SDSU | San Diego State University

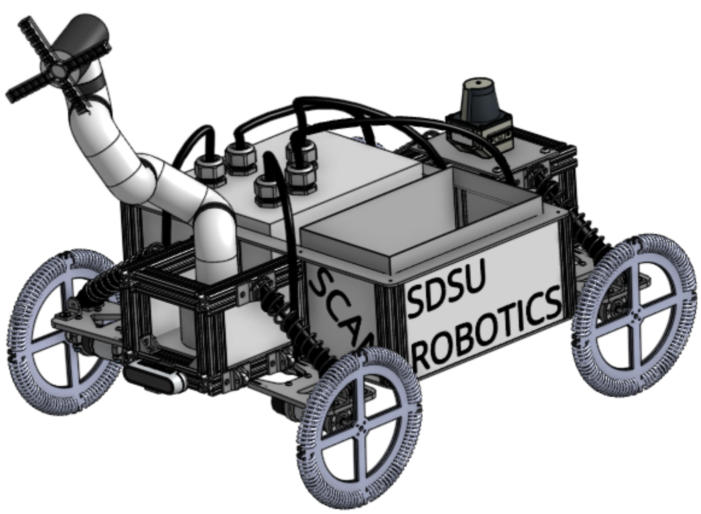
College of Engineering

Departments of Mechanical Engineering and Electrical and Computer Engineering

ECE FINAL REPORT

COMPE-492 - Senior Design B

Project 35, Team 14, Coordinated Multi-Robot for Planetary Exploration.



Team ***S.C.A.N. Robotics***

Split Chore Autonomous Network

ME Team:

Abelardo Garcia, Cameron Jaynes, Sophie Koehler, Andrew Richter, Martin Ruiz

ECE Team:

David Aw, Christopher Choo, Shahad Al Neesan, Uriel Zamorano, Shingo Morita

1 - Executive Summary

This document summarizes the evolution, current system functionality, design characteristics/rationale, debug/validation strategies, costs and scheduling, and individual team member lessons learned throughout the construction of the SCAN robot.

The project began as an overly ambitious and poorly-defined "research task" into the potential of several small robots towards completing unique objectives on Mars divergent to current NASA design philosophy - which favors single large, expensive, and human-operated rovers. These objectives consist of identifying and collecting extraterrestrial samples, autonomous terrain navigation, and coordination amongst these small units towards accident recovery, load distribution, and information dispersal.

After much streamlining and reprioritization of assumed project requirements, the final instantiation reifies the first two requirements for sample collection and autonomous navigation. The design strategy was to construct a single unit capable of the above as soon as possible, with the remainder of Senior Design dedicated to upgrading hardware and firmware until results were satisfactory.

Thus, the SCAN robot is autonomous vehicle that executes the following tasks/requirements:

1. **Navigate a complex environment** containing obstacles of various geometry through depth analysis of immediate view. This continues indefinitely until the "Sample Collection" (2) routine is triggered.
2. **Identify and traverse to user-defined items.** During the "Free Roaming" (1) routine, if a desired sample is detected within the camera view, the robot will change its trajectory towards the sample.
3. **Collect user-defined items using a robotic arm.** Once the sample is within ~4 cm of the robot, the robot will indefinitely stop until the user prompts otherwise. This is to allow the arm operator as much time as necessary to collect the sample. Once the sample is verified to have been collected, the robot will be prompted to continue its "Free Roaming" routine.
4. **Perform all above tasks using a 22.2 V LiPo Battery power supply.**

2 - Project Evolution

Originally, the project was to develop and create several autonomous machines that identify and retrieve objects of interest by coordinating in areas of information gathering, load sharing, and accident resolution.

As Senior Design A progressed, it quickly became apparent that the original vision of the project was not realizable within 2 semesters. The multi-agent coordination aspect was quickly removed from the list of hard requirements, as no team members knew how to implement such a system to begin with.

As such, it was decided that the most practical approach would be to focus on a single unit that achieves intended functionality as soon as possible, with superior components procured after the functionality was deemed capable of further development. No matter the stage of evolution the project was at, the components would always consist of:

1. A small computer (CPU) specifically designed for robotics use, with parallel-computing and image processing capabilities for object recognition.
2. At least one microprocessor (MicPr)to execute serial directives and direct as many processing requirements away from the computer.
3. Four motors for ground traverse.
4. At least two motor drivers (MD) to relay navigation directives between the microprocessor and motors.
5. An RGB camera (Cam) to capture the immediate front view of the robot for the purpose of identifying objects and obstacles.
6. A depth-processing unit (Dep) to formulate conditional motor directives.
7. An IMU to perform real-time angular measurements for tip-prevention.

Stretch components:

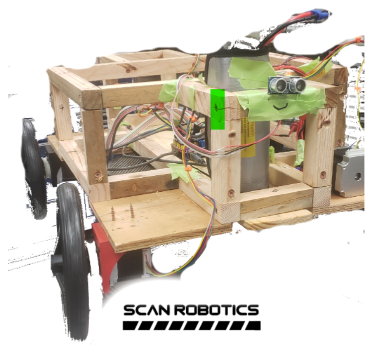
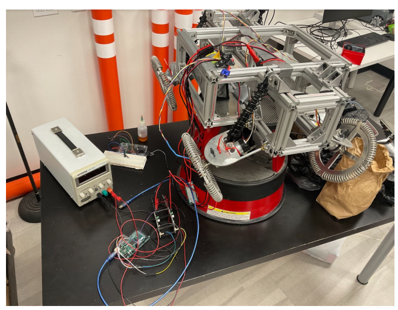
8. Light Detection and Ranging (LiDAR) unit for Simultaneous Localization and Mapping (SLAM).
9. Robotic Arm for sample collection.

Key changes to the project mainly occurred to the selection of motor drivers, motors, and LiDAR.

- The project began with stepper motors, which were replaced with DC brushed motors after they were determined to have insufficient torque output.
- Motor drivers and their quantity changed 5 times. Initially, 3 types of stepper motor drivers with a corresponding microprocessor shield board were used. However, the amount of current required to propel the robot even small distances fried each driver after about 30 seconds of use. Corresponding to the upgrade to DC brushed motors came the

integration of relevant DC brushed motor drivers. The final motor drivers were selected simply as a means to ensure the previous stepper driver incidents never occurred again, as they have a 43 A tolerance per unit - beyond the output possible by the system.

- The LiDAR was eliminated totally. The procured unit was several months late in delivery and also found to be incompatible with the Linux-based system required for this system. Furthermore, the main purpose of having SLAM - to build an autonomous navigation system, became unnecessary when the autonomous features were replicated using the RealSense camera.

Date	Project Status	Description
Nov'. 22		CPU: Raspberry PI MicPr: Arduino Uno Motor System: Stepper Cam: Microsoft Kinect Dep: Ultrasonic Sensor IMU: Present Prototype wood chassis
Jan'. 23		CPU: **Jetson Nano** MicPr: Arduino Uno Motor System: **DC Brushed** Cam: **RealSense Camera** Dep: **RealSense Camera** IMU: Present Steel chassis, which was too heavy for practical use.
Mar'. 23		CPU: Jetson Nano MicPr: Arduino **Mega** Motor System: DC Brushed Cam: RealSense Camera Dep: RealSense Camera IMU: **Absent (temporarily removed to save dev time)** Temporary cardboard chassis while ME team refined the final chassis.

May 23’		CPU: Jetson Nano MicPr: Arduino Mega Motor System: DC Brushed Cam: RealSense Camera Dep: RealSense Camera **Robotic Arm developed and integrated**. Final aluminum chassis that balanced robustness and weight.

Fig. 1: Table of Key Design Evolutions & Dates

3 - System Description

The Robot serves as an autonomous vehicle that utilizes computer-vision algorithms, depth analysis, and serial communication to control 4 DC motors for the purpose of identifying, triangulating, and traveling to a user-defined object.

ECE Component	Purpose	Method	Voltage Requirements
NVIDIA Jetson Nano	Computation	NVIDIA Jetson Nano CPU is the main computational element of the system and is responsible for executing all firmware. All directives and functions are listed below, but implicitly operate due to the program executions unique to this computation subsystem.	5V
Arduino Mega Microprocessor	Motor Control	We use the PWM (pulse width modulation) to adjust the average value of the voltage that's going to the motor driver by turning on and off the power at a fast rate.	5V
Adafruit BNO055 Inertial Measurement Unit	Accident Prevention + Temperature Measurement	The robot's first set of internal safety validation requires detection of an imminent positional hazard, relating to angle and speed. If the robot's body exists at an angle that is too great for frictional force between the wheels and the ground to sustain, the robot tips over and is rendered inoperable. If the robot is too fast, payload security is compromised and presents a general	N/A

		occupational hazard to those around. The robot thus must utilize a gyroscope and accelerometer whose measurements are quickly communicated to a computer for the purpose of ensuring those operating parameters are within bounds. Thus, the Adafruit BNO055 Inertial Measurement Unit and Sparkfun FT232R Breakout Board were procured (infeasibility of fabrication). The unit is conveniently built with both a gyroscope with a measurement rate of ±125°/s to ±2000°/s and an accelerometer capable of measuring ±2g to ± 16g (g = the acceleration due to gravity). The measurement capabilities of this unit transmit positional information in real-time, thus allowing any corrective firmware to execute before an accident occurs	
Intel D435i RGB-D Camera	Object Detection + Depth Analysis	When the robot detects an obstacle impeding its path, the robot is to rotate until it is clear to proceed. 1. The robot detects an object that is correctly marked as an obstacle. 2. The robot is able to begin altering its path by rotating to avoid the obstacle. 3. The robot resumes its path as normal.	5V
4x AndyMark am-3637 Orbital 20 Gearmotor	Traverse	We used the DC gearmotors motor to provide high torque at low speeds. We used PWM (pulse width modulated) DC variable speed drives to turn the four wheels of the robot.	12-24V
4x BTS7960 Motor	Traverse	We are using four of the BTS7960, which is a	6-27 V

Driver		high-current full-bridge motor driver to control the movement of the four wheels of the robot. We used these modules to control DC motors using PWM (Pulse Width Modulation) technique. 1- We used a power distribution board to connect each two drivers in parallel, so we can control the left two wheels and right two wheels correctly. 2- We power these four drivers by using the power distribution board. 3- These drivers convert a constant input voltage to a variable voltage for the motor. The speed is controlled by changing the DC motor voltage. PWMs input ports have a fixed frequency and are controlled by controlling the time that the pulse is HIGH (Duty Cycle).	
22.2 V LiPo Battery	Power	We used 22.2 V Lipo Battery to give us up to 12 current, so the DC motor will get enough current to turn the wheel.	N/A
Power Distribution Board	Power	The system's main source of power as well as what allows for all of the components to function 1. Attach a 24V LiPo battery to the robot system. 2. Inspect components to make sure they are properly activated. 3. Wait for some time to pass before checking to see if the components are still activated.	N/A
MyCobot 280 Robotic Arm + Gripper	Sample Collection	Required for sample collection. Retrieves and collects samples once arrived utilizing SSH interface.	12V

Main Functionality

1. The robot system's components are powered on by a 22.2V LiPo battery. These components include the Jetson Nano CPU, Arduino Mega, the motor-drivers, and Intel RealSense RGB-D Camera.
2. The robot will then begin to scan the environment using the Intel RealSense Camera in order to locate objects that are of particular interest to the robot. This is accomplished via object detection through the camera, where it can distinguish between multiple objects and be able to classify what they are.
3. If no objects are located within the field of view of the camera, the robot will proceed to drive around until an object comes within vision. For the purpose of simulating a situation with a distinguishable sample, we are using a bottle due to its identifiable shape and its availability. This will be a stand in for the martian samples that were to be acquired as per the project description. The camera can also detect humans, where the robot will avoid coming into contact with any passerby within view of the camera. This allows for testing of the depth and obstacle avoidance due to the high population around the San Diego State University campus.
4. If the object of interest (a bottle) is detected, the robot will begin to make its way over to the object by maintaining it within the field of view. The camera can also sense the distance of the object as it begins to arrive at the location of where the object is present.
5. Once the robot has detected that it is 350 millimeters within range of the object, the system will deem that it has arrived at its destination location. At this point, the robot stops moving until the user prompts otherwise.

6. The robotic arm, which is remote-controlled by a 2nd user, retrieves the object and deposits it within the chassis backpack.
7. The robot continues to roam around the area, repeating the above directives until the program terminates.

4 - Design Report

Primary Operation of Circuit:

The brains of the operation starts at the Jetson Nano, this unit controls the processing of both physical motion and interpretive intelligence. To the right of the Jetson Nano is the Arduino Mega which is a microcontroller capable of running as a real-time operating system (RTOS). The arduino mega controls four Infineon BTS7960 motor drivers each capable of handling a stall current of 43A. Additionally the Jetson Nano is connected to the SICK Lidar, Intel Realsense D435 camera, and the IMU sensor. The LiDAR allows the robot to map out a depth map of the XY axis of the robot. The RGB-D camera is what gives the robot the ability to detect obstacles and scan for desired samples to collect. The IMU (Inertial Measurement Unit) sensor keeps track of the robot's orientation and velocity, and also measures the temperature of the electronics enclosure. All these components are powered by a power distribution board that is connected to a 6S Lithium Polymer battery. The power distribution board consists of three DCDC step down converters which drops 22.5V down to 12V and 5V to operate a range of electronics.

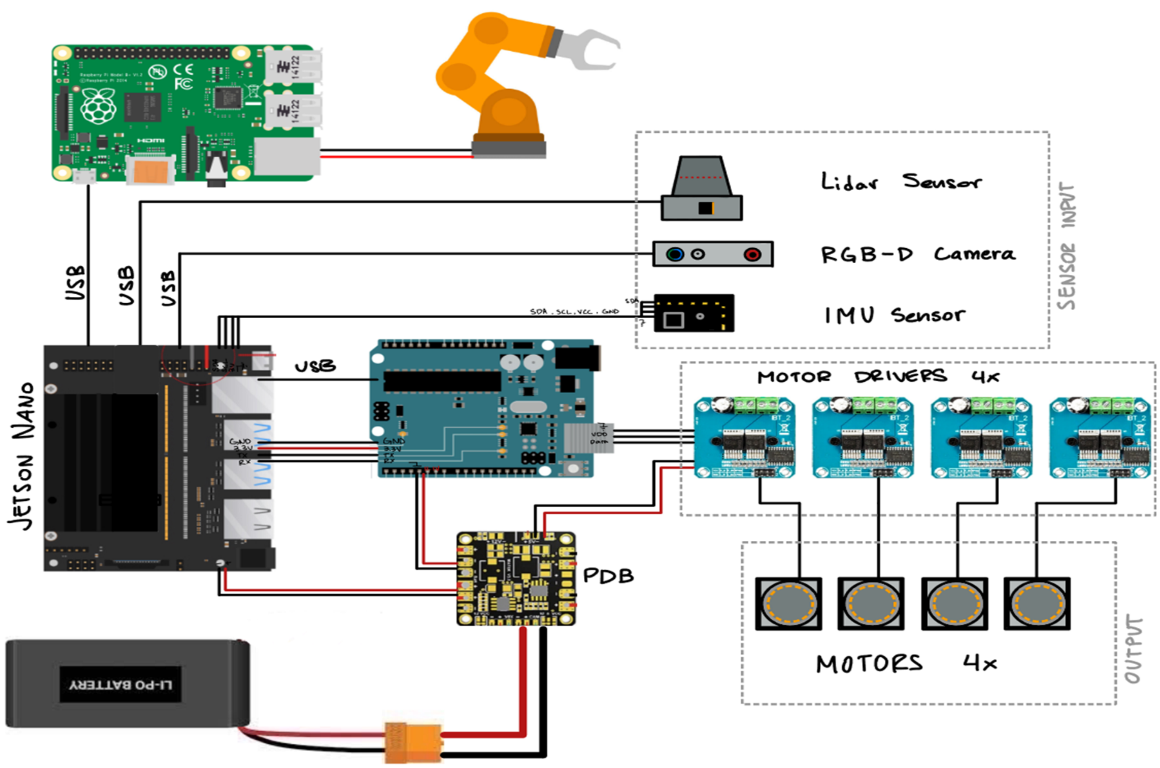


Figure 2: Electronics Diagram

Operational Power Draw

RPM	Voltage (V)	Current (A)
0	0	0
25	5	1.48
50	12	1.9
100	24	5
125	24	6
150	24	8

Fig. 3: Operation of Each Motor Driver (BTS7960)

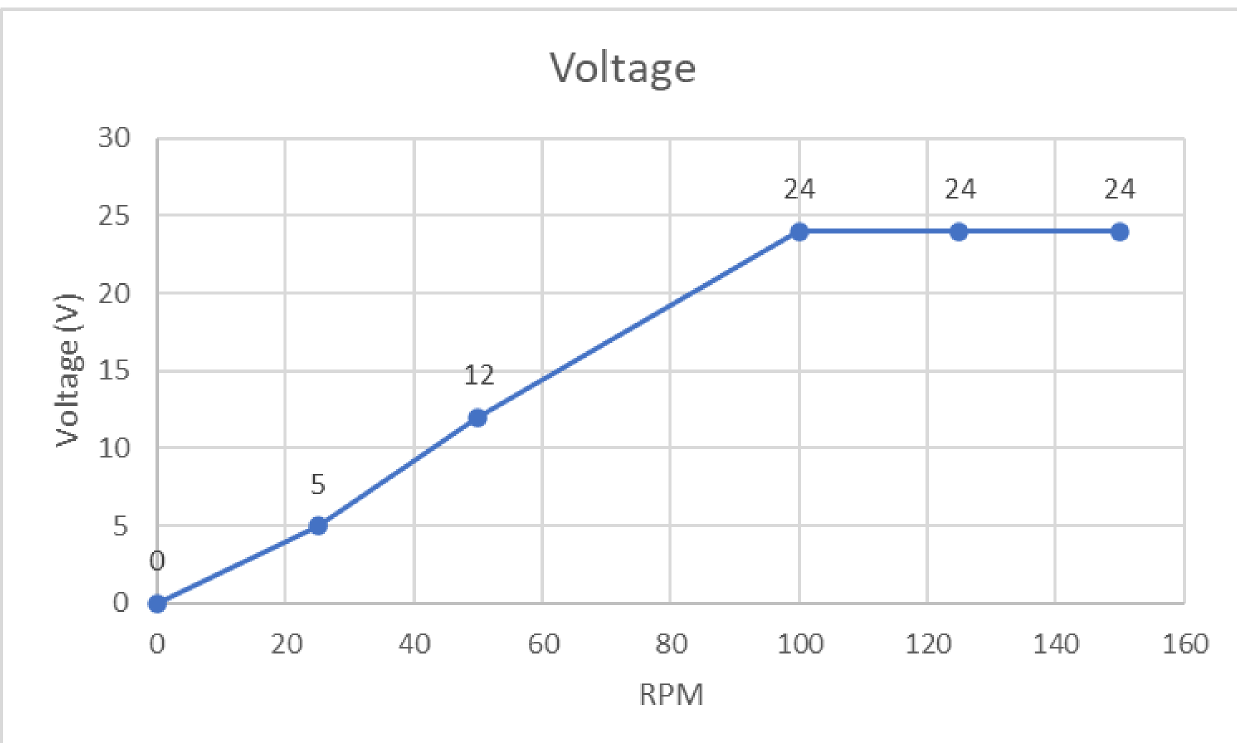


Fig. 4: Voltage Performance Curve of Each Motor Driver (BTS7960)

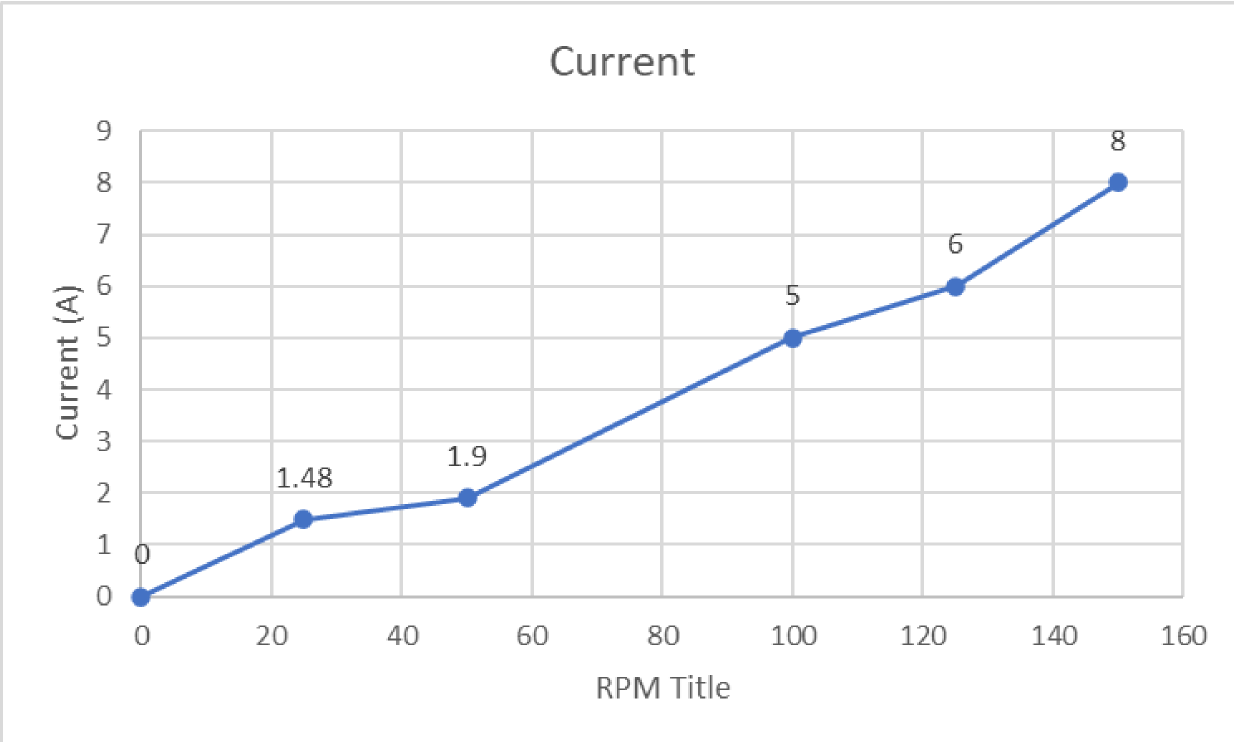


Fig. 5: Current Performance Curve of Each Motor Driver (BTS7960)

Thermal Operation

The thermal rating of the enclosure should be determined by finding the devices which have the most sensitive thermal ratings at the top and bottom end of the threshold. Upon comparison, the jetson nano requires a thermal operation within the range 0°C ~ 60°C to operate properly. During testing, it was not possible to recreate 0°C , however the maximum temperature that the enclosure ever rose to was 51°C .

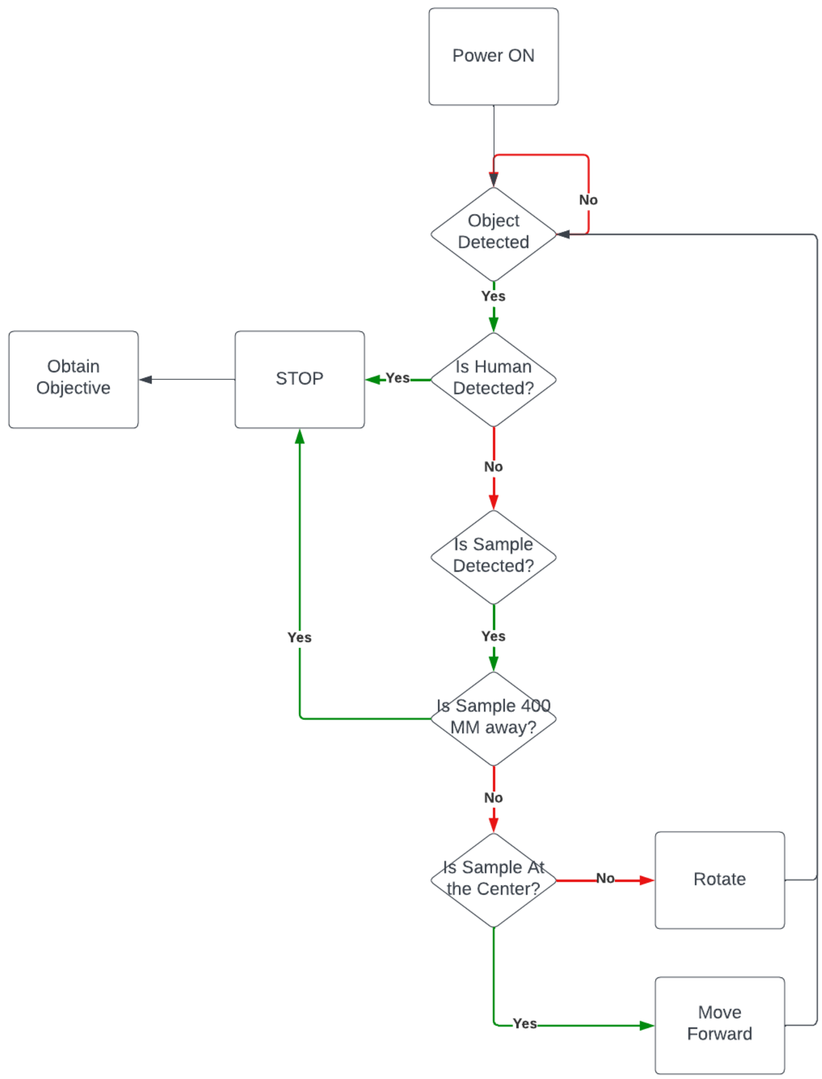


Figure 6: Free-Roaming and Object Traverse System Flow-Chart

Free-roaming

The algorithm utilizes depth analysis to trigger various motor control directives. When the average distance between the lens and surface is deemed to be too close, the motors will turn either left or right depending on which hemisphere of the feed is greater than the other. When the average distance is above the distance threshold, the motor drivers are directed to travel forward.

Object Traverse

The system employs state-of-the-art technologies, including Compute Unified Device Architecture (CUDA) for parallel computing, as well as Inference image-processing packages, to accurately detect and track objects within the camera's field of view.

When no target is detected, the system will roam freely, scanning the surroundings for potential objects of interest. As soon as a target is detected, the system will immediately transition into a tracking mode, adjusting its position to center the target within the camera frame.

Once the target is centered, the system will move forward towards it, maintaining a safe distance of 30 cm, until it reaches a predetermined point where sample collection can begin. At this point, the system will stop and initiate the collection process, ensuring that accurate and high-quality data is collected for analysis.

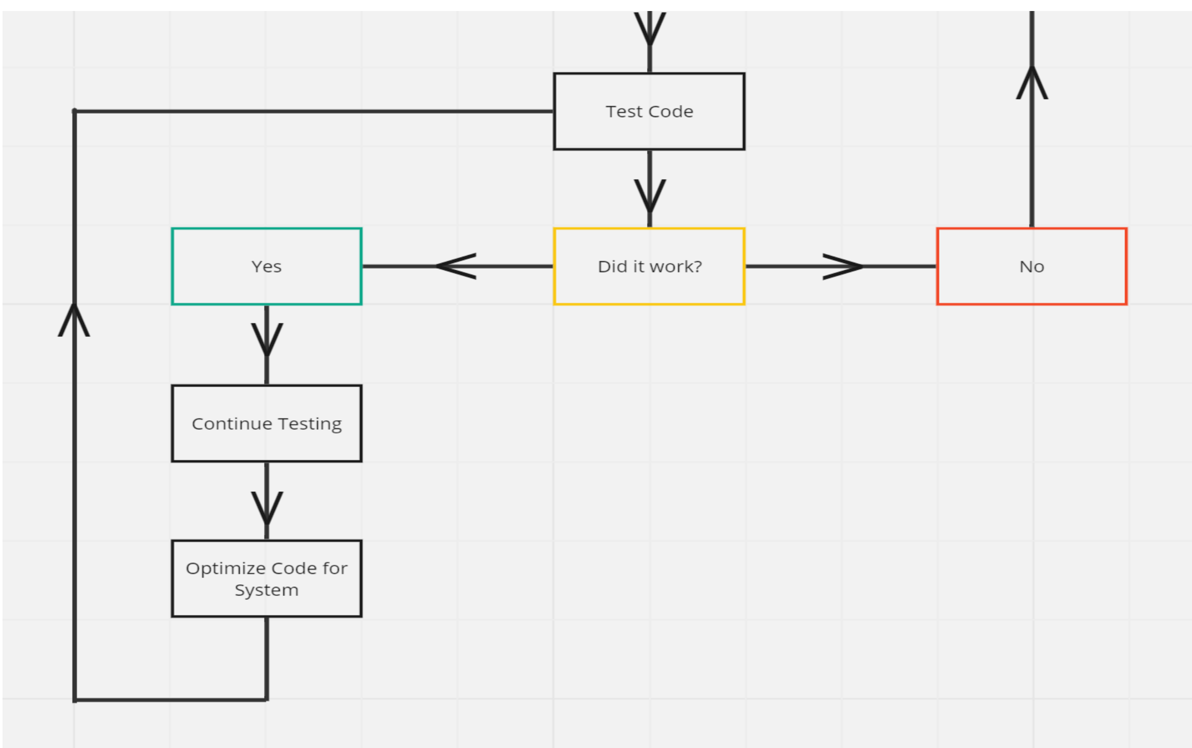
Sample Collection

Once the system has reached the predetermined point, a trained operator will take control of the robotic arm to collect the sample that is within view. The operator will use a real-time camera feed to ensure that the arm is precisely positioned to collect the desired sample and place it securely in the robot's backpack.

To control the robotic arm, we enabled SSH on the Ubuntu OS running on the arm. We created a separate user account with a password, allowing us to connect to the arm via username@IPAddress. Once connected, we can access the arm's files and use the pymycobot library for easy arm control.

5 - Debug and System Validation

` There were several components within the project that required several programs that allow the robot to function as it is. Our methods of integrating these programs was through the means of trial and error, seeing what allows our system to operate under the most optimal conditions. In order to implement the code, we started with basic functions that allowed the premise of the desired feature whether it was code inspired from another previously done method or code that we thought of that made the most sense to execute. Once a basis of the function was established, we began to elaborate on the code, making it perform slightly more with each iteration of the program. As we developed the code further, if we encountered an issue, we would continue to try new methods and adapt to the current code that we had utilizing the full capabilities and skills of each member that had experience with code development. This process continued until the code began to run better with each correction and optimization that was done by the members who worked on the specific programs. It was a continued effort that occurred over extensive amounts of time across multiple days. If the project code hadn't worked, we continued to try and work through it until it had begun to function properly.



We follow these steps to for debugging and system validation:-

1. Connect all components according to the wiring diagram in Section 7, with respect to the new PDB.
2. Verify requisite component power by observing expected results in Section 9.
    a. Verify connections between all components of the Power and Sensory systems. If any component is undetected, reseat with greater care.
3. Open Jetson Nano mapping program and ensure data can be visualized. Data that is output by the ToF sensor should come out as 3D Point Cloud.
    a. Determine accuracy of the generated ToF point cloud relative to terrain and environment.
    b. Measure the angle, height, and dimensions of all objects within the testing site as possible.
    c. Physically move the Sensory system around the test site. Are the characteristics of the site being accurately projected? Are the mission-critical considerations of height and angle measured accurately? Compare the measured vs. experimental data. If the data which is captured matches what is anticipated, the ToF sensor is functional.
4. The IMU functionality can be verified by running the output via a Python program which can communicate over UART. If it reacts to roll, pitch and yaw and displays nonzero values when the device is in linear motion, IMU is functional.
5. After verifying individual Sensory component functionality…
    a. Designate an arbitrary object within the point cloud to be the destination. Deliberately place NEW objects as necessary to ensure a complex simulated terrain.
    b. Allow the Robot to begin traversing the test site. Carefully observe the path chosen, if any. Carefully observe the handling of obstacles, if the Robot does at all.

The pass/fail condition is if the Robot successfully negotiates the test site AND arrives at the destination. To do so would require…

1. CPU to vary the motor subsystem outputs in real-time in response to Sensory subsystem data. This is proof of computational operation and communication with sensory equipment.
2. All requisite power adequately provided by the supply and PDB,

6 - Presentation of Project

Below is the YouTube link showing the project operating in its best-case mode.
https://www.youtube.com/watch?v=9g0WkaO5KS0

7- Cost and Scheduling Summary

The biggest issue that was found when purchasing materials from diverse suppliers for different materials for manufacturing it was approximately 200%-400% more expensive when purchasing 8020 Extrusion Beams from local San Diego Suppliers in comparison to McMaster Carr and was more convenient for our SSF advisor Craig Winton to do purchase orders through this company with fast shipping to arrive in less than 2 days to his office for pickup.

Another issue at the beginning of Spring Semester was the development of a fabricated robotic arm and implementation of an inverse kinematics system from the ground up would be in a sense a Senior Design Project in itself. Our team decided to move forward with purchasing a robotic arm from Elephant Robotics with the basic functionality needed for this project and collaboration between identical robotic arms with ease. The shipping of the material from this company took approximately 2 weeks to process and arrive at San Diego State University.

Table XX: Bill of Materials

Part/Subassembly/ Assembly	Part Number	Part Name	FAB/COTS	Supplier	Part Quantity	Total Cost ($)
Assembly	35-100	Frame Assembly	FAB			
Subassembly	35-100-100	8020 Extrusion Frame	FAB			
Part	35-100-100-101	Corner Bracket	COTS	Amazon	60	$104.97
Part	35-100-100-102	M6 Hex Socket Cap Screw Bolt	COTS	Amazon	120	$0.00
Part	35-100-100-103	M6 T-Slot Nut	COTS	Amazon	120	$0.00
Part	35-100-100-104	T-Slot Extrusion Beam 10 ft	FAB/COTS	Motion AI	3	$115.99

Part	35-100-100-104	T-Slot Extrusion Beam 4 inch	FAB/COTS	Motion AI	20	$0.00
Part	35-100-100-105	T-Slot Extrusion Beam 6 inch	FAB/COTS	Motion AI	4	$0.00
Part	35-100-100-106	T-Slot Extrusion Beam 12 inch	FAB/COTS	Motion AI	4	$0.00
Part	35-100-100-107	T-Slot Extrusion Beam 14 inch	FAB/COTS	Motion AI	2	$0.00
Part	35-100-100-108	T-Slot Extrusion Beam 22 inch	FAB/COTS	Motion AI	2	$0.00
Part	35-100-100-109	24” by 48” Poly-carbonate Sheet	FAB/COTS	Amazon	1	$85.99
Part	35-100-100-110	Internal Corner Brackets	COTS	Amazon	1	$28.00
Assembly	35-200	Suspension System	FAB			
Subassembly	35-200-100	Suspension				
Part	35-200-100-101	Coilover	COTS	ServoCity	4	$63.98
Part	35-200-100-102	Button Head 1/4-20 T-Slot Fastener	COTS	McMaster-Carr	24	$18.30
Part	35-200-100-103	Flat Head 1/4-20	COTS	McMaster-Carr	24	$36.84
Part	35-200-100-104	1-1/4" 18-8 Stainless Steel Hex Screw	COTS	McMaster-Carr	16	$5.83

Part	35-200-100-105	316 Stainless Steel Nylon Insert Locknut	COTS	McMaster-Carr	16	$13.13
Part	35-200-100-106	316 Stainless Steel Washer	COTS	McMaster-Carr	32	$4.11
Part	35-200-100-107	Heim Joint for Control Arm	COTS	McMaster-Carr	8	$53.76
Part	35-200-100-108	Lower Control Arm	FAB	McMaster-Carr	1	$53.38
Part	35-200-100-109	Motor Bracket	FAB	Gobilda	8	$63.92
Part	35-200-100-110	Lower Suspension Bracket	FAB	McMaster-Carr	8 pieces (0.75" x 1" x 0.75" x .125" Angle)	$3.83
Part	35-200-100-111	Upper Suspension Bracket	FAB	McMaster-Carr	8 pieces (0.75" x 1" x 0.75" x .125" Angle)	$7.66
Part	35-200-100-112	Control Arm Mount	FAB	McMaster-Carr	16 pieces (0.75" x 0.75" x 1" x .125" Angle)	$7.22
Assembly	35-300	Robotic Arm	COTS			
Subassembly	35-300-100	Arm Mechanism	COTS			
Part	35-300-100-101	MyCobot280	COTS	Elephant Robotics	1	$799.00
Part	35-300-100-102	Gripper	COTS	Amazon	1	$129.00

Assembly	35-400	Wheel Assembly	FAB			
Subassembly	35-400-100	Wheel				
Part	35-400-100-102	Wheel Rim	FAB	McMaster-Carr	8 Pieces	$242.82
Part	35-400-100-103	Springs	COTS	McMaster-Carr	16 Springs (5" Lg., 0.875" OD, 0.635" ID, 0.12" Wire Dia.)	$85.76
Part	35-400-100-104	Shaft Collar	COTS	Amazon	4	$50.94
Part	35-400-100-105	Rubber Wheel	COTS	Gobilda	4	$35.98
Part	35-400-100-106	Shaft	COTS	Gobilda	4	$11.98
Assembly	35-500	Electronics				
Subassembly	35-500-100	Electronic Housing				
Part	35-500-100-101	Electronics Container	COTS	Amazon	1 (10” x 7.9” x 3.1”)	$20.99
Part	35-500-100-102	Storage Container Mounting Plate	FAB/COTS	McMaster-Carr	2 pieces (3.125" x 12" x .125" Plate)	$40.47
Part	35-500-100-103	Cable Pass Through	COTS	McMaster-Carr	4	$15.28

Part	35-200-100-102	Button Head 1/4-20 T-Slot Fastener	COTS	McMaster-Carr	4	$3.05
Subassembly	35-500-200	Electronic Components				
Part	35-500-200-101	Batteries	COTS	Amazon	2	$69.98
Part	35-500-200-102	Arduino Mega	COTS	Amazon	1	$48.00
Part	35-500-200-103	LiDAR	COTS	SICK	1	$0.00
Part	35-500-200-104	Jetson Nano Kit	COTS	Amazon	1	$299.98
Part	35-500-200-105	AndyMark Motors 1-50.9	COTS	Amazon	4	$280
Part	35-500-200-106	Arduino UNO	COTS	Amazon	1	$30.00
Part	35-500-200-107	Motor Drivers	COTS	Amazon	4	$54.00
Part	35-500-200-108	Heat Sinks	COTS	Amazon	1	$7.99
Part	35-500-200-109	RealSense Camera	COTS	Amazon	1	$315.00
Part	35-500-200-110	VHB Tape	COTS	McMaster Carr	1	$32.15
Part	35-500-200-111	Tanstic 31 pcs	COTS	Amazon	1	$40.00
Part	35-500-200-112	Terminal Block Breakout Board	COTS	Amazon	1	$17.99
Part	35-500-200-113	Raspberry Pi Monitor	COTS	Amazon	1	$80.00

Part	35-500-200-114	12” x 12” Plexiglass	FAB	Amazon	1	$29.99
Part	35-500-200-115	Power Distribution Board	FAB	Amazon	1	$42.76
Part	35-500-200-116	Quick Disconnect Power Terminal	COTS	Amazon	1	$16.96
Part	35-500-200-117	256 GB MicroSD Card	COTS	Amazon	1	$24.99
Part	35-500-200-117	Push Button	COTS	Amazon	1	$12.99
Part	35-500-200-117	Wireless Antenna	COTS	Amazon	1	$21.99
Part	35-500-200-117	64 GB MicroSD Card	COTS	Amazon	1	$7.70
Part	35-500-200-118	Wireless HDMI	COTS	Amazon	1	$129.99
					Total	$7,523.00

Link to our TeamGantt page showing the completion status of your items

https://app.teamgantt.com/projects/gantt?ids=3210435

8- Senior Design Experience and Lessons Learned

Christopher Choo

1. Teaching before execution is important.
2. Sleep is optional
3. No matter how much you understand robotics, hardware drivers are out to spite you.
4. MEs and EEs are screwed if they don’t learn more about each others fields

During this project there were several big lessons which I learned. Overall the experience was more about how to build a technical team from the ground up and work with what you've got rather than how to achieve hyper-complex robotics systems. One aspect of technical oversight which I realized I needed to be more conscientious about was building context of the situation to other team members. Whether it was an electrical, software or mechanical issue, there were several moments where I identified a problem and only communicated the problem and potential solutions to solve it to the person who would then take ownership of the issue. However, I realized that some teams require more in-person collaborative time than others. I figured that in the past, I used to only communicate the problem and potential solutions to the person responsible for resolving it, without giving them the necessary background information or context for others on the team. This resulted in creating confusion and hindering collaboration outside of the context of a given engineering problem. In the future, I plan to be more mindful about building context and sharing information with the entire team, regardless of their role or expertise. Additionally, I acknowledged that different teams may have diverse communication needs, and some might require more in-person collaboration and discussion than others. In the instance of this team, I believe that there could have been significant learning opportunities from both the ECE and ME teams if work sessions were conducted together. By learning from these experiences, I feel better equipped to lead technical teams and achieve successful outcomes in future projects.

An interdisciplinary team consisting of both mechanical and electrical engineers is critical for success on a robotics team for several reasons.First, a robot is a complex system that requires both mechanical and electrical components to work together seamlessly. The mechanical components of a robot include the physical structure, motors, actuators, and sensors. The electrical components include the circuits, controllers, and software that enable the robot to move and perform tasks. Without the expertise of both mechanical and electrical engineers, a robotics team would struggle to design, build, and troubleshoot the system as a whole.Secondly, having an interdisciplinary team allows for a wider range of ideas and perspectives to be brought to the table. Electrical engineers can offer innovative solutions for control systems, software, and sensing, while mechanical engineers can optimize the design for weight, stability, and durability. By working together, the team can come up with more efficient and effective solutions that may not have been possible with a single discipline approach. There were several instances this semester where both ECE and ME teams were trying to solve a single issue in their own way, rather than putting their heads together and identifying the root cause of it. One of them was the problem we faced when the wheels were unable to rotate the robot properly. Finally, interdisciplinary collaboration can also foster creativity and innovation. Engineers from different disciplines bring their unique perspectives and knowledge to the table, which can lead to new ideas and breakthroughs. This can be particularly important in the field of robotics, where new technologies and applications are constantly emerging. Overall, an interdisciplinary mechanical and electrical engineering team is critical for success on a robotics team because it enables efficient and effective design, facilitates a wider range of ideas and perspectives, which is something that could have been more unified through senior design A and B.

I would also like to give an honorary mention to David Aw on my team. From the beginning of senior design A, I came to the understanding that him and I were completely different characters who often butted heads when it came to the approach of solving an engineering problem. I was of the thought train of “if you move fast and break things, you will find your best solution through learning” while David was one of “it will work this way or else”. This came across as off putting for some time since I rarely clash with others in my approach to both interpersonal or technical problem solving. However, the exercise of having to share the weight of driving the project forward lead me to realize that while brute force may not exercise the optimal solution 100% of the time, it is one of the greatest displays of scrutinous and meticulous problem solving. Since building this mutual understanding, our frequency of disagreement has not gone down, however our efficiency rate of generating solutions has risen to 100%. For this, I am thankful for David, as he has given me assurance that I, Chris Choo, am capable of working on a team with anyone of any engineering style :)

Uriel Zamorano

This substantial project that a tremendous amount of effort went into provided an experience truly like no other. Initially, the project in the beginning was a dream that we all shared and were able to design with the greatest amounts of ambition. Tackling these design ideas was the first step into embarking on the long journey that soon after became the SCAN robotics team. As the project scope started to narrow down and the team decided what components we will need to start working with, the project had officially begun. At first, I was unsure how to apply my skills to developing specific components and was checking in with different ECE members on how the development process was going and assisting where I was able to. Most of the components were handled by talented members of my team so my assistance though welcomed and present, was limited. I had continued this support role, where not only did I assist with physical components but also with the documentation and deliverable of the project, for the first half of the development phase of the project.

The second phase of the project was when I was starting to understand how to apply my knowledge and skills after observing my teammates and their approach to the typical issues that the development stage causes. Once the initial components started to function as they should and we had a basis for the first iteration of the project, we started to acquire more components. I was then able to start contributing directly to the project by having the responsibility of leading the development of a component. After being entrusted with this task, I had started to become comfortable with utilizing my skills and attempting the unknown through trial and error. I worked in a hybrid type environment where I was on my own on some occasions and with others in most situations which helped me learn and cultivate my skills and experience with real life components. Through this process, I have gained many late night stories that I consider to be defining of my time during Senior Design that it is difficult to pick just one. A typical night that most of the stories I have follow a pattern of working together with the ECE team, developing and debugging code for a specific component, and staying until either a small win was made or the exhaustion of staying past 3 a.m. led us to do unproductive work. One of my favorite nights was developing the object detection code with David as it had been constantly having problems cooperating with our project since the workload of running that feature had overwhelmed the Jetson Nano and caused an absurd amount of delay and lack of functionality. We had spent an ungodly amount of time doing trial and error to see what we could do to make it better and the night grew longer and longer with each mishap. The night originally started early but by the time it was 1 a.m. and it was looking like a defeated night. However, once we slowly started getting small wins with some features working as they intended we grew more inspiration to keep going. Suddenly 1 a.m. turned into 4 a.m. where we got excited with each little detail that performed better and better. The night ended with us bumbling out of the lab from exhaustion, excited and cheerful knowing that the project had advanced more than it has in the past with the object detection script. This is not even mentioning the other defining moments of learning such as developing the LiDAR device where it was an exciting goal to achieve at first, but we soon found out that despite how much time and effort was placed into its development, it was not going to collaborate with our system. Even though it was not incorporated into our system after designing it, the skills learned from attempting to is what made the experience invaluable.

It is possible to keep on elaborating on different stories and my learning experiences, however it would make this report ridiculously lengthy. While these few experiences are among the countless moments I had with each member of the team, each one of those moments taught me something valuable about what I know, how to apply it, and what I like and want out of my career in the field that I have chosen. The difference in growth between now and at the start of Senior Design is astronomical now that I understand myself and my interests relatively better. This process has truly been enriching to my field of knowledge, as well as my confidence in my ability to perform as a better engineer overall.

Shahad Al-Neesan

While working with my team on our senior design project, I learned many important things, and I gained valuable knowledge, skills and experience. When I worked with my team, all members shared each other's skills and knowledge to create solutions for the issue and reach our project's goals. Thus, I learned a lot of new skills from other members, and I became familiar with explaining and sharing my ideas to my team. Since our project is a joint project with Mechanical engineering, this gave me the opportunity to utilize and grow my programming and electronic skills with Mechanical engineering students to design and complete our project.

While working on this project, which is the robot that autonomously traverses over complex terrain consisting of geographical, physical, and angular obstacles to arrive at a user-defined target sample, I gained many skills. First, I learned how to control a DC motor and stepper motor using an Arduino board and different types of motor controller. For example, In the DC motor that we used in our robot, we used two factors which are speed and direction and we generated the PWM signal in Arduino. Second, I learned how to develop python code that detects the object and measures the distance of the object using a RealSense camera and Linux operating system. Third, I gained experience with installing the packages of the RealSense camera on a Jetson nano. Fourth, I learned how to interface Python IDE and an Arduino with PySerial by implementing python code that sends data that we got from a RealSense camera to Arduino to control the movement of the wheels and build the robot vision. Finally, I learned how important it is to determine the risks of the project at an early stage and try to overcome any risk that could damage the project at the final stages.

Shingo Morita

1. No overpromising
2. Communication
3. No Perfectionism

Throughout this project, I worked an average of over 12 hours a week. One valuable lesson I learned is the importance of managing expectations and not making unrealistic promises. Over-promising can lead to disappointment and frustration when we fail to deliver what we said we would. It's crucial to be honest and realistic about what we can deliver and set expectations accordingly. While it may not always seem exciting or ambitious, keeping expectations lower can prevent disappointment and build trust over time.

Another lesson I learned is the importance of effective communication to prevent misunderstandings. Misunderstandings can occur when communication breaks down or when one person assumes something that the other person does not. In our case, there was little communication between the ME and ECE teams, which resulted in the ME team making promises to the sponsor that ECE was not aware of. It's crucial to check in regularly with others to ensure we are on the same page and understand each other's needs and expectations. I found that having everyone present at least once every other week is the minimum requirement for a successful project when working in a large group.

To complete a project effectively and on time, it's essential to identify the minimum requirements early on. By focusing on the essential features, we can create a working prototype and refine it with additional features. Trying to make everything perfect at once can lead to analysis paralysis and prevent progress. It's important to prioritize the requirements and focus on the critical features first. By doing so, we can avoid overburdening ourselves with too many requirements and ensure that we are making progress towards completing the project. Ultimately, by identifying the minimum requirements and prioritizing effectively, we can complete the project in an organized and efficient manner.

The most valuable thing I learned from this experience was getting to know these four team members. I cannot thank my teammates enough for their efforts.

David Aw

Against my nature, I’ll keep this short. What a [expunged for professional reasons]show, but it's over now. In the miasma of deadlines, I let slip team organization and cohesion, which indicates the need to create a system that works better when I’m incapacitated from exhaustion. Should’ve kept meeting weekly into Semester B - hard loss of productivity that became almost impossible to recover from. Unachievable systems must be quickly and thoroughly explained to customers to be unachievable. For all the technical brilliance a team could emanate, it is no factor in project completion when compared to an ounce of good logistics. Start early, and don’t stop. Communicate, communicate, communicate.

I am convinced this specific project constituted a potential crime against humanity and should be investigated as such by the relevant authorities. Despite this, the Senior Design experience was the best time of my life - I’m ultimately sad it’s over. Through our determination and grit, we survived. I hope the results speak for themselves.