterous Hand Series,” *Shadow Robot*. [Online]. Available: https://shadowrobot.com/dexterous-hand-series/. [Accessed: 04-Sep-2025].