Project #25-318 and Safe Human-Robot Collaboration through AI-embedded Smart Glove System

Preliminary Design Report

Prepared for

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Executive Summary

The executive summary highlights the key points of the document. While your advisor(s) and sponsor are expected to read the document in detail, others may only read the summary looking for a brief overview of the report. Casual readers may look at the summary to decide if they would like to continue reading. Some, more senior decision makers (e.g. executives), may read the summary to help make decisions regarding the future of the project (e.g. continuation, financing, resource allocation, etc.). It is important that all readers get a complete sense of the project, including purpose, primary objectives, design requirements, deliverables, work done to date, and timeline, among other required components provided in a table of contents. Summaries should be considered as "stand-alone" containing a complete account of the essential points of the document in chronological order of the document. Particular focus should be placed on the first sentence in order to draw readers in and should explicitly include the "who, what, and why" of the project. The executive summary is usually between half a page and a full page.

Note: The Executive Summary should be updated between major reports as more knowledge is acquired and understanding of the project expands. For example, when submitting Preliminary Design Report in December 2024, make sure you update this page to reflect the progress on the project since the submission of Project Proposal in early October 2024.

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Section A. Problem Statement

In industries like manufacturing and healthcare, robots are progressively working alongside humans to increase efficiency, reduce manual labor, and improve precision. However, as all these technologies advance and new tech demands need to be met, cost and safety propose new concerns, according to Ryan King's Article talking about the "7 Challenges in Industrial Robotics"[1]. Current systems use complex and costly technologies like computer vision, LIDAR, and motion capture to ensure safe human-robot interaction. Although these technologies are effective, they can become very costly and can bring up more concerns like difficulties in real-time responsiveness and privacy concerns.

This project falls under the general scope of computer science with a mix of artificial intelligence, human-technology interaction, and robotics. More precisely, the project includes the study of AI and cobots (collaborative robots), which are robots designed to 'collaborate' with humans in shared spaces. More research of the use of AI/machine learning for gesture recognition in robots has increased due to its potential to improve the safety and efficiency of human-robot collaboration in manufacturing, healthcare, and other industries. In this project, we are using AI to develop an algorithm that can recognize and deliver hand gestures from a smart glove to a cobot. A smart glove is a glove containing multiple sensors and produces data concerning the movement of the user's hands. The goal is to improve human-robot interaction by making the communication between humans and machines more simple to understand, making it more user-friendly and reducing the need for other sensors that can be expensive. By focusing on gesture recognition through a sensor-embedded glove, this project contributes to the broader goal of making robotic systems more accessible and user-friendly, especially in scenarios where close and safe interaction is required.

This is a faculty-sponsored project that is done in the Engineering East Hall Laboratory at VCU. In the lab, we will be using a CRB 15000 robot (collaborative robot hand grabber) to perform a simple task: picking-up 3D shaped blocks and placing them into their corresponding shaped holes. This task illustrates a real-world application of fine motor skills, which robots struggle with when relying solely on traditional automation techniques. It will present that it can be used to perform an object transfer task. We will use a Rokoko Smart Glove that has multiple sensors in each finger to train an AI model we implement to recognize various hand gestures, which will then control the robot's hand.

A similar project produced by 5 Montclair State University students on the "Development and Implementation of an AI-Embedded and ROS-Compatible Smart Glove System in Human-Robot Interaction" [2] presented an effective, low-cost solution. They integrated their own smart glove system and an Extreme Learning Machine (an AI model) to recognize gesture movements "relaxed", "fist", and "pinch". The "relaxed" state communicated to the robot to open its gripper. The "fist" gesture correlates to the robot closing its gripper. When users performed the "pinch" gesture, the system interpreted this to have the robot pick up an object. Findings show that while the system could recognize the "fist" and "pinch" hand movement very well, it had a hard time interpreting the “relaxed” hand gesture. Overall, the smart glove system successfully controlled the robotic arm in picking up and delivering objects in real-time. The implementation of their own smart gloves used force-sensitive resistors and flex sensors, which are simple sensors that are relatively inexpensive compared to more advanced technologies like LIDAR and motion capture systems.


Figure 1. Top view of a Rokoko Smart Glove [3].

Figure 2. Bottom view of the smart gloves where sensors are placed [4].

In this project, we will be utilizing a Rokoko smart glove instead of implementing our own. These smart gloves have flex sensors placed along the length of each finger to measure the degree of bending at each joint, tracking finger movement. It also includes Force-Sensitive Resistors (FSRs) that measure where the hand applies pressure. They have built-in bluetooth components to transmit the captured data wirelessly to a computer/robotic system as stated on the Rokoko website[5]. This is a tool that combines advanced sensor technology with real-time processing that will greatly contribute to our research and overall build on top of Montclair State University’s study.

Section B. Engineering Design Requirements

These requirements were decided upon our sponsor/advisors needs. It is also derived from potential design usability, like manufacturing and healthcare. It includes our goals that we wanted our design to achieve and certain goals and considerations from similar projects. Some measurable requirements come from measurements of similar project findings.

B.1 Project Goals (i.e. Client Needs)

- Create a cheaper and safer alternative for human-robot interaction
- To produce an improved model that will interpret hand gestures
- Successful smooth real-time connection between the smart glove and robot
- Validate the system in collaborative tasks

B.2 Design Objectives

- The design will include a created AI model to learn a list of hand gestures and accurately recognize the different hand movements.
- The design will relay the data from the Rokoko smart glove to the CRB 15000 robot.
- The robot will perform tasks from the given data of hand gestures derived from the smart glove.
- The robot will respond to human gestures instantaneously.

B.3 Design Specifications and Constraints

- Design must operate within Rokoko Studio Live, Robot Studio, an AI model, and must use a Rokoko Smart Glove.
- Design must capture real-time data from the smart glove until the program is terminated.
- Design must use an AI model to interpret hand gestures with at least a 90% accuracy, them being a fist, an open hand, and hand direction.
- Design must be able to operate for at least 20 minutes, the more the better.
- Design must be cheaper than current technologies being used in human-robot collaboration (LIDAR, motion capture, etc.) of less than $1000.
- Design must have the Rokoko smart glove operate with the CRB 15000 robot.
- Design must have the robot be able to carry an object that is at least a pound and not be well over 5 pounds to be able to deliver the toy to a specific location users choose to put the object.
- Design must be able to connect using hotspots.

B.4 Codes and Standards

Note: The codes and standards section is not required for the Project Proposal, but is required for all subsequent reports. This section should be comprehensive and thorough, requiring a significant research effort.

List all specific codes and standards that are relevant to the design providing specific details of each as they relate to the design. While the terms codes and standards are often used interchangeably, there are in fact important differences in their definitions that should be understood. **Standards** are documents that provide a set of technical definitions, instructions, rules, guidelines and/or characteristics of a product, process, or service meant to provide consistent and comparable results (e.g. performance requirements, dimensions, testing procedures, file formats etc.). They allow for interchangeability of components and system interoperability and are typically produced by industry or professional organizations such as ASME, ANSI, ASTM, IEEE, ISO, ACM, IAPP, AIS, etc. Standards are meant to help ensure quality, reliability, and safety.

Codes are laws or regulations that specify the methods, materials, components, etc. required for use in a certain product, process, or structure. Codes have been *codified* into a formal written policy or law and can be approved at the local (municipal), state, or federal level. While standards provide sets of guidelines, codes are constraints that *must* be met in accordance with the law. It is, however, common for codes to reference or require the use of one or more standards. Some common code producers include the EPA, OSHA, DOTs, and the NFPA. Codes help set minimum acceptable levels in order to protect public health, safety, welfare.

Codes and standards are often listed by their producer followed by an identifying numerical code. They often contain hyphens or periods which may help reference specific parts of a larger code/standard or provide the year of the latest revision. Some general examples in a list of codes and standards are as follows:

- ASME Standard No. xxx – design must consider some specific fatigue failure criteria
- IEEE Standard No. xxx – design components must not exceed some maximum current limit
- ISO Standard No. xxx – design components must adhere to some standard thread size
- OSHA Code No. xxx – operators of design must wear appropriate eye and face protection
- IRTF Standard No. xxx – design must consider internet communication protocols
- W3C Standard No. xxx – design must adhere to some HTML/CSS standards
- NIST Standard No. xxx – design must consider some specific data security standards

Note: Relevant codes and standards should be incorporated into the design specifications and constraints listed above.

Section C. Scope of Work

C.1 Deliverables

Academic:

- A team contract that specifies the roles and responsibilities for each team member.
- A project proposal.
- A preliminary design report detailing performance analysis of gesture recognition accuracy and efficiency on real-time human robot collaboration based on test scenarios.
- A fall poster and presentation displaying the process done so far.
- A final design report detailing the design process, implementation, analysis, and project outcomes.
- A capstone EXPO poster and presentation.

Design, Code, Software, and Testing:

- A list of gestures that will define the robot's performance.
- A system that captures and displays real-time motion sensor data during user use from the smart glove.
- A connection between a hotspot and the smart glove.
- An AI model code for gesture recognition.
- A functional prototype of the smart glove being used to relay gesture recognition data to the robot.
- Detailed comments and explanations within the AI model code and other code files to ensure clarity and update other team members.
- A test plan outlining the methods for evaluating the smart glove's performance
- Test results from experiments involving the robot and different gestures.

C.2 Milestones

All deliverables and milestones should be included in the project timeline found in Appendix 1.

Due Date	Description
Sep 30, 2024	Team contract, GIT repository, planned day to meet with team members and advisor/sponsor
Oct 31, 2024	Individual assignments, project proposal report, obtain Rokoko Studio Live Subscription & Robot Studio License, successful smart glove connection, detailed list of gestures, display data output from smart glove
Nov 15, 2024	Determine AI model, glove & robot research, fall design poster
Nov 24, 2024	Begin development of AI model, required code, and calculations
Nov 25 - Dec 1	**THANKSGIVING BREAK**
Dec 22, 2024	75% AI model code should be complete. (duration during finals week)
Dec 23 - Jan 12	**WINTER BREAK**
Feb 14, 2025	Connection between robot and smart glove achieved
Feb 28, 2025	AI model complete, instantaneous reaction of robot achieved
Mar 7, 2025	Testing procedure plan
Mar 9 - Mar 16	**SPRING BREAK**
Mar 28, 2025	Precision accuracy reached, collected all data needed for final project report
Apr 4, 2025	Final Project Analysis
May ??, 2025	Capstone EXPO poster and presentation

C.3 Resources

- Access to the East Engineering Laboratory
- Softwares: Rokoko Studio Live +, Robot Studio, IDEs (Colab)
- Rokoko Smart Gloves
- AI Models (ELM or LLM) and Machine Learning Libraries (scikit-learn, PyTorch)

Section D. Concept Generation

The concepts below focus on simplifying gesture-based human-robot interaction while mitigating the drawbacks of traditional sensing systems. The glove system will communicate human intentions to the robot in real-time, improving safety, ease of use, and reducing reliance on costly sensors.

<u>Glove Concepts:</u>

Concept 1: AI-Driven Gesture Recognition with Adaptive Learning

In this design, the Rokoko Smart Glove is equipped with multiple sensors that capture detailed finger and hand movement data. AI models are trained to recognize and adapt to various gestures in real-time. This system uses adaptive machine learning algorithms to refine gesture recognition, ensuring that the system learns and improves with continued use, accounting for individual user variations.

Pros:

- It can learn your specific hand movements, making it more personalized.
- It gets better at recognizing gestures quickly.

Cons:

- It may take a lot of time to train the system, especially for different users.
- It needs a lot of computing power, which could slow things down.

Potential Risks:

- If it's not trained well, it might misunderstand your gestures and cause errors.
- High computing needs could lead to delays in responding.

Sub-Problems:

- Researchers need to figure out how to make the AI run more efficiently, using less computing power.

Concept 2: Rule-Based Gesture Recognition with Pre-Defined Gestures

This concept simplifies the AI model by using a set of predefined hand gestures that correspond to specific robot actions. The smart glove communicates these gestures to the robot directly without adaptive learning. This system ensures fast and reliable gesture recognition without the need for extensive training.

Pros:

- Quick to set up because the gestures are already defined.
- Uses less computing power since it doesn't require learning.
- Works well in controlled settings where gestures are consistent.

Cons:

- Not customizable; the set gestures might not fit everyone.
- Users need to memorize specific gestures, which can feel less natural.

Potential Risks:

- The limited list of gestures might not cover all necessary actions for complicated tasks.
- It could struggle to recognize gestures that aren't on the list, making it harder to use.

Sub-Problems:

- Creating the gesture list needs careful thought to ensure the gestures are easy to understand and use.

Concept 3: Biomimicry-Inspired Gesture Recognition with Multi-Modal Feedback

This concept is inspired by biomimicry, simulating natural human hand movements and leveraging multi-modal feedback. The glove uses sensors not only for detecting hand movement but also for providing real-time feedback to the user, allowing for more intuitive interaction with the robot.

Pros:

- Gives instant feedback, which helps users feel more confident and accurate while controlling the robot.
- Mimics how people naturally move, making it easier to use without a steep learning curve.
- Increases safety by alerting users when a gesture isn't recognized correctly.

Cons:

- Needs extra hardware for the feedback, which can make it more complicated and expensive.
- May require advanced technology to combine different types of feedback effectively.

Potential Risks:

- If the feedback isn't set up right, it could confuse users or lead to wrong interpretations of gestures.
- More complicated systems might slow down interactions, affecting real-time communication.

Sub-Problems:

- Combining different types of feedback while keeping the communication with the robot quick and effective is a challenge.

Robot Concepts:

In all cases, the CRB 15000 (robot) will be communicated with via a TCP connection. This connection will inform the robot how and where to move based on the gestures output by the glove.

Concept 1: Discrete Numerical Command Mapping via TCP Socket

This concept implements a straightforward, robust method of robot control where specific numerical values received over a TCP connection directly trigger predefined robotic actions.

Pros:

- Simple and predictable communication protocol
- Low latency between command transmission and execution
- Easy to implement and debug
- Minimal computational overhead

Cons:

- Limited expressiveness of communication
- Requires predefined mapping of numbers to actions
- Less flexible than more complex gesture recognition systems

Potential Risks:

- Limited error handling for complex scenarios
- Potential communication interruptions
- Strict reliance on predefined command mappings

Sub-Problems:

- Ensuring robust socket connection management
- Creating a comprehensive command mapping strategy
- Implementing failsafe mechanisms for unexpected inputs

Concept 2: File-Based Command Interface for Robotic Control

The robot continuously monitors a text file, reading each new line as a command and executing corresponding movements based on the specific text instruction.

Pros:

- Simple file-based communication method
- Easy to debug and track command history
- Low-complexity implementation
- No complex network setup required
- Persistent command logging

Cons:

- Slower than direct TCP communication
- Potential for file access conflicts

- Less real-time compared to socket-based methods
- Limited simultaneous command processing

Potential Risks:

- File access conflicts
- Potential synchronization issues
- Limited real-time responsiveness
- Requires careful file management

Sub-Problems:

- Ensuring reliable file reading
- Handling concurrent file access
- Implementing robust error checking
- Managing file size and history

Section E. Concept Evaluation and Selection

Selection Criteria – After reviewing the project's objectives we identified the following selection criteria for evaluating the design concepts:

- *Performance*: How well the concept addresses real-time gesture recognition and robot control.
- *Cost*: The overall cost of implementing the concept, including hardware and computational resources.
- *Safety*: The concept's ability to ensure safe human-robot interaction in close-proximity environments.
- *Reliability*: The consistency and accuracy of gesture recognition and robot response.
- *Ease of Implementation*: The level of complexity and difficulty in implementing the concept with the available resources.
- *Scalability*: How easily the concept can be scaled to more complex tasks and different industries.

Weighting Factors – We have assigned the following weights to each criterion to reflect their relative importance:

- *Performance* – 40%
- *Cost*: 5%
- *Safety*: 25%
- *Reliability*: 15%
- *Ease of Implementation*: 10%
- *Scalability*: 5%

Metrics

- *Performance* – Measured by response time and gesture recognition accuracy.
- *Cost* – Estimated cost of hardware and computational resources.
- *Safety* – Evaluated based on the potential for safe interaction in a real-time environment.
- *Reliability* – Measured by error rate for recognizing gestures.
- *Ease of Implementation* – Evaluated by complexity of AI model development and the integration of the glove with the robot.
- *Scalability* – The ability to adapt the system for more complex environments and industries.

Decision Matrix – The decision matrix is a scale from 1-10 where 10 being the best and 1 being the worst and converted to percentage.

Design Concepts	Performance (40%)	Cost (5%)	Safety (25%)	Reliability (15%)	Ease (10%)	Scalability (5%)	Total
Concept 1: AI-Driven Adaptive Learning	8 (32%) uses adaptive AI, which provides high performance in real-time gesture recognition	6 (3%) Slightly higher cost due to computing resources	9 (22.5%) accuracy over time & can enhance safety by continuously refining gestures	8 (12%) adaptive nature of the AI	5 (5%) Implementing machine learning can be complex and resource-intensive	7 (3.5%) accommodate more complex gestures	78%

Concept 2: Rule-Based Pre-Defined Gestures	6 (24%) uses predefined gestures, which may not be flexible and may perform worse in certain scenarios	9 (4.5%) Requires less computational power and resources	8 (20%) Provides reliability because of predefined gestures	7 (10.5%) Reliable but doesn't adapt well to unexpected movements	9 (9%) simplicity & reliance on predefined gesture make easier to implement & maintain	5 (2.5%) limited flexibility of predefined gestures	70.5%
Concept 3: Biomimicry-Inspired with Feedback	7 (28%) strong performance, helped by multi-modal feedback that improves user interaction and gesture accuracy.	5 (2.5%) Multi-modal systems add to the cost of dev.	9 (22.5%) real-time feedback, provides safety warnings for users	8 (12%) real-time feedback helps maintain reliability and reduce risk of error	7 (7%) Easier than adaptive learning but still some complexity	8 (4%) biomimicry design is versatile for more complex use cases across industries	76%

Evaluation and Justification

- Concept 1: AI-Driven Adaptive Learning scored the highest, 78% due to its strong performance, safety, and reliability. Its adaptive learning ability allows the AI to improve gesture recognition over time, which is highly beneficial for dynamic environments.
- Concept 2: Rule-Based Pre-Defined Gestures scored 70.5%. It has the advantage of lower cost and ease of implementation, making it a good option for quick deployment. However, its performance is slightly lower since predefined gestures may limit flexibility and naturalness in human-robot interaction.
- Concept 3: Biomimicry-Inspired with Feedback scored 76%, coming in second. It emphasizes safety through real-time feedback, allowing the user to correct gestures on the fly. It also scores well in scalability and reliability. However, its cost and complexity are higher due to the multi-modal feedback integration.

Therefore, based on the scores from the Decision Matrix, Concept 1: AI-Driven Adaptive Learning is chosen as the best design to move forward with. It has the best chance for long-term success because of its adaptability, scalability, and reliability. The improvements in performance and safety make it worth the cost.

Section F. Design Methodology

Since *Concept 1: AI-Driven Adaptive Learning* has been selected as the best design, the methods described here will focus on how this design will be evaluated, improved, and evolved through the iterative engineering design process.

F.1 Computational Methods (e.g. FEA or CFD Modeling, example sub-section)

1. Machine Learning Model Development
    a. Software: The gesture recognition system will be developed using Python, with machine learning libraries like TensorFlow to train networks.
    b. Training and Validation: Data from the Rokoko Smart Glove will be collected to train the model, using a variety of hand gestures. The dataset will be split into training and testing to ensure accuracy and generalization.
    c. Algorithm: The adaptive learning system will utilize a network to detect gesture patterns. Reinforcement learning techniques will further improve accuracy as the system interacts with different users.
    d. Assumptions: The model assumes that gesture data from the glove will be clean and well-suited for recognition, with minimal noise and interference.
2. Simulation of Human-Robot Interaction
    a. Simulation Environment: The system's interaction with the robot will be simulated using Robot Studio (Robot Operating System). The simulation will model how well the robot responds to the hand gestures transmitted by the smart glove.
    b. Boundary Conditions: The simulation will test the response time, accuracy, and safety, speed of gestures, and external interference.
    c. Performance Metrics: The simulation will focus on key performance metrics, such as: gesture recognition accuracy, robot response time, and task success rate.

F.2 Experimental Methods

Prototype Development and Testing

a. Prototype Setup: The physical system consists of the Rokoko Smart Glove and a collaborative robot. The glove will be worn by users to send gesture commands to the robot, which will perform tasks like picking up and placing objects.

b. Testing Equipment: The Rokoko Smart Glove for capturing hand movements. A collaborative robot to carry out actions based on glove input. Data Acquisition Systems to monitor performance and collect real-time data.

c. Testing Procedures: The user will perform predefined hand gestures to interact with the robot. The system will be evaluated based on its ability to recognize gestures and execute commands with high accuracy and speed. Metrics will be recorded to evaluate task completion success, response time, and safety.

2. User Testing
    a. Objective: Test the system with multiple users of different skill levels and hand sizes to evaluate its adaptability.

b. Procedure: Each user will wear the glove and perform gestures in a controlled setting. The system will track the accuracy and speed of gesture recognition, as well as how consistently the robot responds.

c. Data Collection: Performance metrics will include gesture accuracy, response time, and the number of successful task completions. User feedback will also be collected on ease of use and overall experience.

F.3 Architecture/High-level Design

The system's architecture integrates the smart glove, the AI gesture recognition subsystem, and the robot control subsystem.

1. System Overview:
    a. Gesture Recognition Subsystem: The smart glove captures hand movements and transmits the data to the AI subsystem, where gestures are recognized and classified.
    b. AI Processing Subsystem: The AI system processes the data in real time, recognizing specific gestures and sending corresponding commands to the robot.
    c. Robot Control Subsystem: The collaborative robot receives commands and executes physical tasks.
2. Communication Flow:
    a. Data from the glove is sent wirelessly to the AI system, which processes the information and communicates robot commands via the Robot Operating System.

F.5 Validation Procedure

1. Verification Process:
    a. Objective: Ensure that the system meets all performance metrics, including gesture recognition accuracy and response time.
    b. Tools Used: Data from simulation models and prototype testing will be collected to verify the system's performance against the established specifications.
2. Client Meeting and Validation Plan
    a. Time Frame: The validation meeting with the client will be where the final design will be demonstrated through a live, real-time interaction where the glove controls the collaborative robot to perform tasks.
    b. Client Feedback Collection: A survey will be conducted to collect client feedback on performance, ease of use, and overall satisfaction with the system. Team members will observe the client's interaction with the system and take notes on how intuitive and reliable the interface is.
3. Continuous Improvement
    a. Based on feedback from the client and stakeholders, further adjustments will be made to improve the system's performance and ease of use. The AI model will be fine-tuned to enhance accuracy, and any safety concerns will be addressed in the final iterations.
4. Final Validation

a. A final round of testing will be conducted after adjustments have been made. This round will ensure that all objectives are fully met.

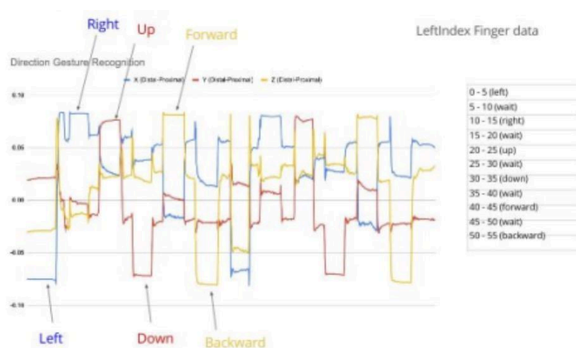
Section G. Results and Design Details

G.1 Modeling Results

AI Model Development

The machine learning model used for gesture recognition was trained using data from the Rokoko Smart Glove, which captured a wide range of hand movements. The training process involved getting data for initial gesture recognition and using reinforced learning to adapt to the system over time.

- Model Accuracy: This test will show the accuracy of the data recognizing the hand gestures.
- Training and Testing Data: The model will be trained using multiple different hand gestures.
- Response Time: In real-time testing, the system will process gestures and send commands to the robot while meeting the design specification response time.
- Figures:



G.2 Experimental Result

Prototype Testing: the system prototype will be tested in a lab environment, where the Rokoko Smart Glove will control a collaborative robot to complete specific tasks, such as object manipulation.

a. Ideally the robot will successfully perform tasks such as picking up and placing objects using gestures from the glove. The key performance indicator here will be the success rate of task completion.
b. Gesture Recognition Accuracy: During the live testing, ideally the gesture recognition accuracy will have a high success, if errors they should be minor errors in more complex hand positions.
c. Safety Measures: The robot has a safety mechanism that if it's interacting with a human it will stop operating until safe again to continue.

G.3 Prototyping and Testing Results

1. Prototype Development
    a. The final prototype consisted of the Rokoko Smart Glove and a collaborative robot, with the AI system functioning as the intermediary for gesture recognition and command translation.
    b. Prototype Features: The glove was equipped with multiple sensors to capture finger and hand movements, AI machine learning will process these movements and identified gestures with high accuracy. The robot responded to gestures in real time, performing specific actions based on recognized gestures.

2. User Testing
    a. We will conduct user testing before the final testing so we know that the system can be adaptable to different users with different motion patterns.
    b. Ideally, AI machine learning will adapt to different users' individual gestures and have a high success rate.

G.4. Final Design Details/Specifications

The projected final design is expected to meet the key specifications outlined in the initial design objectives and constraints. Below are the anticipated performance specifications and features of the design, based on preliminary testing and ongoing development.

1. Anticipated Final Design Specifications
    a. Gesture Recognition Accuracy: Expected to be above 90%.
    b. Robot Response Time: Targeted to be pretty quick depending on the final integration and system optimization.
    c. Task Completion Success Rate: Projected to be above 90% assuming further refinements in gesture recognition and control algorithms.

2. Key Features of the Projected Final Design
    a. Adaptive Learning: The AI system is designed to continuously adapt to the user's gestures over time, with the goal of improving performance in real-world environments.
    b. User-friendly Interface: The system is expected to allow users to control the robot with minimal training, using natural hand gestures.
    c. Safety Controls: The robot is designed with a safety mechanism that automatically stops when a person is interfering with it and will resume when safe to do so.

3. Anticipated Design Diagrams
    a. Data Flow Diagram: The projected final design will include a dataflow diagram showing how gesture data is collected, processed, and sent to the robot for execution.

b. Gesture-to-Command Mapping: The final design is expected to include a mapping between gestures and robot actions, clearly showing the relationship between user input and robot response.

Section H. Societal Impacts of Design

H.1 Public Health, Safety, and Welfare

The CRB 15000 robot has an emergency stop mechanism that activates when it comes into contact with a human while moving. We will also implement additional checks to ensure the system can halt instantly in case of an unexpected hand gesture or system malfunction, preventing harm to the operator or bystanders. The AI gesture recognition system will be carefully calibrated and trained to avoid misinterpretation of hand gestures that could lead to unsafe robot movements.

By providing hands-free control over the robot, the system could help reduce strain or repetitive stress injuries in industries where robots assist with physically demanding jobs. Since the robot operates in close proximity to users, the design must comply with protective protocols and industry standards, such as ISO 10218 for industrial robots. Automating tasks with our gesture control system could increase efficiency in healthcare, manufacturing, and logistics, which would benefit societal welfare by reducing the human workload.

H.2 Societal Impacts

Controlling robots using gestures can increase productivity in industries like manufacturing, logistics, and healthcare, allowing workers to control complex systems more easily, and even potentially perform tasks remotely! This project could also increase accessibility for people with disabilities, offering alternative ways of interacting with machinery without relying on traditional physical controllers or physical labor. The technology may reshape work dynamics as we know it by fostering environments where humans and robots work side by side more frequently, and.

H.3 Political/Regulatory Impacts

This system must comply with existing robotics and safety regulations. For example, the Occupational Safety and Health Administration (OSHA) and ISO standards oversee safety requirements for industrial robots. Adhering to these guidelines will ensure safety and prevent legal challenges. Additionally, since the smart glove technology collects motion data, which is considered “sensitive user data,” it may be subject to privacy laws regulating how personal data is handled.

H.4. Economic Impacts

Automating tasks through gesture recognition could significantly reduce labor costs, especially in industries requiring precision or remote operation, leading to increased productivity and lower business expenses. However, this could also eliminate certain low-skill positions, which may negatively impact the job market. On the other hand, it will create demand for jobs focused on the development, maintenance, and operation of these systems, shifting the focus away from manual labor.

H.5 Environmental Impacts

The robot system must be designed with energy efficiency in mind, especially in industries heavily reliant on robotics. Without energy-efficient designs, the system could cause a large carbon footprint, negatively impacting future generations. Using robots trained for precision (via gestures) could reduce waste in manufacturing sectors by decreasing errors and rework needed.

Currently, the robot and smart glove are not made from recyclable or sustainable materials. If this project becomes widespread, this could be detrimental to the environment, but future development could push for more sustainable materials to address these concerns.

H.6 Global Impacts

This system could be applied across various industries worldwide, fostering global collaboration in robotics and AI development. Companies in different parts of the world may adopt similar systems to streamline processes, particularly in manufacturing and logistics. This could also allow people to control robots remotely across the globe, enabling specialists, such as healthcare professionals, to assist when needed without the need for international travel. This could make life saving care more accessible.

H.7. Ethical Considerations

Automating tasks that humans currently perform could lead to job displacement and higher unemployment rates. As designers, we have considered the social consequences of our innovations and believe this technology could bring more benefits than harm. There is also a potential ethical concern about the AI's ability to recognize gestures equally for all individuals. Bias in gesture recognition could result in the system being less inclusive for certain groups. The last ethical issue is, if gesture data from the smart glove is stored or analyzed, protecting user privacy will be crucial to prevent misuse of personal data, which is a critical ethical concern.

Section I. Cost Analysis

Provide a simple cost analysis of the project that includes a list of all expenditures related to the project. If an experimental test set-up or prototype was developed, provide a Bill of Materials that includes part numbers, vendor names, unit costs, quantity, total costs, delivery times, dates received, etc. Do not forget to include all manufacturing costs incurred throughout the completion of the project. If the design is expected to become a commercial product, provide a production cost estimate including fixed capital, raw materials, manufacturing (including tooling and/or casting), and labor costs to produce and package the device. Note that this type of detailed cost analysis may be listed as a project deliverable.

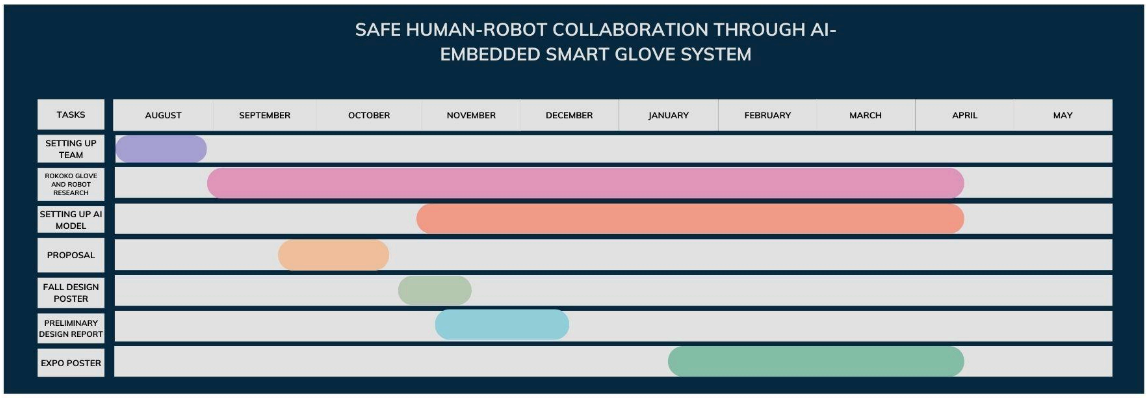
Note: The Preliminary Design Report should include all costs incurred to date. It is expected that this section will be expanded and updated between the preliminary and final design reports.

Section J. Conclusions and Recommendations

Use this section to summarize the story of how the design team arrived at the final design. Focus on the evolution of the design through the use of the engineering design process including lessons learned, obstacles overcome, and triumphs of the final design. Revisit the primary project goals and objectives. Provide a brief summary of the final design details and features paramount to the function of the design in meeting these goals and objectives.

A discussion may be included to discuss how the design could be further advanced or improved in the future. If applicable, summarize any questions or curiosities that the final results/design of this effort bring to mind or leave unanswered. If this project might continue on as a future (continuation) senior design project, detail the major milestones that have been completed to date and include any suggested testing plans, relevant machine drawings, electrical schematics, developed computer code, etc. All relevant information should be included in this section such that future researchers could pick up the project and advance the work in as seamless a manner as possible. Documents such as drawings, schematics, and codes could be referenced here and included in one or more appendix. If digital files are critical for future work, they should be saved on a thumb drive, external hard drive, cloud, etc. and left in the hands of the project advisor and/or client.

Appendix 1: Project Timeline



Appendix 2: Team Contract (i.e. Team Organization)

Step 1: Get to Know One Another. Gather Basic Information.

Task: This initial time together is important to form a strong team dynamic and get to know each other more as people outside of class time. Consider ways to develop positive working relationships with others, while remaining open and personal. Learn each other's strengths and discuss good/bad team experiences. This is also a good opportunity to start to better understand each other's communication and working styles.

Team Member Name	***Strengths each member bring to the group***	***Other Info***	***Contact Info***
Caitlin Ngo	Collaborator, problem-solver, Organized, Creative	I enjoy being a part of a team and meeting new people.	ngoca@vcu.edu 703-400-2786

Sienna Sterling	Works well under pressure, problem solver, determined, good presenter.	Normally I will complete things when I say I will. I'm really deadline oriented.	sterlingsr@vcu.edu 804-895-3042
Chris Hoang	Organization, Punctual, Easygoing, Fast typer, Work well under pressure.	I'm good at coming up with solutions. Good at public speaking.	hoangc3@vcu.edu 703-732-1494
Erin Anderson	Structured, Organized, problem-solver, accountable	I am good at designing.	andersones3@vcu.edu 202-300-4485

Other Stakeholders	***Notes***	***Contact Info***
Example: Faculty Advisor	Also our sponsor	*ebulut@vcu.edu*
Sponsor, Mentor, etc. (Add rows if necessary)		

Step 2: Team Culture. Clarify the Group's Purpose and Culture Goals.

Task: Discuss how each team member wants to be treated to encourage them to make valuable contributions to the group and how each team member would like to feel recognized for their efforts. Discuss how the team will foster an environment where each team member feels they are accountable for their actions and the way they contribute to the project. These are your Culture Goals (left column). How do the students demonstrate these culture goals? These are your Actions (middle column). Finally, how do students deviate from the team's culture goals? What are ways that other team members can notice when that culture goal is no longer being honored in team dynamics? These are your Warning Signs (right column).

Resources: More information and an example Team Culture can be found in the Biodesign Student Guide "Intentional Teamwork" page (webpage | PDF)

Culture Goals	***Actions***	***Warning Signs***

Being on time to every meeting	• *Set up meetings in shared calendar* • *Send reminder email in day before meeting* • *If you are going to be late beyond your control just let us know.*	• *Student misses first meeting, warning is granted* • *Student misses meetings afterwards – issue is brought up with faculty advisor*
Informing the group of any delays in completing assignments	• *Stay up to date with each other's project responsibilities* • *Set reasonable deadlines and note when an extension is needed* • *Inform team members if you're unsure of something*	• *Student shows up for weekly meeting with no considerable work done*
Take notes each meeting.	Document every meeting, including Google Drive and deadlines.	

Step 3: Time Commitments, Meeting Structure, and Communication

Task: Discuss the anticipated time commitments for the group project. Consider the following questions (don't answer these questions in the box below):

- What are reasonable time commitments for everyone to invest in this project?
- What other activities and commitments do group members have in their lives?
- How will we communicate with each other?
- When will we meet as a team? Where will we meet? How Often?

- Who will run the meetings? Will there be an assigned team leader or scribe? Does that position rotate or will same person take on that role for the duration of the project?

Required: How often you will meet with your faculty advisor advisor, where you will meet, and how the meetings will be conducted. Who arranges these meetings?
See examples below.

Meeting Participants	***Frequency Dates and Times / Locations***	***Meeting Goals Responsible Party***
Students Only	*As Needed, On Discord Voice Channel or Facetime.*	*Update group on day-to-day challenges and accomplishments (Avery will record these for the weekly progress reports and meetings with advisor)*
Students Only	*Fridayay*	*Actively work on project (Sienna will document these meetings by taking photos of whiteboards, physical prototypes, etc, then post on Discord and update Capstone Report)*
Students + Faculty advisor	*Every Wednesday at 1 pm in TBD*	*Update faculty advisor and get answers to our questions (Chris will scribe; Erin will create meeting agenda and lead meeting)*

Step 4: Determine Individual Roles and Responsibilities

Task: As part of the Capstone Team experience, each member will take on a leadership role, ***in addition to*** contributing to the overall weekly action items for the project. Some common leadership roles for Capstone projects are listed below. Other roles may be assigned with approval of your faculty advisor as deemed fit for the project. For the entirety of the project, you should communicate progress to your advisor specifically with regard to your role.

- **Before meeting with your team**, take some time to ask yourself: what is my "natural" role in this group (strengths)? How can I use this experience to help me grow and develop more?
- **As a group,** discuss the various tasks needed for the project and role preferences. Then assign roles in the table on the next page. Try to create a team dynamic that is fair and equitable, while promoting the strengths of each member.

Communication Leaders

Suggested: Assign a team member to be the primary contact for the client/sponsor. This person will schedule meetings, send updates, and ensure deliverables are met.

Suggested: Assign a team member to be the primary contact for faculty advisor. This person will schedule meetings, send updates, and ensure deliverables are met.

Common Leadership Roles for Capstone

1. **Project Manager:** Manages all tasks; develops overall schedule for project; writes agendas and runs meetings; reviews and monitors individual action items; creates an environment where team members are respected, take risks and feel safe expressing their ideas.
   Required: On Edusourced, under the Team tab, make sure that this student is assigned the Project Manager role. This is required so that Capstone program staff can easily identify a single contact person, especially for items like Purchasing and Receiving project supplies.
2. **Logistics Manager:** coordinates all internal and external interactions; lead in establishing contact within and outside of organization, following up on communication of commitments, obtaining information for the team; documents meeting minutes; manages facility and resource usage.
3. **Financial Manager:** researches/benchmarks technical purchases and acquisitions; conducts pricing analysis and budget justifications on proposed purchases; carries out team purchase requests; monitors team budget.
4. **Systems Engineer:** analyzes Client initial design specification and leads establishment of product specifications; monitors, coordinates and manages integration of sub-systems in the prototype; develops and recommends system architecture and manages product interfaces.
5. **Test Engineer:** oversees experimental design, test plan, procedures and data analysis; acquires data acquisition equipment and any necessary software; establishes test protocols and schedules; oversees statistical analysis of results; leads presentation of experimental finding and resulting recommendations.

6. **Manufacturing Engineer:** coordinates all fabrication required to meet final prototype requirements; oversees that all engineering drawings meet the requirements of machine shop or vendor; reviews designs to ensure design for manufacturing; determines realistic timing for fabrication and quality; develops schedule for all manufacturing.

Team Member	***Role(s)***	***Responsibilities***
Chris Hoang	*Scriber, Logistics Manager.*	● *Keep a detailed record of meeting notes and share with group* ● *Manages facility and resource usage.* ● *Lead external and internal interactions.*
Caitlin Ngo	Financial Manager, Test Engineer	● researches/benchmarks technical purchases and acquisitions; conducts pricing analysis and budget justifications on proposed purchases; carries out team purchase requests; monitors team budget. ● oversees experimental design, test plan, procedures, and data analysis; acquires data acquisition equipment and any necessary software; establishes test protocols and schedules; oversees statistical analysis of results; leads presentation of experimental findings and resulting recommendations.
Erin Anderson	Project Manager	● develops overall schedule for project ● writes agendas and runs meetings ● reviews and monitors individual action items ● creates an environment where team members are respected ● take risks and feel safe expressing their ideas.
Sienna Sterling	Systems Engineer, Historian	● Analyzes Client initial design specification and leads establishment of product specifications ● Monitor, coordinate and manage integration of subsystems in the prototype ● Develops and recommends system architecture and manages product interfaces. ● Take pictures of our team to document our progress.

Step 5: Agree to the above team contract

Team Member: Chris Hoang *Signature: __Chris Hoang_______________*

Team Member: Sienna Sterling *Signature: ________Sienna Sterling__________*

Team Member: Caitlin Ngo *Signature: ___Caitlin Ngo___*

Team Member: Erin Anderson *Signature: ____Erin Anderson______*

References

Provide a numbered list of all references in order of appearance using APA citation format. The reference page should begin on a new page as shown here.

[1] VCU Writing Center. (2021, September 8). *APA Citation: A guide to formatting in APA style.* Retrieved September 2, 2024. https://writing.vcu.edu/student-resources/apa-citations/

[2] Teach Engineering. *Engineering Design Process*. TeachEngineering.org. Retrieved September 2, 2024. https://www.teachengineering.org/populartopics/designprocess

[3] top view of glove (thanks for citing all this chris :p)

[4] bottom view of glove

[2] Development and Implementation of an AI-Embedded and ROS-Compatible Smart Glove System in Human-Robot Interaction (this is a paper in the related papers folder in our capstone folder)

[1] https://www.rowse.co.uk/blog/post/7-challenges-in-industrial-robotics

[5]https://support.rokoko.com/hc/en-us/articles/4410471103249-Getting-Started-with-your-Smartgloves