# CMSC 451 Project 25-347 ECHO

VCU College of Engineering

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# Executive Summary

This project focuses on advancing human-robot collaboration, addressing the growing need for safe and efficient interaction between humans and robots in various industries. As robots increasingly integrate into workplaces such as healthcare, manufacturing, and creative sectors, ensuring that robots can operate safely alongside humans is paramount. The primary objective of this multi-year project is to develop advanced systems that enhance the safety, efficiency, and precision of industrial and collaborative robots (cobots), specifically improving their ability to detect and differentiate between humans and non-human objects in real time.

In the initial phase of the project, the team successfully created a prototype for virtual choreography of robotic movements using mixed reality. This system enabled real-world mapping of robot actions for precise replay in industrial settings. In the second phase, the project advanced by integrating sensors that allowed cobots to detect humans, represent them as virtual objects in Unity, and use "go" and "no-go" zones to regulate robotic actions based on proximity. LED lights and a haptic feedback system were also incorporated to help maintain safe distances between humans and robots.

In the current iteration (Phase 3), the team's goal is to focus specifically on collaborative robots, further improving the cobot's sensory precision. The system will be enhanced to detect finer details, such as finger movements, and make more accurate distinctions between humans and non-human objects. This refinement is essential for ensuring situational awareness and responsive actions in increasingly complex environments where close human-robot interactions are necessary.

The project is governed by stringent design requirements and engineering objectives. Key goals include developing a more intuitive system for human-robot collaboration in industrial environments, enabling fine-grained interactions in settings such as labs and hospitals, and creating scalable solutions for diverse industries. The system is designed to detect human proximity, orientation, and gestures with millisecond accuracy, improve robot decision-making, and reduce emergency stops by 50%, all while maintaining safety standards. These objectives are supported by a set of technical specifications, including the use of proximity sensors, computer vision systems, and task-planning algorithms.

Work done to date includes finalizing the project scope, conducting a literature review, and initiating the design of a proximity detection algorithm. The timeline outlines several key milestones, such as the creation of a prototype for proximity and gesture detection systems and the development of an integrated hardware-software framework for human-robot collaboration. The project deliverables include working software, simulations, emergency stop systems, and comprehensive documentation to ensure future scalability.

This project holds significant social as well as commercial value by prioritizing safer, more intuitive human-robot collaboration, which is critical as robots continue to permeate industries that require both precision and creativity. By improving cobot awareness and decision-making capabilities, the team aims to set a new standard for human-robot interaction, exploring a future where robots and humans can work together safely and effectively across multiple sectors.

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## Section A. Problem Statement

### History and Background

In recent years, the workplace has undergone significant changes, largely driven by the growing use of robots across various industries. The National Institute for Occupational Safety and Health (NIOSH) has highlighted concerns about the increasing number of injuries related to robotics as automation becomes more widespread.

Historically, industrial robots were designed for high-speed, heavy-duty tasks, often operating in isolation from humans within secure, controlled environments. However, this model no longer meets the needs of modern workplaces. As the demand for industrial robots expands into less controlled environments like laboratories, design studios, and film sets, the need for advanced safety systems tailored to high-traffic, human-robot interactions has become critical.

In response, many robotics companies have developed collaborative robots, or "cobots." These smaller, safer robots are designed to work alongside humans and are equipped with safety features. However, cobots are typically limited to less demanding tasks due to their reduced payload capacity. While they have become invaluable in environments requiring close human-robot collaboration, they are not suited for the high-speed, heavy-lifting applications typically handled by industrial robots.

### Phase 1

The primary objective of this project is to ensure the safety and efficiency of cobots in human-robot interactions. This project has been a multi-year project and has made tremendous progress before our team came together. To give a brief overview, during the first year of the project, the team working on this project was able to successfully develop a prototype to allow virtual choreography of robotic movements using mixed reality and successful real-world mapping of virtual robot actions for precise replay in industrial settings.

### Phase 2

In the second phase of the project, the team developed a system that equipped the cobot with sensors capable of detecting nearby humans. When a sensor identifies a human, the individual is represented as a virtual object in Unity. In Unity, designated "go" and "no-go" zones are defined based on the human's proximity to the robot. Once the human enters one of these zones, the robot either continues its operations or halts if the person is too close, ensuring safe interaction. The cobot was additionally outfitted with LED lights to indicate to the human which zone they are in, along with a haptic feedback system designed to help maintain a safe distance from the cobot.

**Phase 3**

For this iteration, our team is focused on advancing the progress made in the second phase. Specifically, we aim to enhance the cobot's ability to detect and differentiate between humans and non-human objects. Our goal is to improve the system's granularity, allowing the cobot to recognize finer details such as finger movements, while also ensuring accurate differentiation between human and non-human elements captured by the sensors.

This refinement is critical to improving the cobot's situational awareness and responsiveness, ensuring it can interact more safely and effectively in complex environments. This highlights the core problem we are addressing: increasing the cobot's sensory precision and decision-making in real-world human-robot collaboration.

The social value of this project is significant, as it prioritizes improving safety, efficiency, and smooth interaction in environments where humans and robots collaborate. As robots become more integrated into industries like healthcare, manufacturing, and service sectors, the ability to accurately detect human presence and movements—down to granular details like finger motions—ensures a safer workspace and reduces the risk of accidents.

Improving the cobot's ability to distinguish between human and non-human objects also fosters trust and comfort in human-robot collaboration. Workers are more likely to feel secure and confident in environments where robots can reliably recognize and respond to human actions, creating a safer and more intuitive workplace. This improvement opens doors for robots to be used in more dynamic and collaborative roles, expanding their utility in spaces that require delicate precision, such as labs, hospitals, and creative sectors.

In a broader societal context, such advancements contribute to a future where human-robot collaboration supports more inclusive, diverse job roles. This helps improve productivity and quality of life, as humans and robots can work side by side, blending the strengths of human creativity with robotic precision and efficiency.

## Section B. Engineering Design Requirements

The design requirements outlined in this section were developed through thorough research and a collaborative decision-making process. Our team began by looking into current human-robot collaboration systems, focusing on their limitations and areas for improvement. We then held multiple meetings with our faculty advisor and project sponsor to identify key challenges and potential solutions.

To refine our goals and objectives, we analyzed case studies from various industries, including manufacturing, healthcare, and creative sectors, to understand real-world needs and constraints. We also consulted with industry experts to gain insights into practical considerations and usability requirements.

Our specifications and constraints were derived from a combination of technical feasibility studies, market analysis of available components, and budget considerations. We used iterative discussions and feedback loops with our advisor and sponsor to ensure that these specifications align with both academic rigor and industry relevance.

The selection of relevant codes and standards was based on a thorough review of international and national regulatory frameworks for robotic systems and human-robot collaboration. We prioritized standards that are widely recognized in the industry and that address the specific safety and performance aspects of our project.

Throughout this process, we continually refined and adjusted our requirements to strike a balance between innovation, practicality, and adherence to established safety and performance standards. This approach ensures that our project goals are ambitious yet achievable within the given constraints of time, budget, and available technology.

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

The following goals represent the most important needs of our client, and define the overarching purpose of our project. They are designed to address the biggest challenges in human-robot collaboration.

- To explore a more intuitive and safe system for human-robot collaboration in industrial settings
- To enable fine-grained interactions between humans and robots in environments like labs, hospitals, and creative studios (e.g. design, architecture, film production, etc.)
- To create a scalable solution that can be deployed across multiple industries

### B.2 Design Objectives

To meet the client's goals, we have defined these specific, measurable objectives. They provide concrete targets that will guide our design process and allow us to evaluate the success of our final product.

The design will…

- allow increased precision of awareness of human proximity, orientation, and gestures within 100 milliseconds
- implement turn-based interaction protocols for collaborative human-robot tasks
- integrate task-planning algorithms to optimize robot actions in a collaborative setting
- improve upon current collision detection systems by allowing robots to operate safely within 30 cm of humans
- reduce robot emergency stops by 50% compared to current systems while maintaining safety standards

### B.3 Design Specifications and Constraints

To ensure that we can achieve our objectives, we have defined these specifications and constraints. These parameters set clear boundaries for our design, ensuring that our final product meets both technical requirements and practical limitations.

- The proximity detection system must have a minimum sensing range of 3 meters with 1 cm accuracy
- The computer vision system must be able to track human movements at a minimum of 30 fps
- The system must operate within our $1000 budget constraint
- The system must be compatible with existing industrial robot and cobot arms and controllers
- All sensing and control system components must fit within a 50 cm x 50 cm x 50 cm enclosure to allow for portability
- The system must operate on standard 120V AC power
- The user interface must be operable by individuals with basic computer literacy
- Software must be developed using open-source tools to allow for future modifications

## B.4 Codes and Standards

Our design will follow these relevant codes and standards. These guidelines will ensure that our system meets industry requirements for safety, interoperability, and functionality.

- ISO 10218-1:2011 - Robots and robotic devices -- Safety requirements for industrial robots
- ISO/TS 15066:2016 - Robots and robotic devices -- Collaborative robots
- ANSI/RIA R15.06-2012 - Industrial Robots and Robot Systems - Safety Requirements
- IEC 61508 - Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems
- IEEE 1872-2015 - Standard for Ontologies for Robotics and Automation

These codes and standards will guide our development process to ensure safety, interoperability, and industry compliance. We will regularly review our design against these standards throughout the project lifecycle.

## Section C. Scope of Work

The scope of our project includes the development of advanced human-robot interaction systems, with key objectives focusing on improving robot sensing. The project timeline spans the development of multiple weeks of milestones, all to be completed within the specified timeframe and budget. The team is responsible for the design, testing, and integration of these systems using tools such as computer vision, proximity sensors, and task-planning algorithms, while also ensuring compliance with safety standards, including the implementation of emergency stop mechanisms. Tasks falling outside of the team's scope include large-scale deployment or manufacturing of the systems, which will not be addressed in this phase. The development will follow a chosen methodology, such as agile or waterfall, with close collaboration and clear communication with the faculty advisor and project sponsor to manage expectations, avoid scope creep, and ensure timely delivery of all promised deliverables.

### C.1 Deliverables

This project includes multiple deliverables, including project and academic-based deliverables. For the academic deliverables, they are as follows:

- Team Contract
- Project Proposal
- Fall Design Poster
- Preliminary Design Report

The previous list of academic deliverables are all also in order based on due dates. The following list of deliverables is for our project deliverables (in no specific order):

- Create shared Google Drive folder (Available remotely)
- Working mmWave software on an individuals device (Available remotely)
- Working Isaac Sim with given Python code from previous Capstone group (Available remotely)
- Use Isaac Sim/Unity to work with the robot located in East Engineering computer lab (On-campus task)
- Use mmWave and other resources to test proximity detection around the robot (On campus task)
- Emergency stop systems integrated into the robot interface (On-campus tasks)
- Integrated hardware-software framework that supports human-robot collaboration (On-campus task)
- A prototype of proximity and gesture detection systems that allow real-time robot movement adjustment (On-campus task)
- Tutorials and documentation for replicating the system and understanding its design for next Capstone group (Available remotely)

### C.2 Milestones

**1. Planning & Research Phase**
September 25, 2024 – October 18, 2024

- **Milestones:**
  - Finalize project scope and objectives.
  - Conduct literature review on existing proximity management systems and sensor technologies (mmWave, Haptic Feedback System).
  - Identify relevant APIs, hardware, and software tools.
  - Draft initial project plan and timeline.

**2. Initial Design & Development**
October 19, 2024 – November 15, 2024

- **Milestones:**
  - Fall Design Poster Due Nov 15th
  - Develop a high-level system architecture.
  - Start hardware procurement (sensors, edge devices).
  - Design the proximity detection algorithm.
  - Initial coding setup for communication between sensors and robot systems.

**3. Prototyping & Simulation**
November 16, 2024 – December 9, 2024

- **Milestones:**
  - Preliminary Design Report Due Dec 9th
  - Set up simulation environment
  - Implement the first version of the proximity detection system.
  - Test the system in simulation for basic functionality.
  - Collect and analyze initial data.

### C.3 Resources

**Isaac Sim**: Engine designed to interact with 3D objects, allowing us to virtualize the robot,
**Unity**: Engine designed to interact with 3D objects, allowing us to virtualize the robot,
**Intel RealSense:** 3D camera designed to give machines and devices depth perception capabilities, **Proximity Sensor, LIDAR**

## Section D. Concept Generation

The concept generation phase focused on designing solutions to improve collaborative robot interactions with humans, ensuring safety, precision, and efficiency in dynamic environments. From many brainstorming sessions and extensive research, the team came up with three primary design concepts. Each concept addresses the problem of improving sensory precision, reducing emergency stops, and ensuring seamless collaboration in various tasks.

**Concept 1**: Dynamic Shape Maintenance on Workspace

The robot is programmed to maintain a predefined arrangement of blocks on a table. When a human adjusts or removes blocks from the shape, the robot detects the change and repositions other blocks accordingly to restore the original pattern. This concept uses sensors, object detection, and environment simulation to monitor the workspace. The robot will be able to detect deviations, and execute corrective movements to preserve the intended layout.

**Concept 2:** Boolean Subtraction-Based Self-Filtering System

This concept addresses a fundamental challenge in robot perception: distinguishing between the robot's own body and other objects in its environment. Using Isaac Sim's boolean subtraction capabilities, the system creates a "negative space" model that filters out the robot's own geometry from sensor data in real-time.

**Concept 3**: Adaptive Reverse Kinematics for Dynamic Obstacle Navigation

This concept implements an advanced motion planning system that enables the robot to dynamically recalculate its movements in real-time when encountering obstacles, using reverse kinematics to determine optimal joint configurations for navigating around barriers while maintaining end-effector objectives.

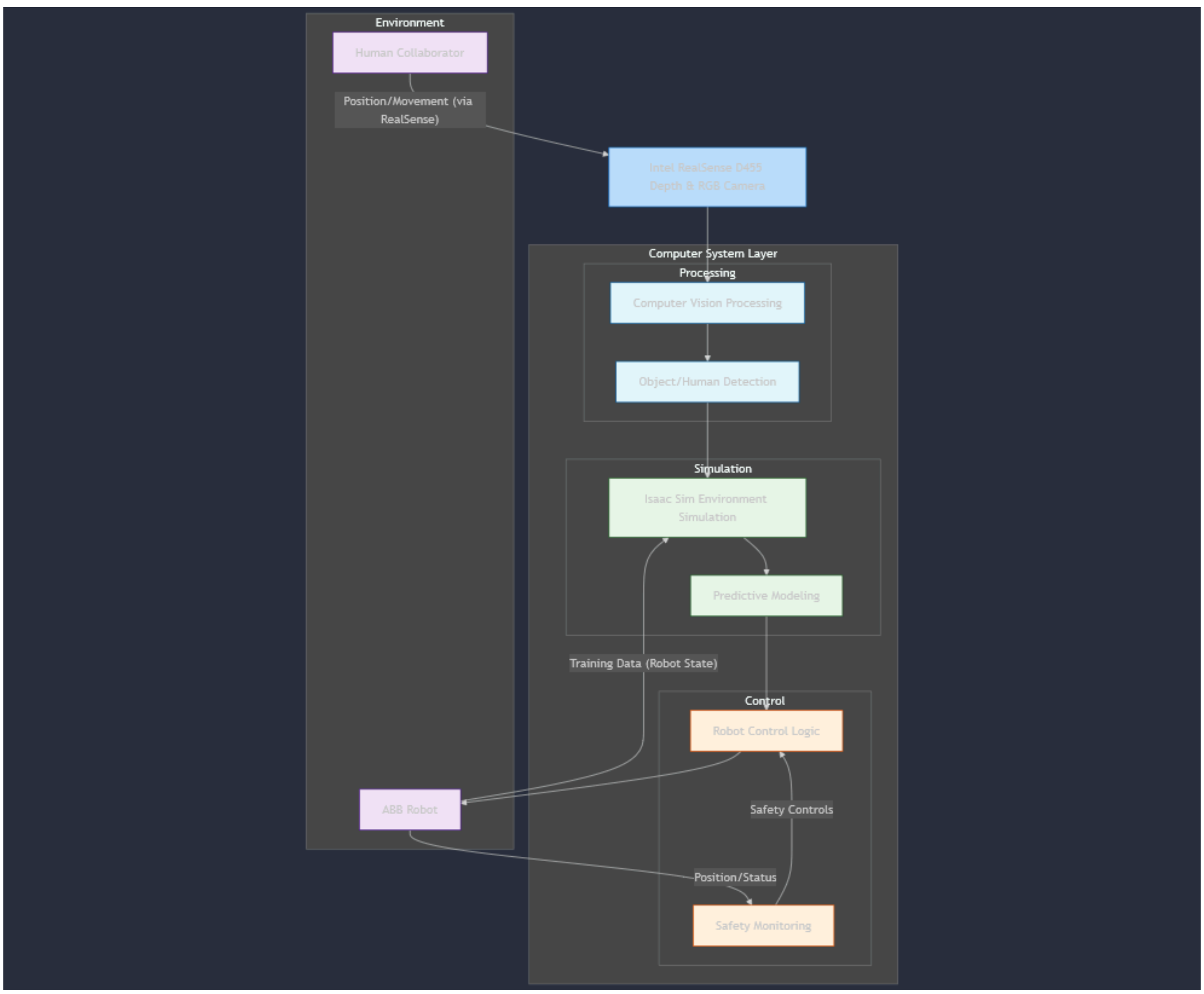
## Section E. Concept Evaluation and Selection

After thorough research and consultation with our faculty advisors, we developed three distinct technical approaches for achieving our Phase 3 objectives of enhanced human detection, differentiation, and granular movement tracking:

### Concept 1: RealSense-Based Vision System

This concept uses the Intel RealSense D455 depth camera as the primary sensor, leveraging its built-in stereo depth sensors and RGB camera. The system would:

- Process both depth and RGB data streams for human detection
- Use computer vision algorithms for skeletal tracking
- Integrate directly with Isaac Sim for real-time simulation
- Employ predictive modeling for movement anticipation



**Concept 2: Hybrid mmWave-Kinect System**
This approach combines mmWave radar technology with Xbox Kinect's infrared sensing:

- mmWave provides precise distance measurements and movement detection
- Kinect handles skeletal tracking and gesture recognition
- Sensor fusion algorithms combine both data streams
- Custom processing pipeline for real-time performance

**Concept 3: Multi-LIDAR Array System**
This design uses multiple small LIDAR sensors arranged in an array:

- Creates a high-resolution 3D point cloud of the workspace
- Provides redundant coverage for safety
- Uses machine learning for human-object differentiation
- Integrates with existing proximity detection systems

To evaluate these concepts systematically, we developed a weighted decision matrix based on our specific project requirements. The criteria weights were determined through consultation with our faculty advisors and project sponsors, focusing on our Phase 3 objectives:

**Table 1. Decision Matrix.**

| **Criteria** | **Weight** | **Metric** | **RealSense** | **mmWave-Kinect** | **LIDAR Array** |
|---|---|---|---|---|---|
| Detection Precision | 0.25 | Sub-centimeter accuracy | 9 (2.25) | 7 (1.75) | 8 (2.0) |
| Real-time Performance | 0.2 | Processing latency < 100ms | 8 (1.6) | 9 (1.8) | 6 (1.2) |
| Integration Complexity | 0.15 | Development time estimate | 9 (1.35) | 6 (0.9) | 5 (0.75) |
| Cost Effectiveness | 0.15 | Within $1000 budget | 8 (1.2) | 6 (0.9) | 5 (0.75) |
| Reliability | 0.15 | Expected uptime % | 8 (1.2) | 7 (1.05) | 9 (1.35) |
| Space Constraints | 0.1 | Fits 50cm³ envelope | 9 (0.9) | 7 (0.7) | 6 (0.6) |
| | | Total Score | 8.5 | 7.1 | 6.65 |

## Section F. Design Methodology

The Collaborative Sorting and Supplying Workflow concept focuses on an adaptive and collaborative approach to sorting and organizing tasks, ensuring efficient robot-human interaction. The design methodology incorporates computational and experimental methods to refine sorting algorithms, validate system reliability, and ensure user-centric functionality.

### F.1 Robot-Human Interaction and Coordination System

The robot-human interaction system focuses on building an intuitive interface for collaborative task execution. Key components of this system include real-time feedback, adaptive task planning, and seamless communication. The goal is to create a workflow where the robot continuously adapts to human actions without requiring constant input.

1. Task Adaptation: The robot adjusts its actions based on the human's progress. For instance, if the human completes a zone faster than expected, the robot will adjust the task plan to optimize the overall sorting process. Proximity sensors and visual feedback help the robot track the human's actions in real time.

2. Dynamic Coordination: While the human sorts the blocks, the robot continuously monitors the workspace. If the human moves outside a designated zone or changes sorting criteria, the robot dynamically reallocates its resources to maintain the desired workflow.

### F.2 Experimental Methods

Real-world testing will validate the robot's ability to adapt dynamically during collaborative tasks.

Equipment and Setup:

- A robotic arm with the RealSense camera at the base and gripper mounted over a workspace divided into two zones.
- Assorted blocks varying in color.
- Use of software (OpenCV) for object and human detection.

Testing Procedures:

- Sorting Role: Blocks are randomly scattered on the workspace, and the robot organizes them into predefined zones. Metrics include placement accuracy and completion time.
- Hybrid Task Execution: Both roles are performed simultaneously, evaluating the robot's ability to prioritize and switch tasks efficiently.
- Data Acquisition and Analysis: Sensors and cameras track robot movements, block positions, and human gestures. Data is logged and analyzed to improve system response and reliability.

### F.3 Data Flow

Data Collection and Processing

- Sensors: The RealSense D455 captures depth and RGB data, enabling accurate perception of the workspace.
- Data Processing: OpenCV processes spatial and visual data in real-time to identify block attributes (color, size, shape) and detect humans.
- Detection Algorithms: Advanced object and human detection algorithms differentiate between the human collaborator and blocks, ensuring precise interaction.

Virtual Environment Construction

- Simulation Environment: Isaac Sim creates a real-time digital twin of the workspace, modeling the physical environment for task planning and optimization.
- Task Optimization: Simulated scenarios enable the robot to test and refine task strategies, ensuring efficient sorting and supplying.
- Safety Monitoring: Continuous validation in the virtual space ensures the robot adheres to safety constraints, avoiding collisions with humans or objects.

Collaborative Task Execution

- Task Coordination: The robot dynamically aligns its actions with the human collaborator's tasks, ensuring synchronized operations.
- Workspace Management: Real-time monitoring adapts to changes, such as block rearrangement or human requests, maintaining workflow continuity.
- Task Adaptation: The robot prioritizes and switches tasks efficiently, balancing sorting and supplying roles based on human inputs and workspace demands.
- System Optimization: Iterative updates refine the interaction and ensure both robot and human roles are effectively integrated.

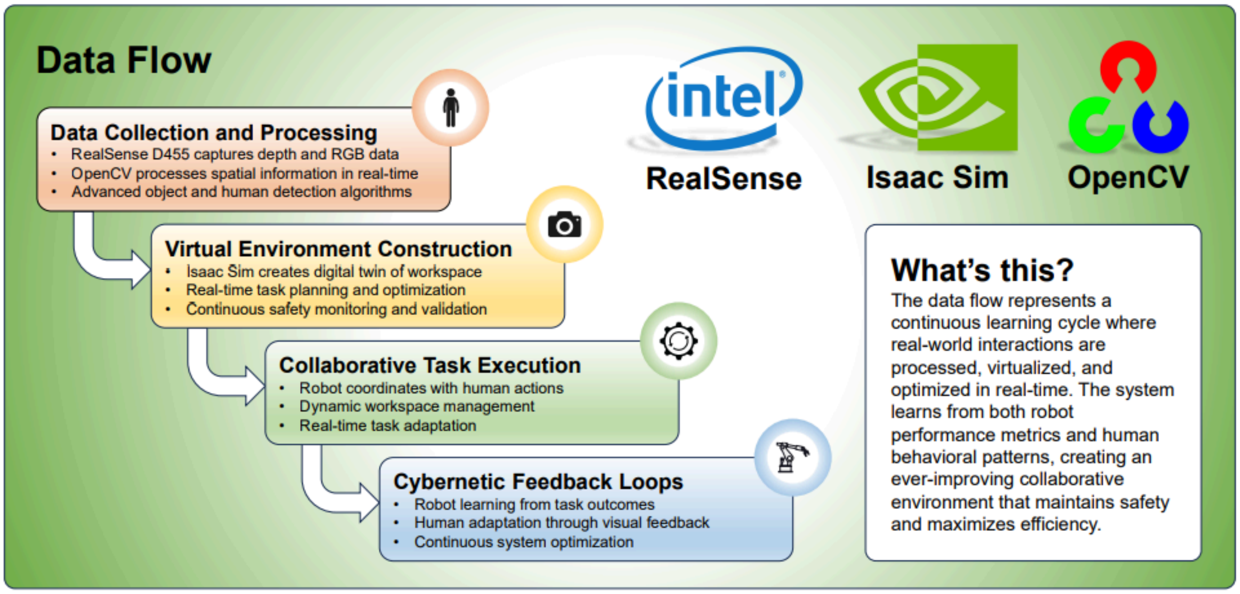
**F.4 Validation Procedure**

To validate that the final design meets the client's needs, a comprehensive validation procedure will be implemented. This will include a prototype demonstration and experimental testing, followed by feedback collection. The design team will meet with the client in early April to present the final prototype and showcase its functionality. The robot's ability to dynamically sort and supply blocks, as well as collaborate with a human user, will be demonstrated in both simulated and real-world environments. This demonstration will help assess the robot's adaptability, precision, and task execution efficiency.

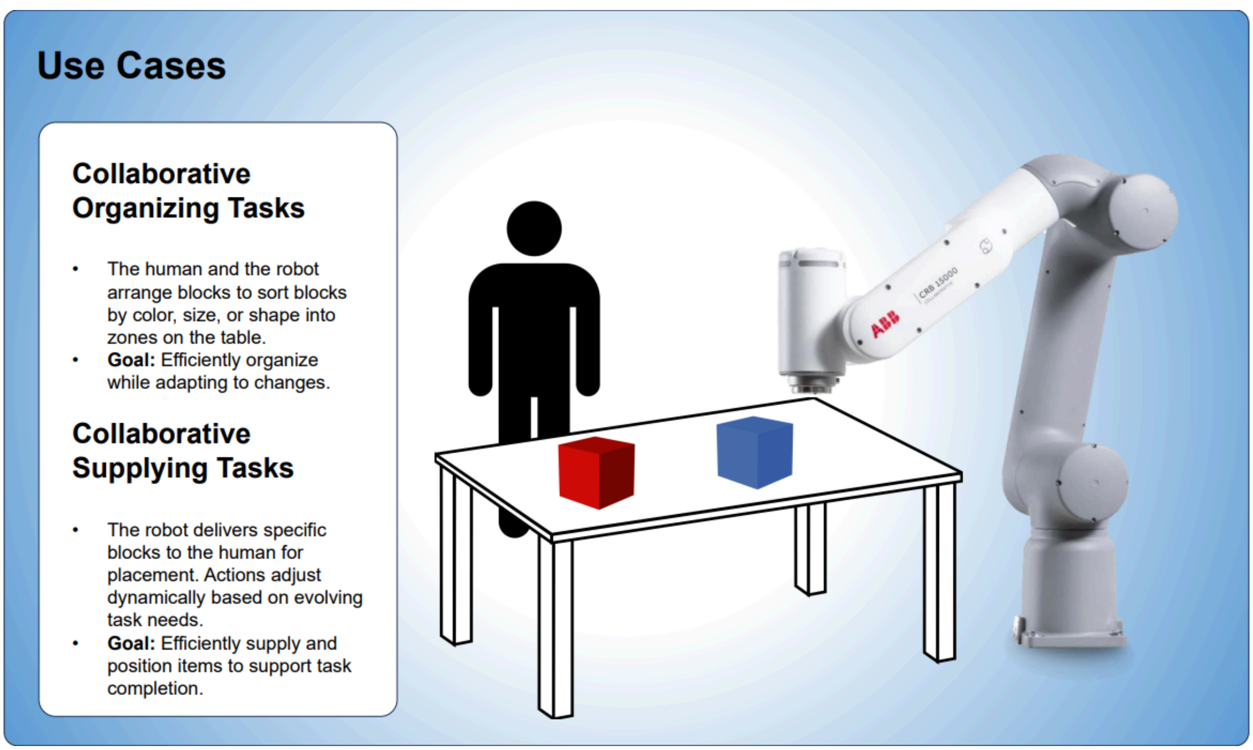
Client feedback will be gathered through a formal survey and direct observation of the prototype in use. The survey will focus on aspects such as system usability, performance, and the quality of human-robot interaction. Additionally, the client will be invited to test the prototype and provide feedback on its overall effectiveness. This feedback will guide any final adjustments to the design before final validation and deployment.

## Section G. Results and Design Details

### G.1 Data Flow Model

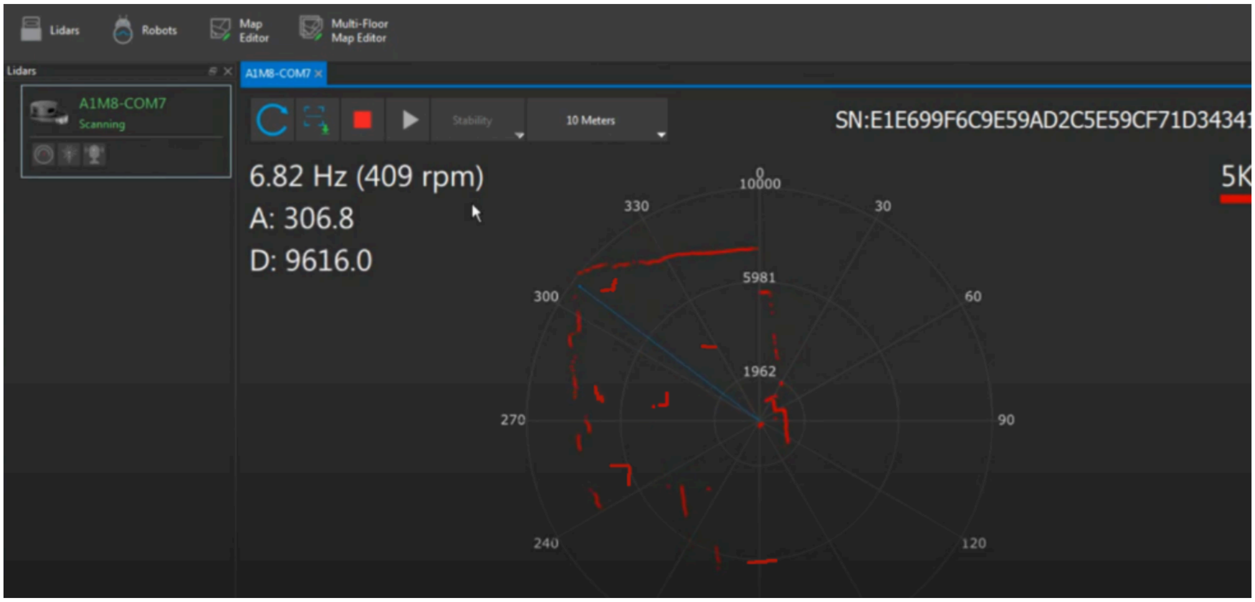



### G.2 Use Case Set Up

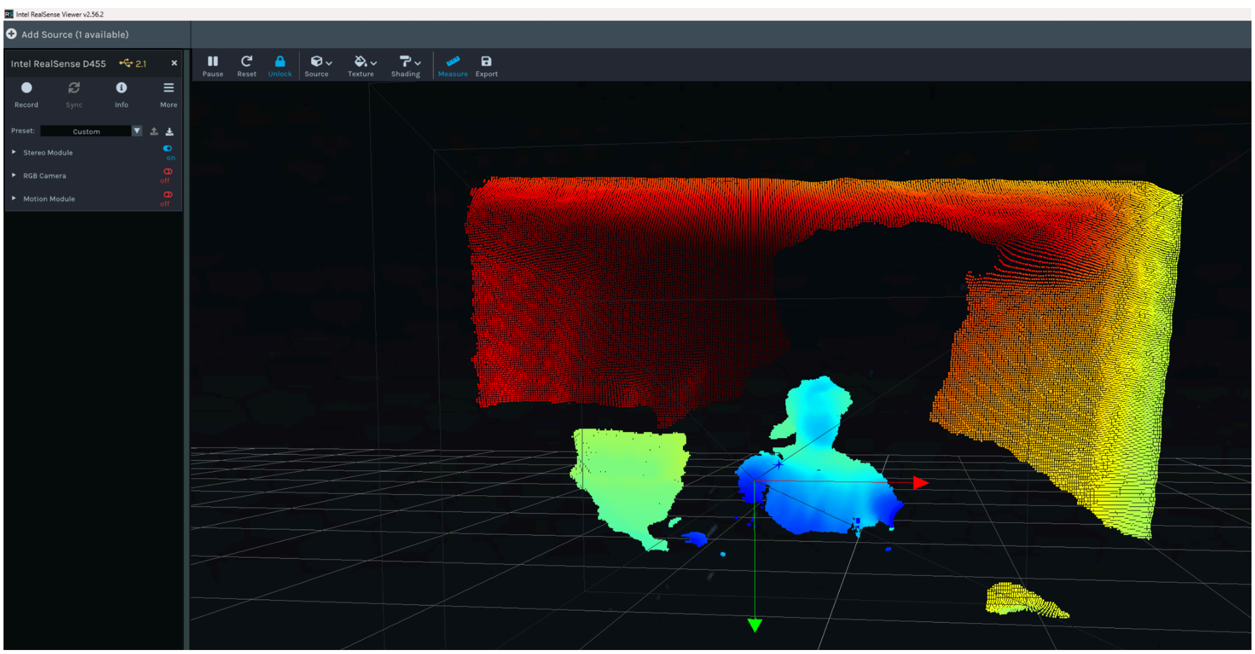



### G.3 Experimental Results (example subsection)

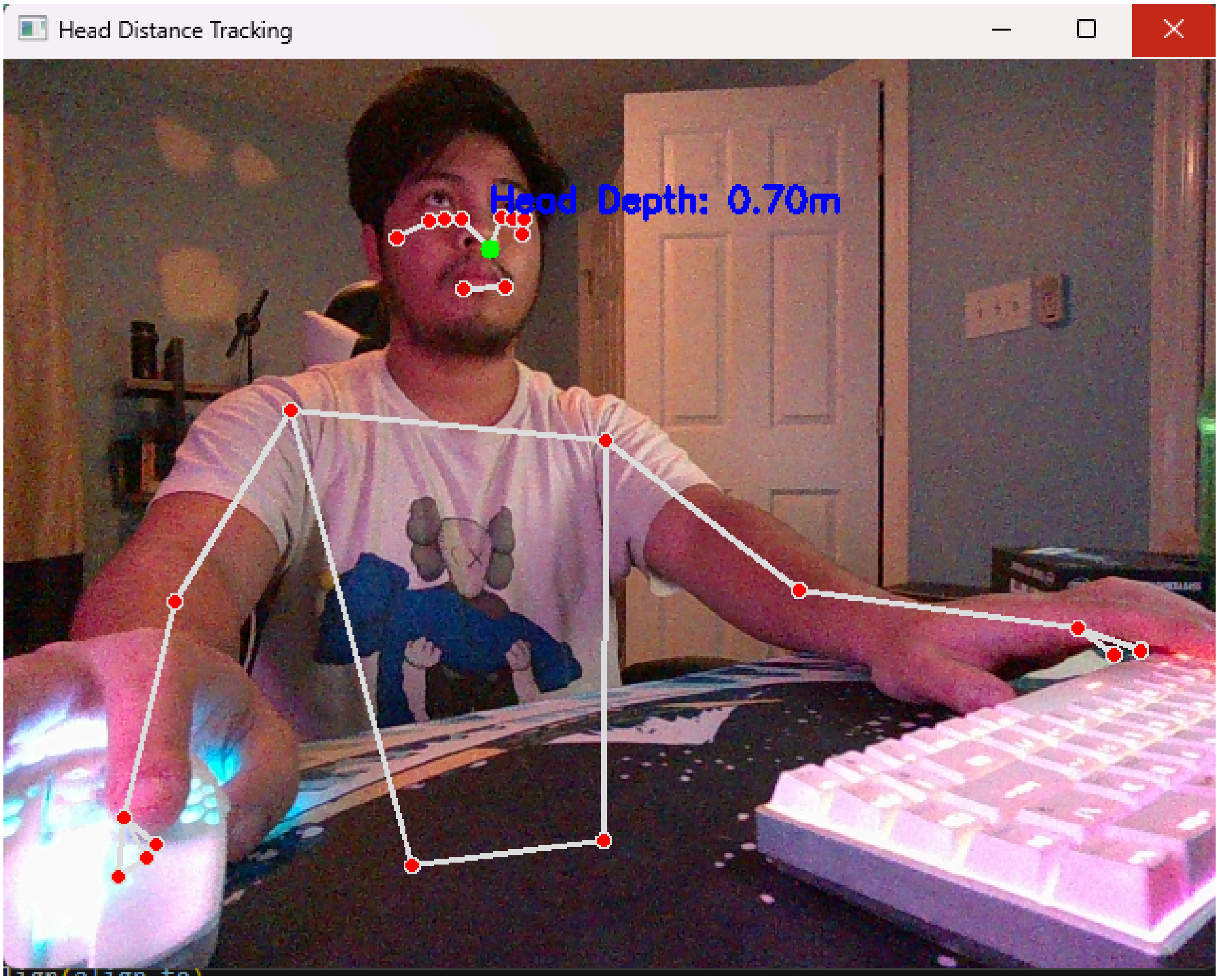
### G.4 Prototyping and Testing Results




The image above utilizes Lidar technology to detect objects around it in a two dimensional plane.




Initial results of RealSense Testing. The view in the image is a three dimensional view of the environment. Goal would be to load the point cloud data onto the Isaac Sim environment.




Human detection script results. This script will eventually be combined with the point cloud data in order to provide the robot with the capability to detect humans and the environment around the robot.

During the testing phase, a Microsoft Kinect V2 sensor was initially used for human and distance detection but the team ultimately decided to not go forward with that decision due to system compatibility issues and latency concerns with the robot. Linked below is the github repository that was created to document the progress that was made with the Kinect sensor:

https://github.com/lilyanniii/KinectHumanDetection

**G.4. Final Design Details/Specifications (example subsection)**

Note that while the design constraints and specifications may have provided minimum or maximum values, or ranges or values, that the design needed to meet, the final design specifications should be listed here showing that the required design values were met. A list of final design details can also be included to demonstrate fulfillment of the design objectives.

## Section H. Societal Impacts of Design

### H.1 Public Health, Safety, and Welfare

In the context of collaborative robotic systems, safety is a primary concern. To mitigate any risks to human health and well-being, several safety features have been integrated into the design. These include:

- Proximity Sensors: The robot is equipped with sensors along with software to detect the human's position in real-time. These systems help prevent collisions by ensuring the robot maintains a safe distance from the human operator at all times.
- Emergency Stop Mechanism: Robot has a built in emergency stop system which halts all robot actions when it detects that it has crashed onto an object/human.
- Collision Avoidance Algorithms: The robot employs real-time obstacle detection algorithms to prevent unintended collisions with humans, other robots, or objects within the workspace. These algorithms are designed to adjust the robot's path dynamically as it reacts to the human's movements.

### H.2 Societal Impacts

The introduction of collaborative robots in everyday tasks can have significant societal impacts. One major area is the improvement of labor conditions. The robot's role is to support the human, not replace them, enabling workers to focus on higher-level tasks, while the robot handles repetitive and physically demanding aspects of work. This collaborative approach could lead to safer, more efficient work environments in industries like warehousing and manufacturing.

Additionally, the design could reduce physical strain on workers by performing repetitive tasks, potentially lowering workplace injuries and health issues related to strain, such as musculoskeletal disorders. On a broader scale, as robots become more integrated into daily life, they may foster a new wave of human-robot collaboration, changing the way people work together and improving productivity across various industries.

### H.3. Economic Impacts

The economic impacts of collaborative robotic systems extend to both the labor market and business efficiency. By automating certain tasks while maintaining human oversight, this design can significantly reduce operational costs in industries where large-scale sorting or organization is required. The robot can work alongside humans, enhancing their productivity, reducing downtime, and improving task precision, which can result in greater overall output.

Furthermore, the technology could create new opportunities in robotics and automation industries, fostering growth in research, development, and manufacturing sectors. As robots become more prevalent in small-to-medium enterprises, this could lower the barrier to entry for automation in industries that previously couldn't afford large robotic systems.

### H.4. Ethical Considerations

There are several ethical considerations surrounding the design and deployment of collaborative robots, particularly in human-centric environments:

- Privacy and Data Security: The use of cameras and sensors to monitor human actions raises potential concerns around privacy. The design should ensure that all data collection (such as human movements or facial recognition) is anonymized and compliant with data protection laws, such as GDPR. Additionally, the robot should not record or store sensitive personal information unless explicitly consented to by the user.
- Human Autonomy and Control: The robot's reactive design is aimed at enhancing human decision-making, but it is crucial to ensure that the human retains full control over the process. There must be mechanisms in place to prevent the robot from taking actions that could limit the human's ability to intervene or make decisions, ensuring the robot remains a tool that serves human needs without diminishing human autonomy.
- Fairness and Accessibility: The design should be developed in a way that is accessible to diverse users. This includes ensuring that people with disabilities can also benefit from human-robot collaboration, either by adapting the robot's interface or providing assistive technologies that allow broader use of the system.

## Section I. Cost Analysis

Purchase Orders

| Priority | Order | Category | Status | Order date | Arrive by | Cost |
|---|---|---|---|---|---|---|
| P1 | https://www.mouser.com/ProductDetail/Sh | Sensor | Ordered | 10/1/2024 | m/d/yyyy | $15.30 |
| P1 | https://www.robotshop.com/products/rplid | Sensor | Ordered | m/d/yyyy | m/d/yyyy | $85.00 |
| P1 | https://www.amazon.com/Microsoft-Xbox- | Sensor | Ordered | 10/1/2024 | m/d/yyyy | $47.97 |
| P1 | https://www.amazon.com/Adapter-Xbox-O | Sensor | Ordered | 10/1/2024 | m/d/yyyy | $24.99 |
| | https://amazon.com/dp/B008GRTSV6 | | | m/d/yyyy | m/d/yyyy | $27.60 |
| P3 | https://amazon.com/dp/B01MSQOX0Q | | | m/d/yyyy | m/d/yyyy | $13.29 |
| | https://amazon.com/dp/B07LFD4LT6 | | | m/d/yyyy | m/d/yyyy | $6.99 |
| | https://amazon.com/dp/B01EV70C78 | | | m/d/yyyy | m/d/yyyy | $6.98 |
| P3 | https://amazon.com/dp/B07VQ6YNSC | | | m/d/yyyy | m/d/yyyy | $19.79 |
| P3 | https://amazon.com/dp/B01D8KOZF4 | | | m/d/yyyy | m/d/yyyy | $35.99 |
| | https://amazon.com/dp/B094WB8H3F | | | m/d/yyyy | m/d/yyyy | $xx |
| P3 | https://amazon.com/dp/B08KJCRCGG | Sensor | | m/d/yyyy | m/d/yyyy | $410.00 |
| | Order | | | m/d/yyyy | m/d/yyyy | $xx |
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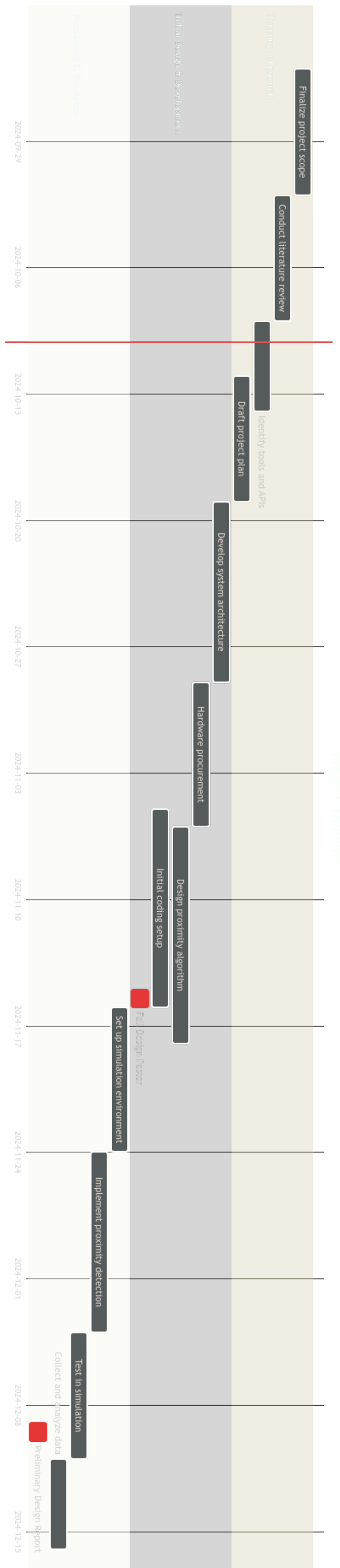
## Section J. Conclusions and Recommendations

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*** |
|---|---|---|---|
| Ian Richards | Organizing notes, planning ahead, coding experience | *Access to advanced networking resources* | richardsig@vcu.edu |
| Gianni Bautista | Industry experience, Cloud experience, React, Spring Boot, Full Stack Dev | *Access to someone with AR technology experience* | bautistag@vcu.edu |
| Ekta Shethna | Industry experience in Full Stack Development, Angular and Springboot | *Also majoring in Bioinformatics* | shethnaec@vcu.edu |
| Samuel Sarzaba | Industry experience in Full Stack Development, Angular and Springboot | N/A | sarzabase@vcu.edu |

| ***Other Stakeholders*** | ***Contact Info*** |
|---|---|
| Tamer Nadeem | tnadeem@vcu.edu |
| Shawn Brixey | brixey@vcu.edu |

## 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*** |
|---|---|---|
| Meeting once a week without fail | - Set up meetings in shared calendar<br>- Send reminder email in day before meeting | - Student misses first meeting unexcused, warning is granted<br>- 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<br>- Set reasonable deadlines and note when an extension is needed | - Student shows up for weekly meeting with no considerable work done |
| Weekly sprints | - Set up Google Meet every week<br>- Send reminder in discord before each meeting | - Student fails to show decent progress without reasoning |

## 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 the 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<br>Dates and Times / Locations*** | ***Meeting Goals<br>Responsible Party*** |
|---|---|---|
| Students Only | As Needed, On Discord Voice Channel, Required-Every Thursday 6-6:50, | Update group on day-to-day challenges and accomplishments<br>(Gianni will record these for the weekly progress reports and meetings with advisor) |
| Students +<br>Faculty Advisor/ Sponsor | Will meet every Friday in zoom/ In person. In person will be every other week | Update faculty advisor/sponsor and get answers to our questions |
| Students (Working Sessions) | As Needed, | Most work will be done independently and will be assigned using Trello. If individual needs help then they can ask for help on the discord and will have a work session with someone who can help |

## 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*** |
| --- | --- | --- |
| Ian R | Finance | ● Get a detailed list of resources needed<br>● Note prices and find less expensive items that <u>do not</u> impede on quality<br>● In charge of ordering items on time<br>● In charge of delivering items to project meeting location |
| Gianni | Project Manager | ● Makes sure that everyone is one track with the to- do list for the meeting<br>● Ensures that everyone is aligned with project goals<br>● Helps plan out the scope and objectives of the project |
| Ekta | Manufacturing Engineer | ● Coordinates all fabrication activities to ensure they meet the final prototype requirements.<br>● Ensures that all engineering drawings comply with the specifications of the machine shop or vendor, and reviews designs to guarantee manufacturability.<br>● Establishes realistic timelines for fabrication and quality, and develops a comprehensive manufacturing schedule. |
| Samuel | Systems Engineer | ● Lead product specification based on client design.<br>● Monitor integration of subsystems in the prototype.<br>● Develops and recommends system architecture and manages product interfaces. |

## Step 5: Agree to the above team contract

*Team Member:* *Signature: Ian Richards*

*Team Member:* *Signature: Ekta Shethna*

*Team Member:* *Signature: Gianni Bautista*

*Team Member:* *Signature: Samuel Sarzaba*

## Appendix 3: [Insert Appendix Title]

Note that additional appendices may be added as needed. Appendices are used for supplementary material considered or used in the design process but not necessary for understanding the fundamental design or results. Lengthy mathematical derivations, ancillary results (e.g. data sets, plots), and detailed mechanical drawings are examples of items that might be placed in an appendix. Multiple appendices may be used to delineate topics and can be labeled using letters or numbers. Each appendix should start on a new page. Reference each appendix and the information it contains in the main text of the report where appropriate.

***Note:*** Delete this page if no additional appendices are included.

## 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. Retreived September 2, 2024. https://www.teachengineering.org/populartopics/designprocess