ELECTRICAL AND COMPUTER ENGINEERING
COLORADO STATE UNIVERSITY

Electrical and Computer Engineering Outreach Team:

RamBOTs

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Summary:

RamBOTs is a multidisciplinary senior design team composed of electrical, computer, and mechanical engineers. In this project, we plan to learn about robotics through the development of a quadrupedal robot and integrate newer technologies that are currently changing robotics. We will work with different aspects of engineering such as machine learning, kinematics, motor control, computer aided design (CAD), and power systems to create a robot that will be able to navigate an unknown environment to follow a thrown object. The team also aims to demonstrate the pieces that make up the robot in a way that's accessible and exciting for different age groups in tandem with Electrical and Computer Engineering (ECE) Outreach.

Importance:

This project is important because it addresses the need to inspire and engage younger generations in engineering. By developing a quadrupedal robot that showcases various engineering concepts in an accessible and exciting way, RamBOTs aims to spark interest in STEM fields among future engineers. It serves as a valuable tool for learning and can help bridge the gap between theory and practical application, ultimately contributing to motivating the future workforce in engineering.

Revision History:

Date	Comments	Version	Approved by
9/19	Initial document	1.0	
9/22	Revised initial document	1.1	Jon Lotz

Figure 1: Revision History Table

Problem Statement:

The primary objective of this project, consistent with previous years, is to create an educational and outreach tool in the form of an open-source quadrupedal robot. RamBOTs is an ongoing multi-year project now entering its third year, with significant progress already achieved.

In the initial year, the focus was on harnessing machine learning to identify objects using a camera. That team initially adopted the openDog V2 project by James Bruton and began the process of replicating it. However, during that year, a new iteration called openDog V3 was released, which briefly shifted their course. Despite this, by the end of the first year, they had successfully 3D printed several essential robot components.

The second-year team continued from where the previous team left off, completing the 3D printing phase and moving on to assemble the robot's electronics, software, and hardware. By the close of the second year, the robot could walk, perform push ups, and engage in various activities.

Currently, the robot faces significant reliability issues, which have become a primary focus for this year's efforts. In addition to enhancing reliability, we aim to make the robot a more engaging engineering tool. To achieve this, we plan to enable the robot to navigate an uneven concrete surface to play fetch - allowing users to throw a ball for the robot to follow. This entails teaching the robot to maneuver autonomously, with a strong emphasis on safety through obstacle detection to prevent collisions. Object detection and tracking will also be pivotal this year, enabling the robot to locate the ball accurately. Furthermore, as a stretch goal, we hope to implement voice commands to offer users an interactive way to engage with the robot dog.

These tasks are challenging, so we have a range of supporting tasks, including documentation, simulation, and stress tests, which are equally essential. These tasks will not only enhance the robot's functionality but also provide valuable insights for the next year's team as they embark on further improvements.

Multi-Year Project Status and Plans for This Year

Previous Tests

- A 3D printed chassis / body
- Motors and drivers (not all have been tested)
- A stand for storage/transportation
- Basic Object Detection

This Year

- Build a fifth leg (and a stand to support it) for testing before uploading to the robot.
- Object detection and tracking
- Collision Avoidance using LiDAR
- Determine a method (stand/elbow clamps) to hold the legs in the correct startup position at least 19 out of 20 times
- Improve the robot’s coding for better balance
- Complete testing and simulations of major components to ensure they all operate within expected parameters, and replace them if necessary

The 2023-2024 team intends to first improve the startup process of the robot and ensure that it works properly and more reliably compared to last year. We plan to build upon the design by creating a way for it to walk on uneven surfaces and have better balance overall. This year’s team also has three mechanical engineers compared to the two that were involved last year, which will allow for more reevaluation or even reconstruction, as a few of the parts have become worn over the years.

Goals & Objectives:

The primary objectives of the RamBOTs project can be categorized into short, medium, and long-term goals. These objectives are designed to guide the project's development and measure its success using SMART criteria: Specific, Measurable, Achievable, Realistic, and Timely.

Short-Term Goals (<1 month):

In the initial phase, the team's objectives are to familiarize themselves with the project's history and get the robot up and running for basic functionality. This includes ensuring the robot can perform standard procedures like those during last year's E-Days and move each leg individually for stress testing. Additionally, the mechanical team plans to build a fifth leg for testing and a stand for the robot. This leg will be useful in understanding specific kinematics of the robot and will help the team with later goal items such as fine tuning movement (see Medium-Term Goals). For the electrical and computer engineering teams, the goal is to enhance the robot's recognition abilities by understanding the existing code, training a machine learning algorithm, and implementing a LiDAR sensor to detect objects within 1 foot. The team would also like to address some safety issues, such as exposed wire connections, accessibility and treatment of the batteries, and lack of safety procedures.

Medium-Term Goals (first semester):

In the medium term, the project aims to make progress towards more advanced capabilities. This includes getting the robot to walk on an uneven concrete surface, and quantifying its performance limits. The goal is to have the robot run for 20 minutes at a time and consistently operate on a 5 percent grade. Mechanical engineering will focus on simulation and stress testing of the legs which includes having a physical leg model for testing as well as a versatile Finite Element Analysis (FEA) simulation model. FEA simulation will be considered complete when the full model (as well as individual components of interest) have accessible and editable project files with clearly defined attributes such as tensile, shear and compression strengths. Meanwhile, the computer and electrical engineering teams will work on object recognition and tracking (increasing the size of our training set for specific objects), measuring the amount of current going to each motor, and self-tests for motors and ODESCs. Safety reviews and documentation of wiring are also planned.

Long-Term Goals (by E-Days):

By E-Days, the team envisions the robot being able to play fetch, follow a person using various commands, and increase bystander engagement through enhancing the interactive aspects of the project. The mechanical engineering team plans to increase the reliability and robustness of the base to ensure the robots mechanical functionality at outreach events, while the electrical engineering team aims for comprehensive documentation, safety reviews, and complete schematic diagrams. These documents will ensure a smooth transition to the next team that works on the project. The computer engineering team will ensure the safety of bystanders and the robot by using obstacle detection. It is important to note that obstacle detection is not intended to be used for navigation purposes. The software should successfully follow a specified 'fetching' object, while retrieval of the object is not initially planned due to its inherent mechanical complexities. Lastly, by E-Days everyone on the team should be able to explain the major aspects of the robot encompassing the mechanical systems, electronic integrations, software stack, and the synergy of the whole system.

Stretch Goals:

Stretch goals for the project includes achieving more advanced capabilities like having a slower walk cycle (longer time between footfalls) and picking up and returning a thrown ball. Additionally, there is a goal to have the robot dance and walk around at various school events like a basketball game. The purpose of going to events would be to raise awareness for the ECE Outreach program and possibly fundraise. If time is allotted, we would also like to investigate the ability for the robot to respond to visual hand movements or voice commands to direct it to do different operations.

Overall, these objectives provide a clear roadmap for the project, ensuring that it progresses methodically and addresses both short-term and long-term goals. They are designed to be Specific, Measurable, Achievable, Realistic, and Timely to track the project's success and development throughout its duration.

Budget Justification:

The RamBOTs project is going into its third year, and many of the materials and components have already been purchased; however, there are still a lot of items that need to be purchased to improve the performance capabilities of the robot. The budget will consist of products that will help the robot in navigating an unknown environment.

This year's budget is $1800, $200 for each senior on the team. This should be enough to cover all of the improvements that the team plans to make throughout the year. This is how the budget will be spent currently:

Subgroup	Item Name	Price	Quantity	Total	Notes
Hardware					
	Screws, washer, bolts, nuts	$75.00	>1	$75.00	Reference OpenDog V3 Bill of Materials in Inventory
	Bearings	$300.00	>1	$300.00	Reference OpenDog V3 Bill of Materials in Inventory
	Carbon fiber rod for spare leg	$30.00	1	$30.00	
	Belts	$15.00	2	$30.00	1 for spare leg, one for spare
	Other:	$30.00	1	$30.00	
Electronics					
	PI-4	$90.00	1	$90.00	
	O-DESCS	$250.00	2	$500.00	
	Arduino Teensy	$40.00	1	$40.00	
	Battery	$45.00	2	$90.00	Need to test extra batteries
	Motor Encoder	$20.00	2	$40.00	
	LIDAR Sensor	$150.00	2	$300.00	
	5V Voltage Regulator	$5.00	1	$5.00	
	Microphone	$25.00	1	$25.00	
	Google Colab Subscription	$70.00	7 months	$70.00	
	Other:	$30.00	1	$30.00	
Other					
	3D Printing Filament	$23.00	3	$75.00	
	Label Maker	$40.00	1	$40.00	
	T-Shirts	$15.00	2	$30.00	
TOTAL				$1,800.00	

Figure 2: Budget Justification Table

Risk Analysis:

Proposed FMEA Table:

Process Step	Potential Failure Mode	Potenetial Failure Effect	SEV1	Potential Causes
What is the step?	In what ways can step go wrong?	What is the impact on the customer if the failure mode is not prevented or corrected?	How severe is the effect on the customer?	What causes the step to go wrong (i.e. how could the failure mode occur)?
Boot up process	Legs aren't correctly positioned	Legs not being operable, rendering the device useless.	8	Operator error. Not correctly setting up the legs into the correct position.
	Batteries not at similar voltages	Batteries will not perform as expected and could possibly result in a fire.	9	The batteries not charged at the same time or to the same level, resulting in one outputting more current than the other.
	Controller not correctly paired	Operator will have to get a new controller or redo the boot up cycle.	4	Not following the setup instructions correctly or not having the controller charged properly.
Controlling the robot	Raspberry Pi can't correctly arbitrate commands to Teensy and to control system	The device won't be responsive to the commands of the operator and will require a reboot or hotfix.	7	Could include incorrect command arbitration or a fault in the Pi bootup process.
	Robot falling over accidentally	Possible broken legs and other broken parts on the robot.	5	One of the legs collapses, walks on uneven terrain that it cannot handle, or someone hits it.

OCC2	Current Process Controls	DET3	RPN4	Action Recommended
How frequently is the cause likely to occur?	What are the existing controls that either prevent the failure mode from occuring or detect it should it occur?	How probable is detection of the failure mode or its cause?	Risk priority number calculated as SEV x OCC x DET	What are the actions for reducting the occurence of the causes or for improving its detection? Provide actions on high RPNs and on severity ratings of 9 or 10
6	Currently, the legs not functioning indicate that it was likely thrown into open loop, which would signal to the operator that they need to restart, but it isn't explicitly obvious.	4	192	Produce a stand that helps the operator correctly get the legs into the correct position every time, reducing the likelihood of occurence. Additionally, implementation of an indicator that the legs aren't positioned correctly could tell the operator that something is not correct, resolving the detection.
2	There are voltage readers on the robot that allow us to see how charged each cell of the battery is and will alert us if a battery gets too low.	4	72	Develop procedure in the start up sequence to read the values on the voltage readers to ensure all batteries are in a similar range. Create a sign to say to indicate when the batteries are charging and no one is allowed to turn on the robot until the sign is removed by the person who put it there.
3	The controller has a built in light that indicates charge if it is correctly paired.	3	36	Reducing occurence would be charging the remote frequently and making sure the documentation on startup is readily available and correctly followed.
2	None.	3	42	Implementing a way to diagnose issues during startup, checking the code, and making sure it is correctly connected to all parts.
4	Do not have robot currently walk on uneven terrain.	2	40	Watching the robot when it is in operation and not on a stand. Test all parts of the robot to be confident that all parts will operate correctly when walking on the ground.

Figure 3: FMEA Table

Proposed Project Risk Analysis Table:

#	Risk Event	Probability /100	Impact (days)	Score (days)	Effect	Risk Mitigation Plan	Person responsible for implementing control
1	Batteries falling below required voltage	70	7	0.5	Battery becomes too dangerous to charge and must be replaced.	Have a battery sensor that will alert us when the batteries get to 2.5V for each cell so we can turn off the robot and charge it.	Current team member that is operating the robot and anyone else on the team nearby.
2	Motors Fail	10	7	10	Decreased functionality of robot or lost time during repair	Ensure that motors stay protected from outside debris and long term wear	Team that is currently working on it will report to one of the mechanical engineers who will look into the issue.
3	Teensy/Raspberry Pi/ODESC Failure	30	Vary based on parts in house. 7-14 days	10	Lost control of the robot if in operation or unable to turn on the robot and perform at events.	Individually test electronics and their code before implementing new ideas on the robot by using spares and double checking with teammates. Also ensure each device is connected properly.	Team members that are working directly with the electronic parts and the team leader for that area of the robot.
4	Personal injury (team or bystander)	5	0.5	4	Lost time for the teammate working while healing	Ensure that those working on device follow the created safety plan. And all nearby bystanders are aware of potential risks.	Anyone on the team who is working on the robot or demonstrating it.
5	Improper wire connections	65	Vary based on severity, but more than 5 days	0.5	Shorting and complete failure of the electronics, fire, and dangerous areas of the robot that people can accidentally touch	Double check all solder and wire connections with other teammates. Learn how to properly solder wires and include heat shrink everywhere there is exposed wire. Do a conductivity test of wires to ensure proper connections.	Documentation and Safety Team: Aironas, Anna, and Joey.
		Total Risk:	25 days				

Figure 4: Risk Analysis Table

Project Timeline:

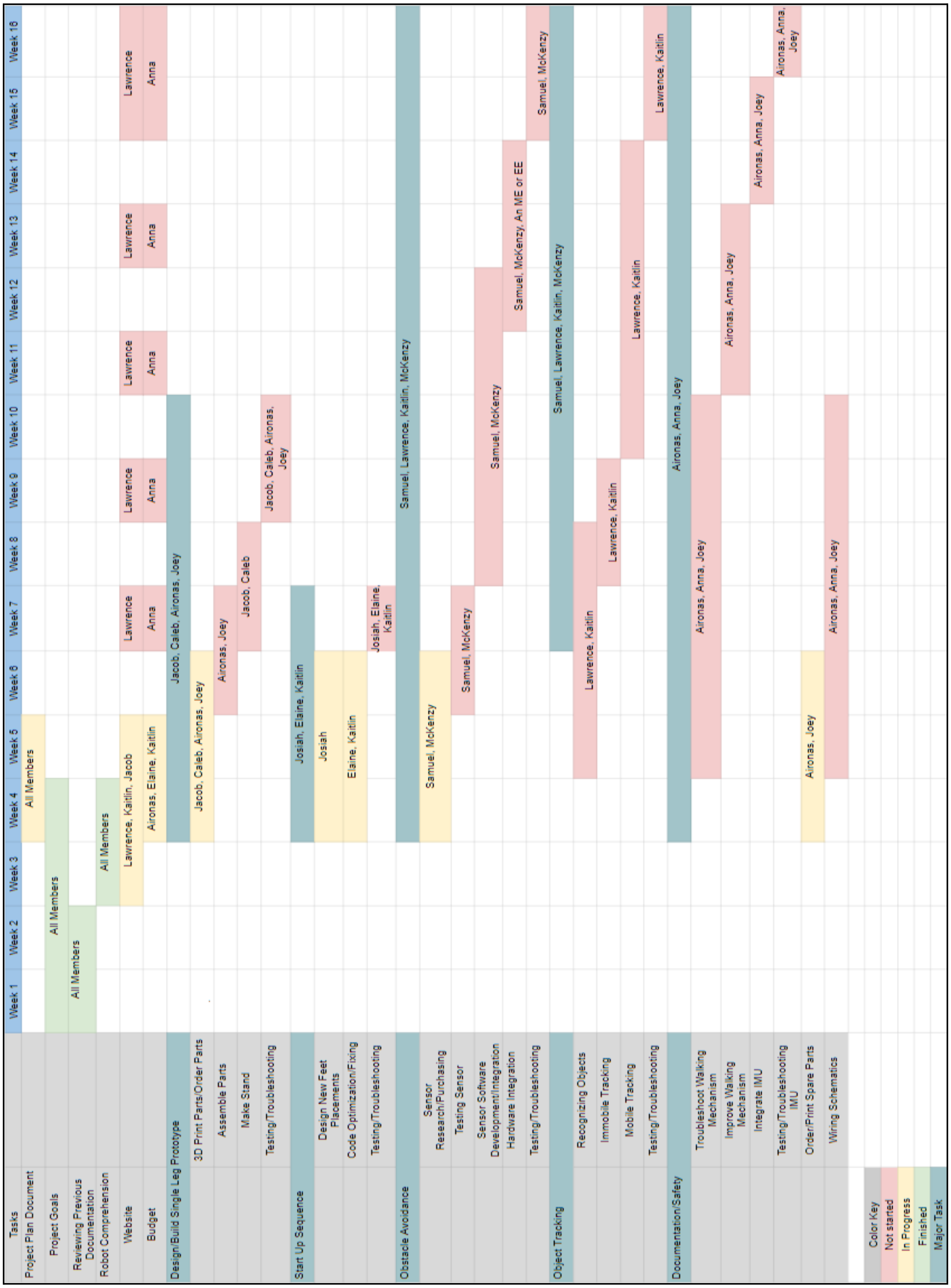

Figure 5: Semester 1 Timeline

Tasks		Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26	Week 27	Week 28	Week 29	Week 30	Week 31	Week 32
Update Project Plan Document		All Members															
Website		Lawrence			Lawrence		Lawrence		Lawrence		Lawrence		Lawrence, Kaitlin, Jacob			Lawrence	
Budget		Anna			Anna		Anna		Anna		Anna		Anna				
E-Days Preparation													All Members				
Transition Document Creation																All Members	
Obstacle Avoidance		Samuel, Lawrence, Kaitlin, Mckenzy															
	Testing/Troubleshooting	Samuel, Lawrence, Kaitlin, Mckenzy															
Object Tracking		Samuel, Lawrence, Kaitlin, Mckenzy															
	Testing/Troubleshooting	Samuel, Lawrence, Kaitlin, Mckenzy															
RamBOT Simulations		Jacob, Caleb, Josiah, Elaine															
	Design SolidWorks Model	Jacob, Caleb, Josiah															
	Run FEA On Model			Caleb, Josiah													
	Research Simulation Software				Jacob, Elaine												
	Port Model to Software						Jacob, Caleb, Josiah, Elaine										
	Testing/Troubleshooting											Jacob, Caleb, Josiah, Elaine					
Fetch					Aironas, Anna, Kaitlin, Lawrence, Samuel, Caleb, Elaine												
	Research Object Retrieval				Aironas, Kaitlin,												
	Design Object Retrieval Method				Aironas, Kaitlin, Caleb, Anna, Lawrence, Samuel												
	Purchase Needed Equipment					Anna											
	Assembly of Retrieval Method						Aironas, Anna, Caleb										
	Software Development								Elaine, Kaitlin, Lawrence, Samuel								
	Testing/Troubleshooting											Aironas, Anna, Kaitlin, Lawrence, Samuel,					
Color Key																	
Not started																	
In Progress																	
Finished																	
Major Task																	

Figure 6: Semester 2 Timeline