Group A5: Final Project Proposal

R.A.D.C. (Remote Autonomous Disaster Cleanup)

CPRE 2880: Embedded Systems I: Introduction (Fall 2024)

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Problem Statement

R.A.D.C (Remote Autonomous Disaster Cleanup)

In hazardous environments like Chernobyl, restricted human access makes cleanup challenging, yet manually removing dangerous debris is still necessary. Current cleanup methods are often unsafe, inefficient, or unreliable for handling materials without endangering human lives. Our project aims to develop an adaptable robotic arm attachment for the Cybot platform, which can autonomously navigate complex terrain, identify objects, and safely grasp and transport debris. **By enhancing Cybot's capabilities with object recognition, navigation, and manipulation functions, this project seeks to provide a safer, more effective solution for autonomous cleanup in contaminated or unsafe areas, reducing the need for human exposure to dangerous environments.**

Application Narrative/Story

In areas affected by nuclear accidents or toxic spills, environments often stay dangerous and off-limits for long periods. Places like Chernobyl still have zones with high health risks for people, making it hard to clear away radioactive or hazardous materials. Although technology has advanced, manual cleanup sometimes can't be avoided, putting workers in high-risk situations. This challenge has created a need for safe, reliable robots that can handle and cleanup debris remotely while keeping human beings away from danger.

Our project addresses this need by creating a robotic attachment for Cybot—a mobile robot designed to move through hazardous areas. R.A.D.C.'s main users would include cleanup teams, disaster response units, and organizations managing dangerous sites. By adding a robotic arm with a special gripper, R.A.D.C. will be able to move, identify, and pick up debris, reducing the need for people to work in unsafe areas.

Our plan focuses on three main areas: identifying objects, moving through tricky terrains, and picking up items. First, R.A.D.C. will use object recognition to identify hazardous materials. Second, it will be able to move remotely or on its own over rough or unstable ground. Finally, a flexible gripping tool will let it safely pick up different types of small hazardous items and relocate them to a safer place.

Our goal is to create a reliable, adaptable robot that makes cleanup operations in risky areas safer and more efficient. This autonomous system will help cleanup teams by reducing the need for direct human involvement in contaminated zones, prioritizing safety while supporting effective environmental cleanup. The project's name is R.A.D.C (Remote Autonomous Disaster Cleanup).

Empathy Map:

Creating an empathy map helps clarify the needs, challenges, and experiences of our users. Here's an empathy map structured around our potential users, which can include but is not limited to environmental cleanup teams, disaster response units, and hazardous site managers:

1. What the User Says
    a. "Safety is absolutely our top priority, but we also can't afford to sacrifice efficiency in these high-stakes situations." - Environmental Cleanup Team Member
    b. "We really need a safer way to handle hazardous debris without putting anyone on the team at risk." - Disaster Response Unit Coordinator
    c. "Working in these areas is draining, stressful, and honestly, dangerous for everyone involved." - Hazardous Site Manager
    d. "We need a tool that we can rely on, especially when lives are on the line." - Research & Development for Robotic Solutions
    e. "Our people need reliable equipment that can reduce exposure risks and keep everyone safe." - Safety Officer
2. What the User Thinks
    a. "If only we could find a way to keep our team out of these contaminated zones altogether." - Environmental Cleanup Team Member
    b. "The technology needs to be flexible enough to handle the unexpected challenges that come up on the ground." - Disaster Response Unit Coordinator
    c. "I'm concerned about how accurate and dependable autonomous machines can be in these kinds of conditions." - Hazardous Site Manager
    d. "We have to make sure any system we develop is incredibly resilient and doesn't jeopardize safety." - Research & Development Team for Robotic Solutions
    e. "If this technology fails, it could really set back cleanup efforts and put both people and the environment at risk." - Safety Officer
3. What the User Does
    a. Adheres to strict health and safety protocols, wearing PPE to minimize exposure in contaminated zones. - Environmental Cleanup Team Members
    b. Trains and supports cleanup teams on complex protocols and safety procedures. - Disaster Response Unit Coordinator
    c. Inspects contaminated areas to assess risks and ensure proper handling. - Hazardous Site Manager
    d. Tests, maintains, and deploys robotic or automated systems in challenging environments. - Research & Development Team for Robotic Solutions
    e. Regularly audits safety protocols, ensuring all equipment and team actions align with strict safety standards. - Safety Officer

4. What the User Feels
    a. **Stress and Anxiety**: There's constant worry about the safety of the team and the overwhelming complexity of the cleanup tasks we face. - Environmental Cleanup Team Member
    b. **Hope and Motivation**: There's a strong desire for innovation that could make hazardous cleanup safer and more efficient, cutting down risks for everyone involved. - Disaster Response Unit Coordinator
    c. **Caution**: There's always a nagging fear that the technology might fail or that unforeseen challenges will come up in these contaminated zones, complicating everything even more. - Hazardous Site Manager
    d. **Trust and Skepticism**: It's hard to fully trust autonomous technology, especially when lives are on the line and the stakes are so high. - Research & Development Team for Robotic Solutions
    e. **Caution**: Constant vigilance around any new equipment is crucial; one failure could put lives and the environment at significant risk. - Safety Officer
5. Research and Documentation for User Needs
   For citations and specific sources, please refer to the "Sources Cited" section of the document.
    a. Environmental Cleanup Teams
        i. Government Guidelines: Greener Cleanups | US EPA
            1. This resource from the EPA outlines guidelines for conducting environmentally responsible cleanup activities by reducing waste, energy use, and environmental harm during the process. [4]
        ii. Best Practices: Green Remediation Best Management Practices: Integrating Renewable Energy
            1. The EPA's document offers best practices for integrating renewable energy solutions into remediation efforts, promoting sustainable cleanup methods and reducing the environmental impact. [5]
        iii. Community Initiatives: Empower Change: 10 Steps to a Successful Community Cleanup
            1. This article provides practical steps and strategies for organizing and executing successful community cleanup initiatives, focusing on engagement, planning, and sustainable results. [3]
    b. Disaster Response Units
        i. Federal Emergency Management Agency (FEMA): How Communities and States Deal with Emergencies and Disasters
            1. FEMA's guide outlines the roles of local and state authorities in disaster preparedness and response, detailing the collaborative efforts needed to manage emergencies effectively. [6]
        ii. Recovery Resources: Recovery and Resilience Resource Library
            1. FEMA's library is a comprehensive collection of resources to assist communities in disaster recovery and building resilience, offering guidelines on grants, recovery efforts, and rebuilding infrastructure. [9]
        iii. Operational Guides: Sources of Recovery Resources
            1. FEMA provides documentation on identifying federal disaster recovery resources, including financial aid, loans, and technical assistance, essential for both immediate recovery and long-term rebuilding. [13]

c. Hazardous Site Managers
    i. Occupational Safety and Health Administration (OSHA): Safety Management - Hazard Prevention and Control
        1. OSHA's guidelines focus on preventing workplace hazards and controlling risks, with recommendations for ensuring safety in high-risk environments such as hazardous waste cleanup sites. [12]
    ii. Industry Articles: The Importance of Site Access Management on High-Risk Sites
        1. This article emphasizes the critical role of access management in hazardous sites, discussing strategies to control site entry and mitigate risks to workers and the public. [14]
    iii. Safety Manuals: Occupational Safety and Health
        1. OSHA's safety manuals offer detailed guidelines on managing occupational safety at hazardous sites, covering hazard assessments, safety programs, and regulatory compliance. [8]

d. Research & Development for Robotic Solutions
    i. Research Institutions: Robotics Research & Development
        1. This resource from the Southwest Research Institute (SwRI) highlights cutting-edge research and development efforts in robotics, showcasing innovations in automation and robotics across various industries. [10]
    ii. Funding Opportunities: Robotics
        1. The NSF page on robotics explores funding opportunities for research in robotics, focusing on advancing technology in fields such as automation, AI, and autonomous systems through grants and collaborative projects. [11]
    iii. Industry Collaboration: Hugging Face and NVIDIA to Accelerate Open-Source AI Robotics Research
        1. This article discusses the collaboration between Hugging Face and NVIDIA to advance open-source AI for robotics, aiming to accelerate development in autonomous robots and enhance their capabilities through AI-driven technologies. [7]

e. Safety Officers
    i. Responsibilities Overview: The Top 30 Responsibilities of Any Safety Officer
        1. This article outlines the primary responsibilities of a safety officer, including ensuring workplace safety, conducting inspections, managing risk assessments, and complying with safety regulations to maintain a safe working environment. [15]
    ii. Detailed Duties: 40 Duties of a Safety Officer You Must Know
        1. This resource provides a comprehensive list of the essential duties of a safety officer, including monitoring workplace safety protocols, training staff, conducting safety audits, and enforcing safety measures to reduce hazards. [17]
    iii. Safety Resources: Officer Safety and Wellness Resources
        1. The U.S. Department of Justice provides a variety of safety and wellness resources for law enforcement officers, focusing on mental and physical health

support, training programs, and tools to ensure the well-being of officers in high-risk environments. [18]

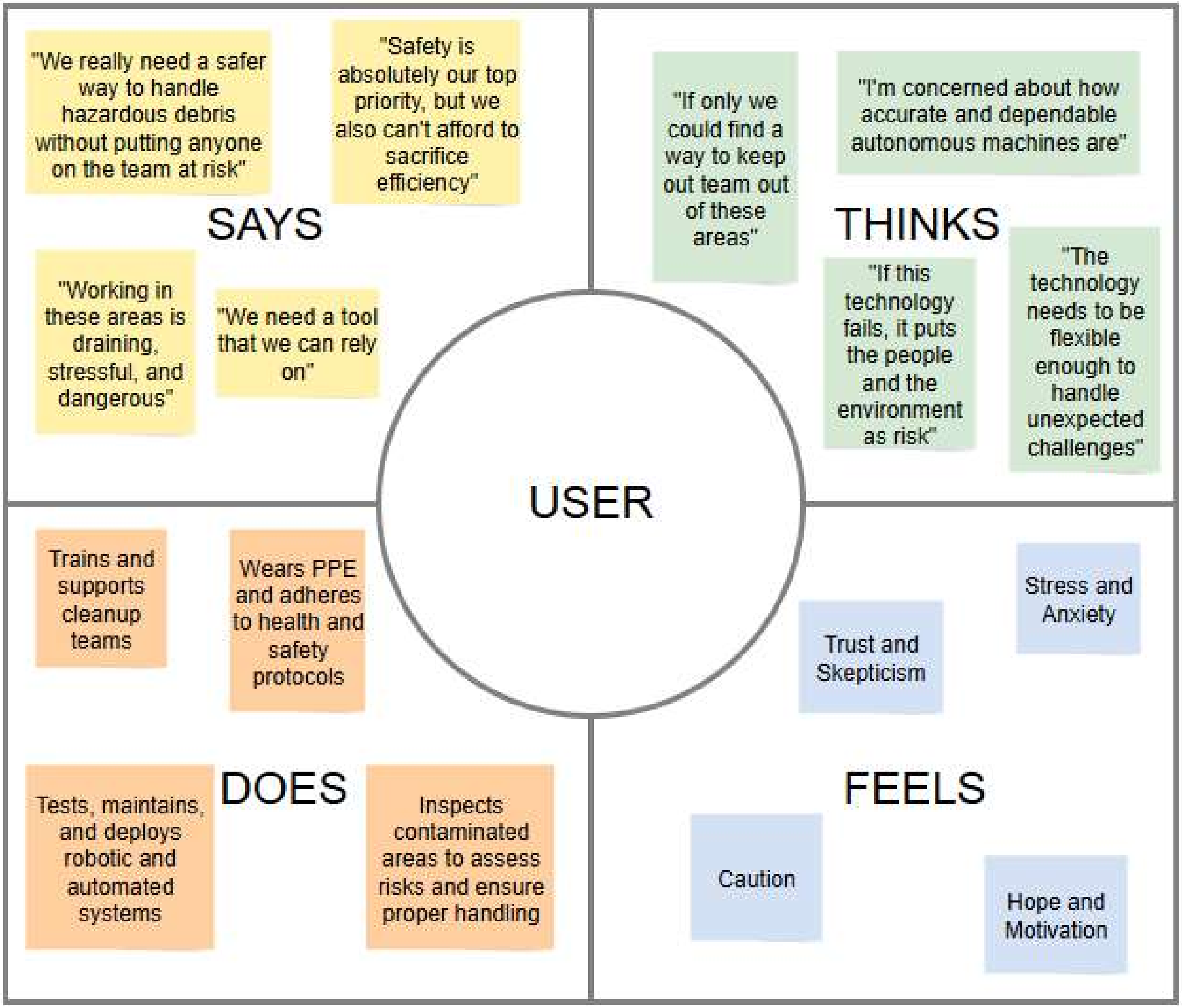

Fig. 1: Empathy Map of **ALL** User Needs

Based on the empathy map in **Fig. 1**, we can identify key user needs:

- **Safety and Reliability:** The robotic solution must be highly reliable and able to operate in extreme, unpredictable conditions without constant human intervention.
- **Efficiency and Effectiveness:** Users need a tool that can efficiently recognize, grasp, and transport different types of debris, reducing time spent in dangerous areas.
- **Adaptability:** The robot should be able to adjust to varied terrains and unexpected obstacles within hazardous zones (such as holes or tall objects in respect to our test field).
- **Clear Communication and Control:** Users may prefer a level of oversight or control over the robot's actions to feel more secure about its autonomous operations (toggle mode).

Point-of-View Statements:

1. **Environmental Cleanup Team Member:**
    a. "Our cleanup teams need a safe, reliable way to clear debris autonomously, so they can focus on effective cleanup without risking their health in dangerous environments."
        i. Insight: The current methods require team members to get close to dangerous materials, which puts their health and safety at risk.
2. **Disaster Response Unit Coordinator**
    a. "Disaster response coordinators need a safe, adaptable robotic solution to autonomously manage debris removal in hazardous areas, allowing them to handle unpredictable terrain and debris types efficiently."
        i. Insight: Coordinators are under pressure to reduce exposure time for workers while ensuring thorough and safe cleanup in unpredictable environments.
3. **Hazardous Site Manager**
    a. "Hazardous site managers need a reliable robotic system to safely and autonomously handle and transport debris, ensuring a thorough cleanup while keeping people out of high-risk areas."
        i. Insight: Site managers are looking for dependable technology that can perform precise cleanup tasks autonomously to reduce human involvement in dangerous areas.
4. **Safety Officer**
    a. "Safety officers need an advanced robotic solution to autonomously clear debris in hazardous zones, helping to protect workers by reducing their direct exposure to contamination."
        i. Insight: Safety officers are often faced with balancing the urgency of cleanup tasks with the priority of keeping workers safe from contamination and harmful exposure.
5. **Research & Development Team for Robotic Solutions**
    a. "Research and development teams need a highly adaptable robotic cleanup system that can autonomously navigate hazardous zones, efficiently remove dangerous debris."
        i. Insight: Developing a robust and autonomous robot that can navigate, identify, and manipulate objects in complex terrains presents unique technical challenges but has high-impact potential for safety improvements.

Functional Requirements

Base Functionality Mapping to Application Narrative (Needs Statements)

Base Functionality	Needs Statement	Implantations
Cybot Communication	Our Cybot must be equipped with reliable communication systems to enable remote operators to receive real-time data while also sending control commands for safe operation.	ESP 32 Module(WIFI) UART
Cybot Movement	The Cybot must navigate complex and hazardous environments autonomously, including moving over uneven terrain and around obstacles to reach specific cleanup locations	Open Interface, robot movement Python GUI (remote controlled/autonomous modes)
Object Detection	The Cybot must be able to detect and locate debris within its environment using sensors.	Ping sensor(Timer interrupts) IR sensor(ADC) Scanner arm servo(PWM) Embedded C coding
Object Avoidance	The Cybot needs to identify and avoid obstacles to prevent damage to itself or the environment during cleanup operations	Bump sensors Cliff sensors (Automatic rerouting)
Arrival at Destination (Goal Completion)	The Cybot must autonomously reach its goal location within the hazardous environment to perform specific tasks, such as debris removal, and signal completion when the task is done	Embedded C program which retraces the bots steps to navigate
User Interface	A user interface must allow operators to control and monitor the Cybot, including setting boundaries, reviewing status, and triggering actions such as manual control or alerts	Python GUI , Sends: User-commands Receives: Sensor/Movement data Displays a map of surroundings and controls
Application-Specific Functionality (Opportunities for Bonus)	The Cybot could provide opportunities to integrate advanced features like autonomous robotic arm attachments for grasping and transporting debris, further enhancing its capabilities	External gripper arm constructed from 3D printed materials, SG-90 servo motors and Arduino microcontroller User-Friendly GUI(python)

Advanced Feature: Robotic Arm

Advanced Feature (Robotic Arm)	Needs Statement	
Robotic Arm Functionality	The robotic arm must be capable of grasping, handling, and manipulating various sizes and types of debris	Designed to grab small-objects from the test field.
Adaptability of Gripping Mechanism	The arm should feature an adaptable gripping mechanism that can modify its grip based on the object's shape, size, and weight	3D printed exoskeleton and SG-90 servos for precise control of grippers movements.
Autonomous Manipulation	The robotic arm should operate autonomously to remove debris from the environment	TM4C123GPHM microcontroller GPIO pins send small activation signal which prompts an external microcontroller to open/close gripper arms

Lotus Blossom Diagram for Functional Requirements

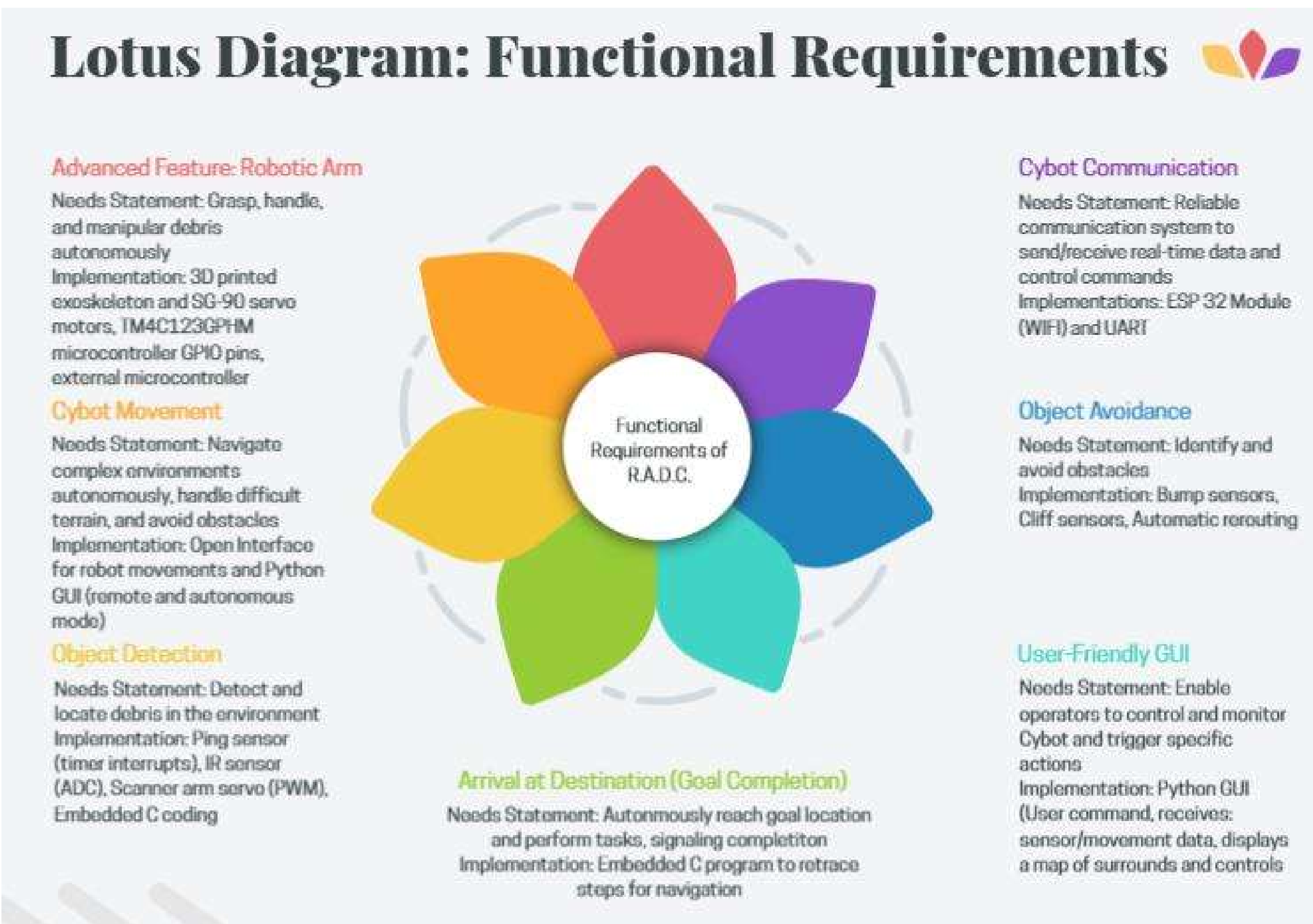

Fig. 2: Lotus Diagram Functional Requirements

The functional requirements for Cybot were determined by analyzing the core objectives of autonomous navigation, debris detection, and removal in hazardous environments. Each requirement was mapped to specific needs statements reflecting the challenges and expectations of the project. The implementation methods were chosen based on their feasibility and effectiveness in meeting these needs, ensuring Cybot's capability for safe and efficient operation.

Narrative of Functional Requirement Identification:

Our project aims to develop an autonomous mobile robotic solution to clean up hazardous environments safely and efficiently, such as nuclear disaster zones, where human presence is highly restricted. To achieve this, the Cybot platform will be improved with several key functionalities. First, it needs reliable communication capabilities to transmit real-time data and receive operator commands. Additionally, the R.A.D.C must navigate complex terrains, avoiding obstacles and adhering to predefined boundaries to ensure its safe operation. Object detection and avoidance are also crucial to ensure the robot can identify and steer clear of tall objects while focusing on the cleanup task.

A core component of the R.A.D.C's functionality is its ability to autonomously remove debris using a robotic arm. This arm must be adaptable and capable of gripping and transporting debris of varying shapes and sizes. The robot's arm will allow for safe manipulation of objects, reducing the risk of contamination or further damage to the environment. By integrating these capabilities, R.A.D.C will effectively handle tasks that are too dangerous or complex for humans to perform in these environments.

Ultimately, this solution aims to bridge the gap between human safety and efficient cleanup operations. With the combination of autonomous movement, object detection, and advanced robotic manipulation, R.A.D.C will enable faster and safer cleanup of contaminated zones, reducing the need for human exposure to debris and hazardous environments. By meeting these functional requirements, R.A.D.C will offer a reliable and scalable solution to one of the most challenging and high-risk tasks in disaster recovery.

Prototype (Two Sketch types):

User-centered Sketch:

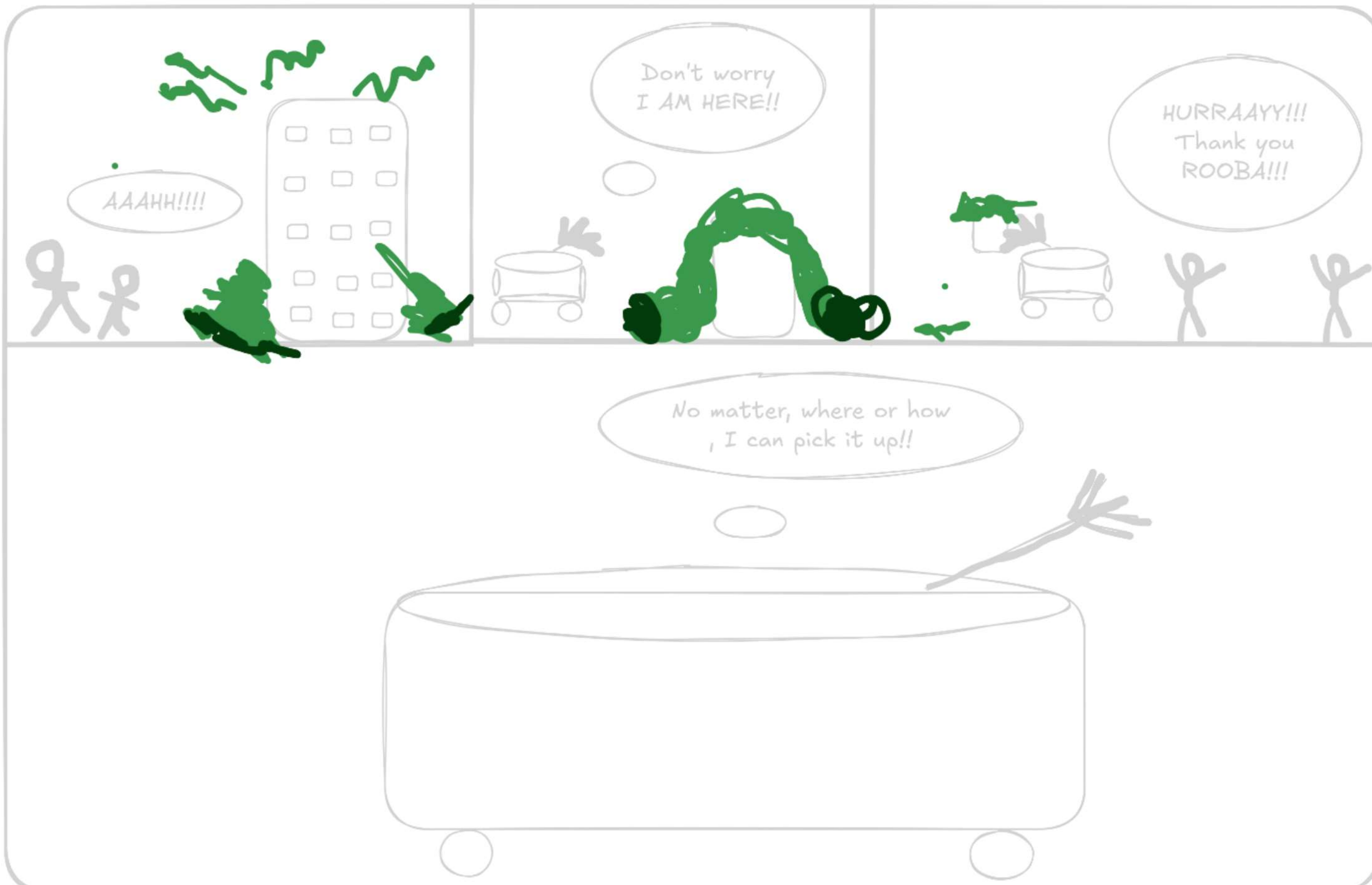

Fig. 3: User-Center Sketch of R.A.D.C in action after an explosion

In this comic in **Fig. 3**, a building explodes, scattering hazardous waste across the area as panicked bystanders flee the scene. Amidst the chaos, our cleanup robot arrives, swiftly navigating the debris with precision and safely removing rubble. Spectators watch in awe, cheering as they see the robot taking charge of the dangerous cleanup with ease. The User-Centered Sketch is in reference to our Application Narrative as we based our test field on Chernobyl.

Technical Overview Sketch:

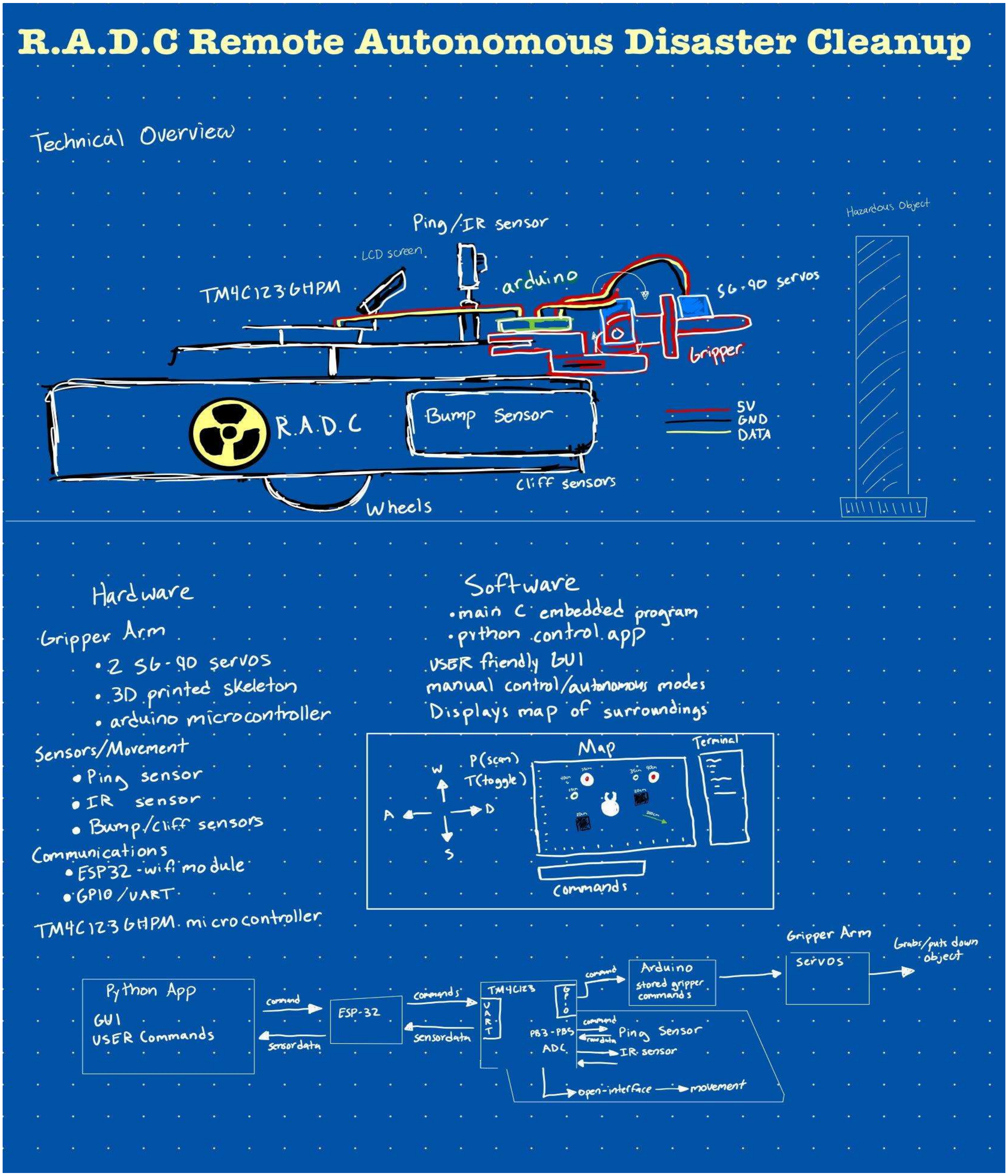

Fig. 4: Technical Overview Sketch

The technical sketch outlines the cleanup robot's components and operation, featuring a gripper arm for waste pickup, movement and environmental sensors (ping/IR, bump, and cliff sensors), and servo motors for precise control of its arm and wheels. A microcontroller processes sensor data and manages commands. The software includes an embedded C program for autonomous operation and a Python control app for flexibility. The robot switches between manual and autonomous modes, with a user-friendly GUI displaying real-time sensor feedback and a dynamic map for navigation. It detects, picks up, and transports debris, avoiding obstacles with its sensors, while its 3D-printed components enable efficient waste collection.

Test Field Sketch

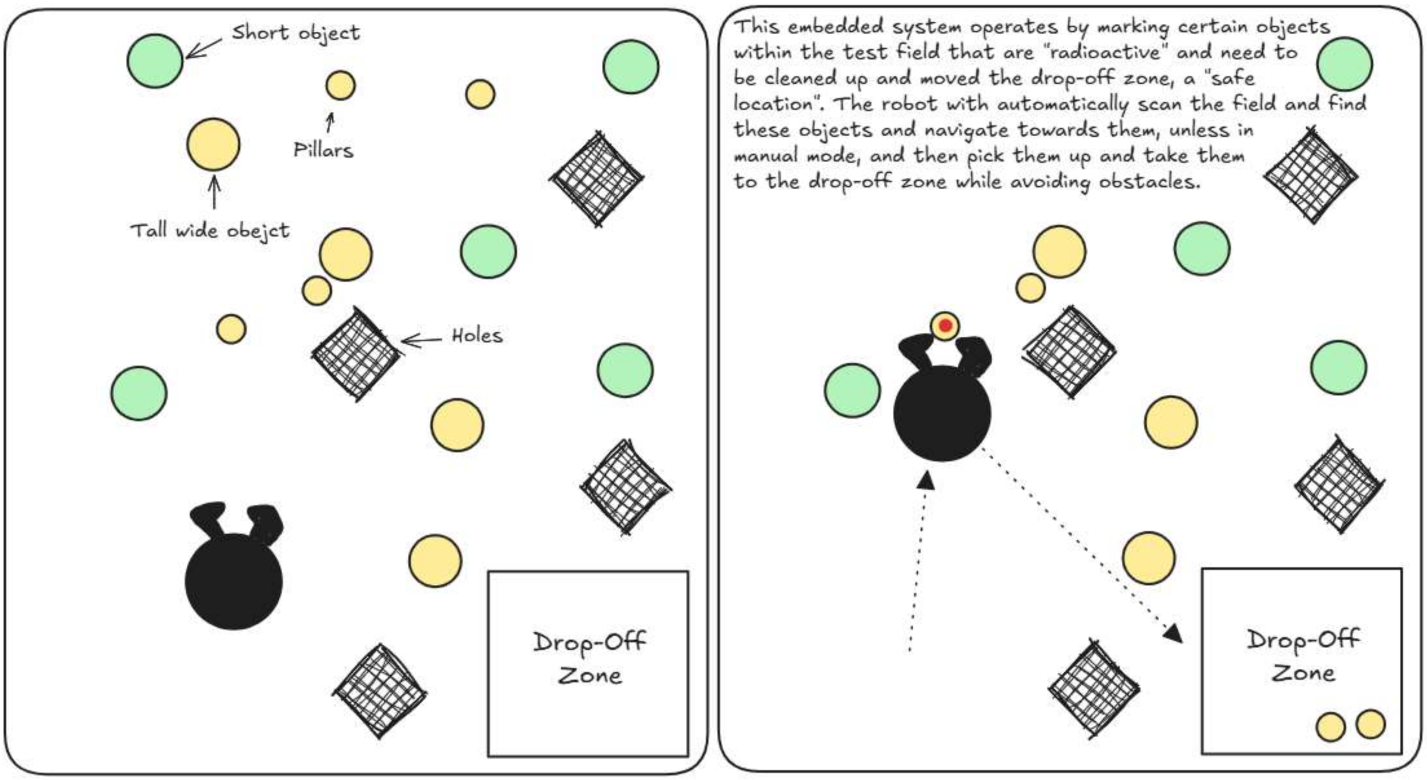

Fig. 5: Test Field Layout for R.A.D.C Navigation and Cleanup

This sketch illustrates the test field designed for the Remote Autonomous Disaster Cleanup (R.A.D.C.) robot. The field includes a variety of obstacles—short and tall/wide objects, holes, and pillars—alongside a designated drop-off zone marked as the "safe location" for collected debris. The embedded system identifies specific "radioactive" or "hazardous" objects scattered throughout the field. In autonomous mode, the robot systematically scans the area, locating these objects and planning its route to safely reach them. The R.A.D.C. robot then navigates toward each skinny object, picking it up with its gripper arm and transporting it to the drop-off zone. In manual mode, an operator can directly control the robot's actions. The robot is programmed to avoid obstacles and potential hazards during navigation, ensuring efficient cleanup operations.

Final Product

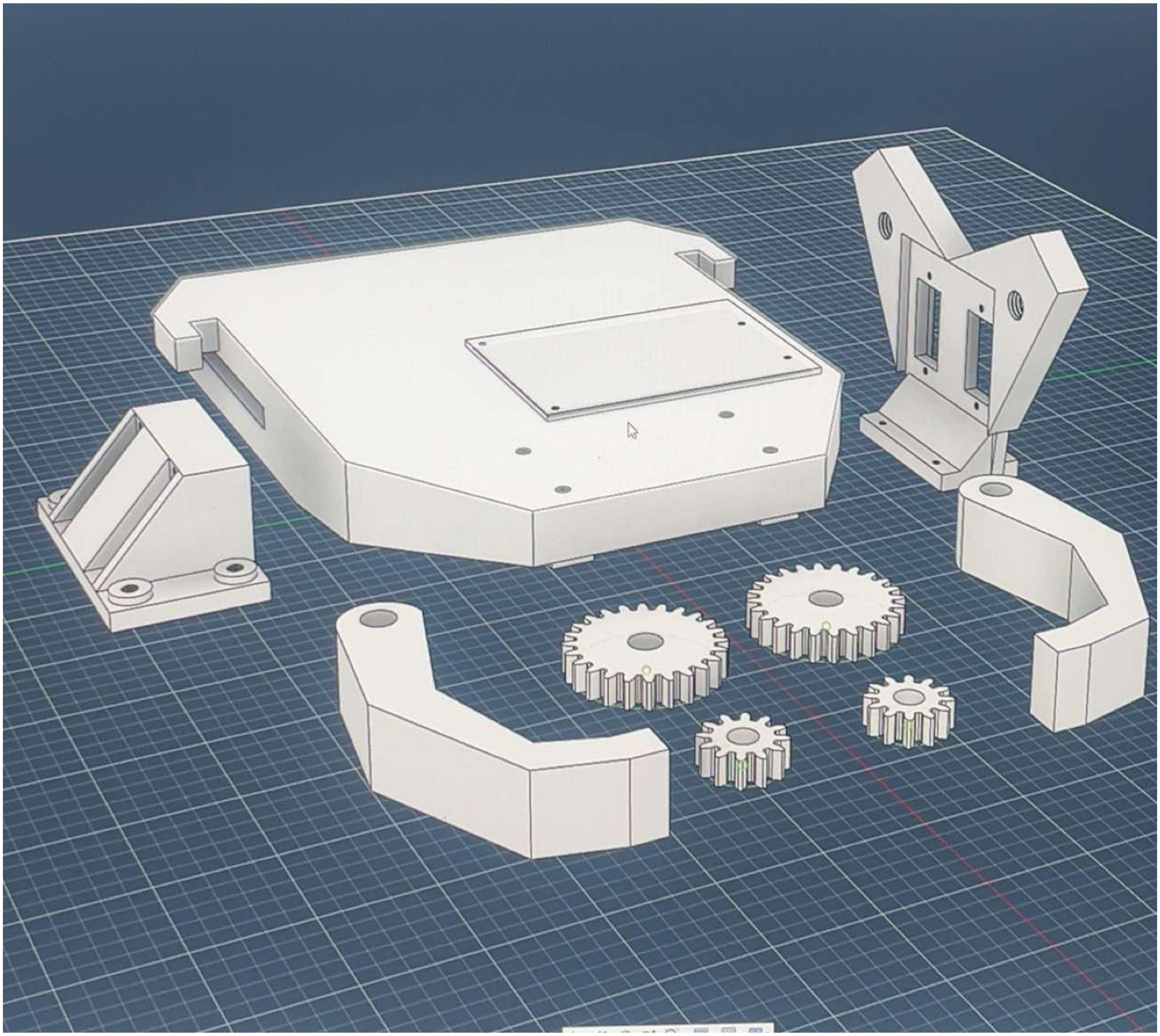

Fig. 6: Gripper Arm for RADC Laid Out for 3D Printing

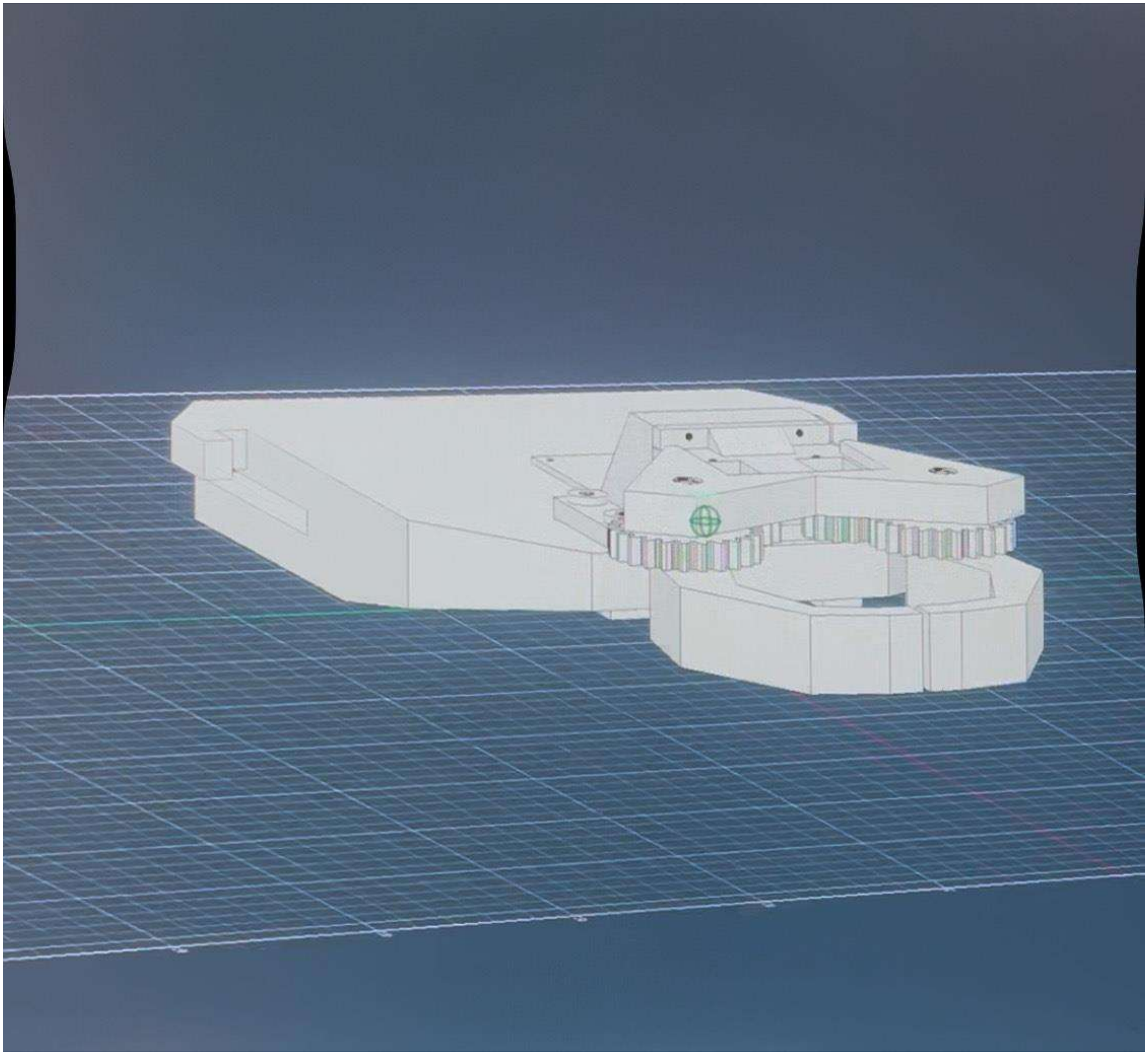

Fig. 7: CAD(Fusion 360) Model of Gripper Arm Assembled

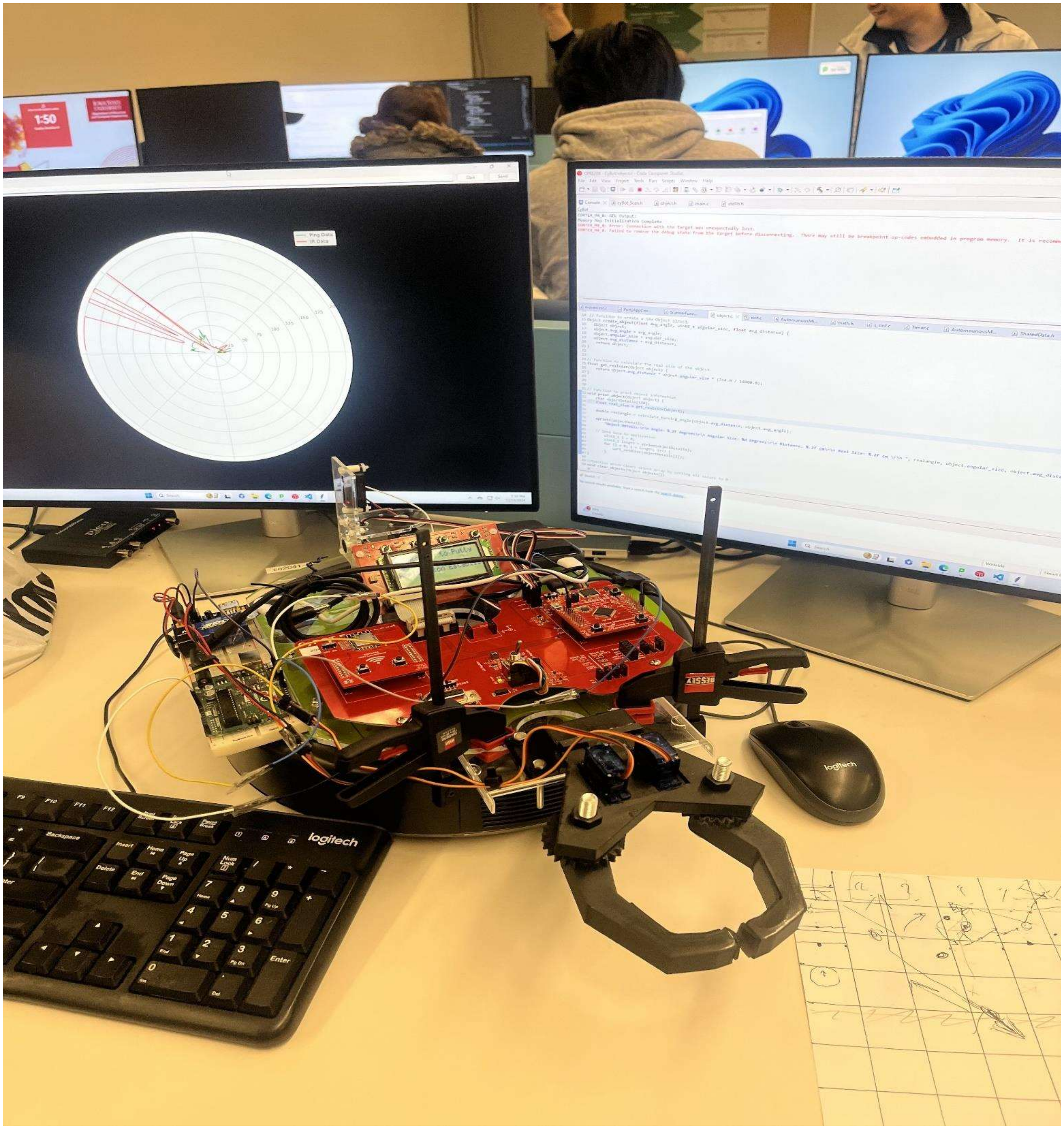

Fig. 8: Gripper Arm Fully Assembled Onto the Base of the CyBot

Team Collaboration

Team Member	Contribution
Ben Boldog	I contributed to the project by creating the test field sketch and designing the layout for the test field. I helped determine how to test the embedded system of our final project, and I played a role in deciding the direction for the project by brainstorming ideas. Additionally, I contributed to the development of a user-friendly GUI, ensuring it could differentiate between various types of readings, including movement, IR, Ping, and others, to enhance usability and clarity.
John Brittain	I contributed to the R.A.D.C project by proposing a robotic arm to enhance functionality and suggesting the CyBot as a cleanup robot for hazardous environments like Chernobyl. I developed technical sketches, outlined the gripper mechanism's interaction with the microcontroller, and created a high-level flowchart for hardware and software integration. I modeled the arm in Fusion 360, helped to 3D print the components, assembled it, and programmed the Arduino and microcontroller, adding GUI features for better user interaction. The arm attaches to the back of the CyBot, improving efficiency. I also improved the CyBot by implementing cliff sensors, adjusting turning angles, refining autonomous movement, enhancing GUI development.. Additionally, I focused on improving servo calibration, IR accuracy, and Ping accuracy.
Ethan Haberer	I assisted in creating the documentation associated with our project and contributed to the brainstorming process. Additionally, I helped implement cliff sensors, adjust the turning angles and autonomous movement, and work on improving GUI development by finding a better toggling mode method. I also added a celebration song at the end of the robot’s tasks. I also focused on improving servo calibration, IR accuracy, and Ping accuracy, and I will contribute to coding the robot to accomplish our tasks more efficiently.
Gabe Kiveu	I created a user-centered sketch to demonstrate our project's reliability in reaching hazardous areas and efficiently completing missions. I worked on the robotic arm by modeling it in Fusion 360, 3D printing components, assembling the arm, and programming the Arduino and microcontroller. I also added GUI functionality to differentiate between movement, IR, and Ping readings. The robotic arm, designed to attach to the back of the robot, enhances its capabilities in hazardous environments.
MacKenzie Woods	I contributed through leadership, coordination, and technical input, ensuring clear communication to keep the project proposal on track. I identified problems, offered solutions, and helped refine our approach. I also supported the team with development, troubleshooting, and ensuring all aspects of the project came together effectively. I played a key and vital role in drafting the proposal and worked with Ethan on CyBot improvements, including cliff sensors, turning angles, autonomous movement. Additionally, I wrote the script for the elevator pitch to clearly communicate our project.

As a team, we focus on working together and communicating clearly throughout the project. Each team member brings different skills and ideas, allowing us to approach problems in creative ways. We have regular meetings to make sure everyone is on the same page, discuss challenges, and adjust our plan to meet the project goals.

We divided tasks based on what each person does best, whether it's designing hardware, developing software, or testing. We help each other out whenever needed, whether it's stepping in to assist with other tasks or offering suggestions to improve each other's work. This teamwork ensures that all parts of the project come together smoothly, from the Cybot's communication to its movement and object handling.

In the end, we believe that working together is the key to the success of this project. By combining our skills and dedication, we're confident that we can create a robotic solution that will make cleanup in dangerous environments safer, quicker, and more effective.

Fig. 9: Team Photo

Conclusion

In summary, our project aims to tackle the task of safely cleaning debris from areas unfit for humans. In addition to navigating obstacles, navigating an area, and finding a safe zone, our robot will pick up thin objects with a mechanical arm controlled by a servo. We believe that our proposal addresses all the required criteria for this assignment. Additionally, we will be using new technology and practices that have not been covered in class. This project would be beneficial for many real-world applications as it has the potential to keep human lives safe.

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