The FRCC Nostromo: Autonomous Rover vs. Sand, Everywhere

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Abstract

As part of the Colorado Robotics Challenge, our rover, the FRCC Nostromo, was designed to move across sandy terrain, detect and avoid objects, and move up an incline. The outer shell, based on the Xenomorphs from the movie *Alien,* was designed to not impede movement and add additional protection to the electronics inside the rover. Inspired by the Mars Exploration Rovers, we employed a rocker-bogie design to adapt to uneven terrain, which is achieved by the split axis that allows for all six wheels to be in contact with the ground. For object detection, the FRCC Nostromo uses a time-of-flight sensor, an Ultrasonic sensor, and an accelerometer. These in conjunction with the ESP-32 Wrover Board are responsible for pathing, detecting location in an XYZ plane, acceleration, and object avoidance.

Multiple tests were conducted to target these goals. Modular/incremental code testing was done individually to determine functionality. Batteries were tested by leaving the rover powered on for 4.5 hours. A sand test was conducted to see how the rover would fare, to which we encountered no issues with movement. The outer shell is easily removable and also shielding thanks to its bulkier design.

The FRCC Nostromo blends a fascination with aerospace and science fiction into a rover that showcases the rocker-bogie mechanism on a smaller scale, as well as the capabilities of technology that is readily accessible and affordable. By replicating facets of the Mars Rover technology, we created a design that integrates sensors and mechanics, adapts to its environment, and uses data to make decisions.

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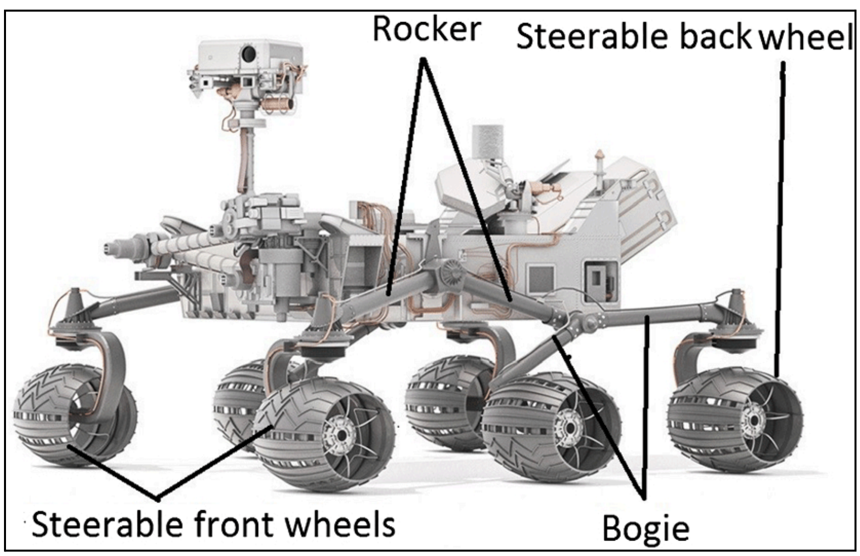
Introduction

Inspirations & Previous Research

The FRCC Nostromo in its final design was inspired by the Mars Exploration Rovers, specifically for the rocker-bogie mechanism. As an autonomous rover, its main tasks are to path, detect objects to avoid, and gather research. Covering a large area of ground without getting stuck in debris was imperative to this task. The FRCC Nostromo replicated this on a smaller scale in the Great Sand Dunes, built with the intention of completing an obstacle course without becoming stuck.

The Mars Exploration Rovers use a rocker-bogie mechanism, which is a suspension system that "rocks" in order to maximize surface contact. This mechanism generally features three wheels on either side, with a smaller fringe that attaches at a hinge. The chassis was easier to keep level and could adapt to terrain in this way. The courses for the Colorado Space Grant Consortium were on sand with a variety of obstacles in the way, obstacles that the rocker-bogie easily maneuvered with its suspension.

Figure 1.1: NASA Curiosity Rover Rocker-Bogie Suspension System[1]



[1]Tarkoh, M. (2020, September 1). A unified kinematics modeling, optimization and control of universal robots: from serial and parallel manipulators to walking, rolling and hybrid robots [Review of A unified kinematics modeling, optimization and control of universal robots: from serial and parallel manipulators to walking, rolling and hybrid robots]. Research Gate. https://www.researchgate.net/figure/NASAs-Curiosity-Mars-rover-showing-passive-components-rocker-and-bogie-and-actuated_fig1_342942937

In terms of aesthetics, the FRCC Nostromo took inspiration from the movie *Alien* (Scott, 1979)[2] and the xenomorph antagonist. The sleek design of the xenomorph was used in designing an "exoskeleton" to both have the rover stand out in terms of its design, while also encasing the internal electronics and shielding them from the sand.

Figure 1.2: Initial Exoskeleton Sketch

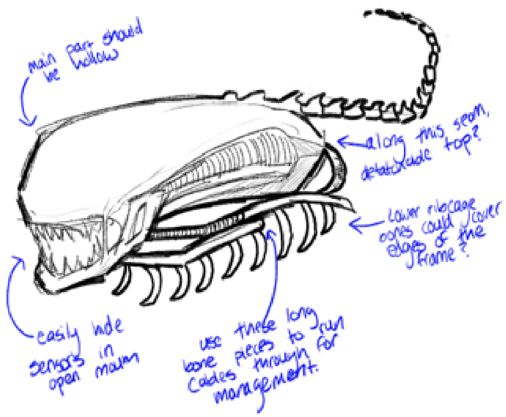


Figure 1.3: Exoskeleton & Rocker-Bogie

Goals & Initial Concerns

The FRCC Nostromo's overall objective was to autonomously move across rough terrain. Specific goals for the initial planning stage were:

1. Obstacle avoidance and object pathing.
2. Use real-time calculations to adjust for dynamic conditions.
3. Avoid sand incursion.
4. Successfully climb over an incline.
5. Engineer a method to become unstuck.

Several concerns were immediately evident in this initial stage, with the primary one being difficulty with team members being able to meet in person. The Front Range Community College team is spread across all three campuses in Fort Collins, Boulder, and Westminster. For efficiency, the team met in-person and online every other week, and delegated different aspects of system coding to each team member.

[2] Alien Movie: Scott, R. (1979). Alien. Twentieth Century Fox.

Methods & Materials

Materials List

The FRCC Nostromo was designed with a $500 budget, using easily accessible materials that could be experimented with and adapted to overcome the inevitable challenges it would face in testing. The total expense came to be **$316.27.** A complete list of parts includes:

1. ESP32 Wrover Board
2. Time-of-flight Sensor (ToF)
3. Ultrasonic Sensor
4. LI3DH Triple-Axis Accelerometer
5. LIS3MDL Compass
6. PLA Filament
7. 3.7 Volt Batteries
8. Battery holder
9. 2 Pc L298N Motor Driver Controller Board
10. 4pc 9g Servos
11. 8pc Gearbox Motors
12. Tank treads
13. Wheels from a chassis kit
14. QWIIC & Dupont Cables
15. Loctite Spray Foam
16. Triple-axis Magnetometer

GitHub & Visual Studio Code

The primary languages used for coding the rover were C and C++, and GitHub was used to store code, edit, and collaborate. GitHub was an essential part of the team's process with the varied, remote locations of team members. Visual Studio Code was used to write the bulk of the code, using the extension Platform.io to integrate between the platform and the Git repository.

Two GitHub repositories were used: a general repository for storing each section of code, as well as an integration repository to stitch the code together for the final product. The general repository was split into Mechanical and Sensor code sections, with preliminary testing folders for future integration. The integration repository was edited manually, taking sections of code piece-by-piece in order to fully combine each subsystem. GitHub was selected for this process due to its accessibility, code-storing functions, open-source code to borrow, editing capabilities, and significance as an industry standard.

Role of Mentors & Makerspaces

The team's various mentors, and designated makerspace, were intrinsic to the development process of the Nostromo. Scott Stricker, a retired Principal Servo Engineer at Seagate Technologies, was often a great sounding board for ideas, leading the team to think more critically about the rover plans as well as our plans of action. The team's other industry mentor, David Stearns, was on the board of directors at Tinkermill, the makerspace the team spent the bulk of their time. Tinkermill is a non-profit charity with several workshops available to members, with a large variety of tools and machines not typically available outside of commercial use. Tinkermill ended up being a pivotal meeting place for the Front Range Community College team, utilizing its meeting spaces and tools to craft elements of the final rover. For GitHub, Tom Voth, a Systems Architect at Mobile Accord, taught the team how to use the software, explained the function of repositories and troubleshooting, which was key for all elements that were completed remotely, away from fellow team members.

Process & Testing

Conceptual Design: Early Build

The original plan for the device was centered around the rocker-bogie suspension system. Original planning featured tank treads on the "rocker" section of the suspension. Initially, the team had planned to include tank treads with the idea of maximizing contact with the ground and preventing individual wheels from getting stuck in holes. This part of the phase used a pre-built RC chassis in order to determine wheel and rocker-bogie functionality.

Figure 2.1: Tank Tread Rocker-Bogie

Initial sand testing with the tank treads proved to be troublesome. The treads, while efficient in distributing weight and surface contact, struggled to function alongside the regular back wheels. The treads provided too much traction and caused the back wheels to dig deeper into the sand. The treads were swapped for regular tire wheels from the chassis kit, which were tested on sand, and did not encounter problems with dynamic movement, inclines, or obstacles. With the treads, only four motors were used, and six were needed for the wheels. In order to handle the power of the extra two motors, an extra motor driver was needed. Each channel on one motor driver could handle the current needed to run two motors, but could not handle three. The addition of a motor driver allowed for splitting the motors, one motor driver per side, three per motor driver, with one on one channel and two on the other channel.

With a suspension system selected and the decision not to use the tracks, priorities shifted to the internal mechanisms of the rover. An ESP32 Wrover board was selected for its available RAM, storage, and affordability, as well as compatibility with the chassis kit. Sensor-wise, the FRCC Nostromo uses an ultrasonic sensor, a time-of-flight (ToF) sensor, a magnetometer, and an accelerometer. During part selection, the team was interested in choosing a sensor that would efficiently get a view of a scene and intelligently select a path to navigate around several obstacles simultaneously. This led to considering both Lidar and ToF as the top options. The team chose a ToF sensor for its cost and complexity. At this point in the project, a grid of distance values could be obtained from the sensor, so the team moved on to working on interpreting that data. Many issues started to occur that would remain until the completion of the project. The time-of-flight sensor had integral flaws due to its design which the team was not knowledgeable enough at that point to resolve.

Preliminary Design: Subsystem Expectations & Interactions

Sensors needed to be able to detect and signal objects, detect position in an XYZ plane, and accurately avoid obstacles. With other subsystems, the sensor and movement codes should not impede on the other, and the design of the robot should support placement of physical sensors.

For movement, all wheels needed to be capable of turning and redirecting, moving forward and backward, navigating around obstacles, and avoiding being impeded by the uneven terrain. Code needed to reflect the output of the demands. With other subsystems, the design was required to support efficient movement, and the motors needed to be powerful enough to fulfill movement. This required two motors on left side and two motors on the right, with each side working independently.

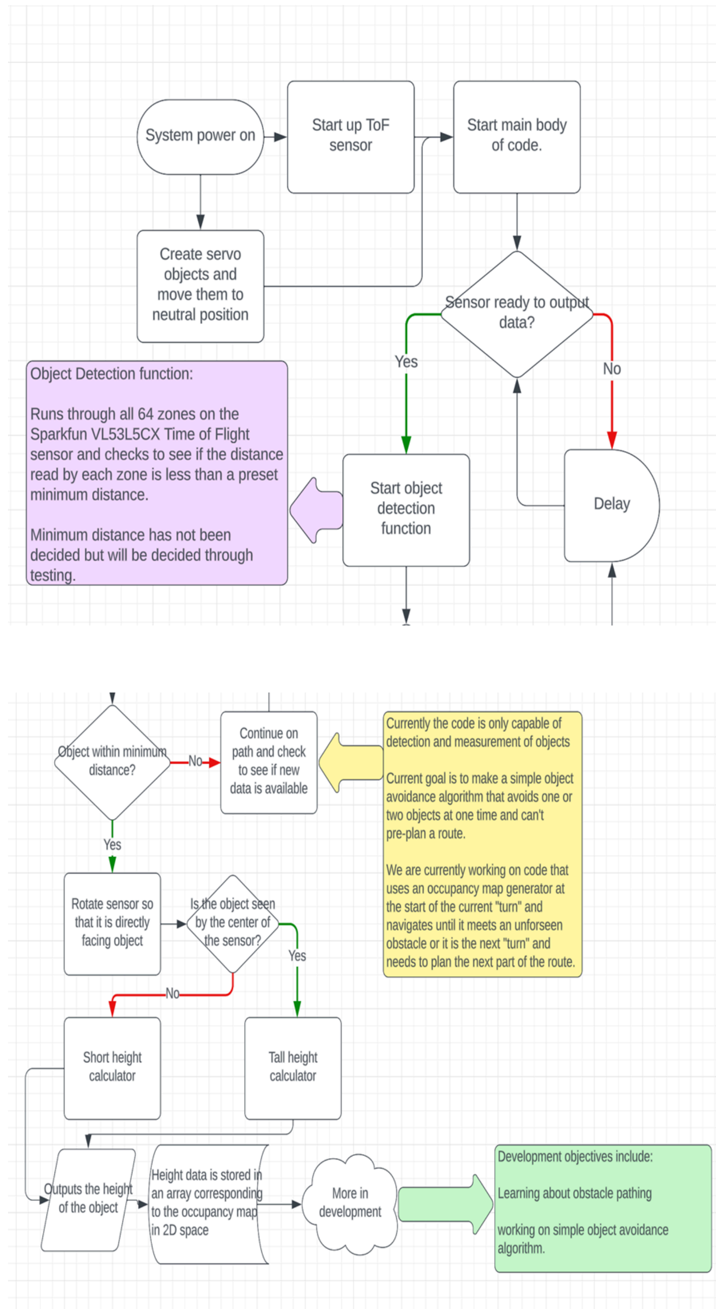
Electronics and power needed to be able to sustain power to all parts of the robot as it completed its course without running out of battery, electronics should be compatible with one another, batteries should be easy to replace. With other subsystems, power was required to support each area while also being protected within the design.

The design should keep sand out of the electronics, be lightweight, be able to maneuver in an uneven environment, and allow easy access to interior components for fixes/crisis management. The design must not impede on the function of the subsystems, but instead, should support them.

Preliminary Design: Subsystem Testing

General testing occurred at each step of the preliminary design phase, by running code off the ESP32 board and obtaining data for the various subsystems. In testing the power, the rover batteries (which were not fully charged) ran for nearly 4.5 hours before powering off. The power was determined to be sufficient for the demand. More movement tests were conducted on sand that was in a creek bed with small rocks and hills. While manually controlled, the wheels and motors were efficient at rolling over the debris and moving up an incline. Around this point in the project, the object recognition code was advanced enough to be able to recognize objects and measure their height. This was done by using the full view of the ToF sensor to detect an object within distance and use the center of the sensor to measure its height using some complex trigonometry and precise servo movement. Though this code was later discarded for a different methodology to better utilize the ToF with the team's skill set, it was intended to use the measured heights to differentiate between objects within the ToF's view and navigate around them using a pre-planned path. At this point in the project, the team was still using an electronics kit that used the control board for any testing and used an already written piece of movement code that used remote user inputs instead of autonomous navigation.

Figure 3.1: Block Diagrams



Interim: Mechanics & Exoskeleton

Having moved from the treads to wheels, the rocker-bogie suspension was adapted for a base-plate box, with the idea of encasing the box with a xenomorph outer shell/exoskeleton. The ultrasonic sensor would hang from the base plate to sense obstacles up close, with the time-of-flight sensor either mounted to the exoskeleton or protruding from the mouth. The legs, plate, and box were all 3D-printed. The box provided adequate space for all of the internal electronics, as well as keeping everything safe from the elements.

Figure 4.1: 3D Model

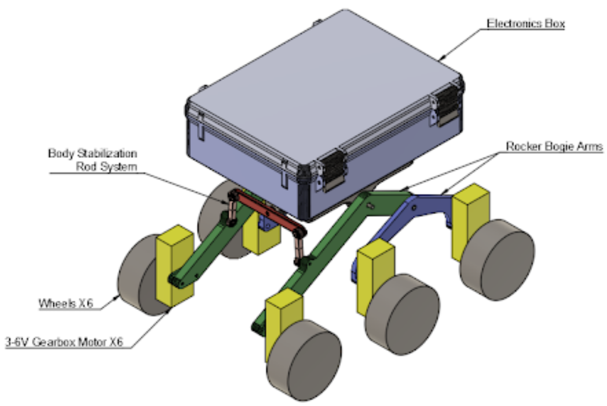
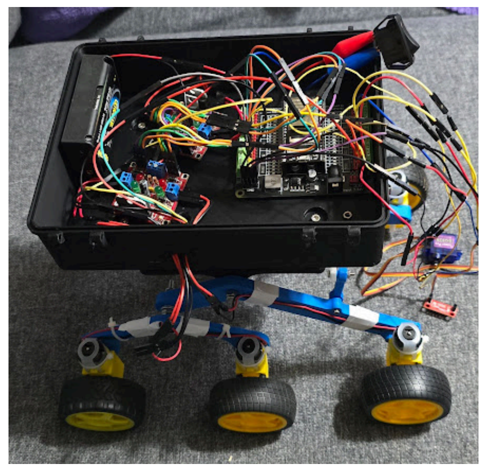
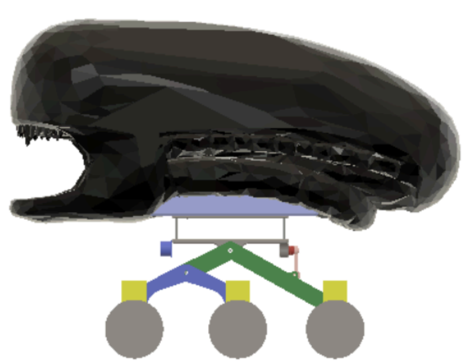


Figure 4.2: FRCC Nostromo *Beta*



For the xenomorph exoskeleton, the team first used spray foam as a means of creating a base that would later be scanned and adapted as a 3D model, with the intention of printing it later. The foam was allowed to solidify over a sample electronics box, then was sanded down with a rotary tool to form a general shape. Fusion 360 was used to add decorative elements such as teeth, and refine the rough shape of the foam.

Figure 4.3: 3D Model of Xenomorph Exoskeleton



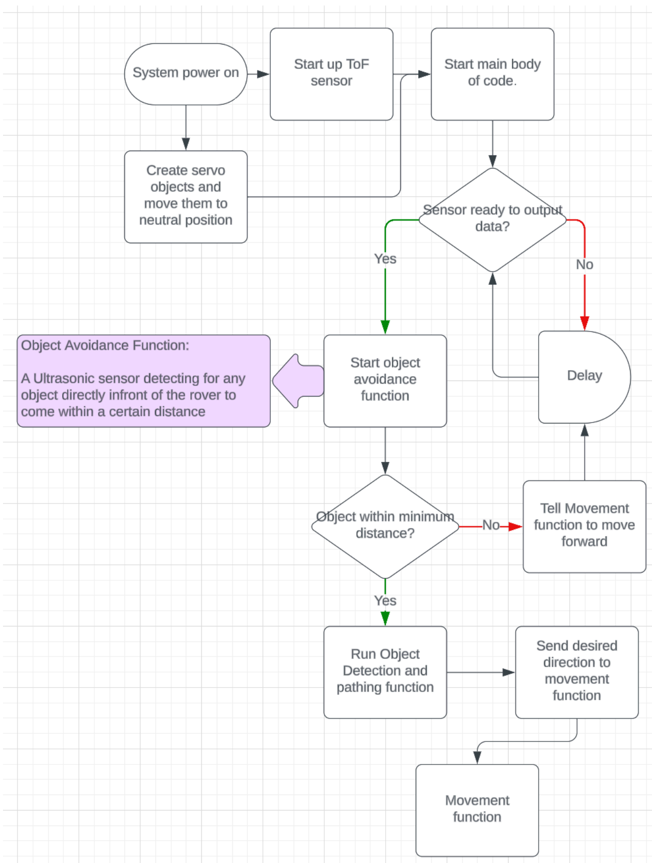
Critical Design: Integration Testing

Integration testing began by removing the RC chassis from the rocker-bogie suspension system and replacing it with a box containing the wired-up ESP-32 and motor drivers. The code to move the rover was loaded and movement was controlled via serial communication with the ESP-32 and a laptop. Once that was successful, integration of the accelerometer began.

The initial plan with the accelerometer was for it to control turns. During integration testing, it was found that the Nostromo could not do that reliably. To test the accelerometer, the rover was placed on a turntable that had been marked at every 45 degrees between 0 and 360. The turntable was lined up with a mark on the table and then turned to each 45-degree mark and data from the accelerometer was recorded. The accelerometer would return a certain range of values for each direction it faced, but there were values for each direction that overlapped with the directions next to them. This made it impossible to stop turning facing the correct direction. Though this did not help make turns, the accelerometer was still used to determine if all movement had ceased and turn off the motors. Collisions caused additional movement issues, so an ultrasonic sensor was added for crash avoidance.

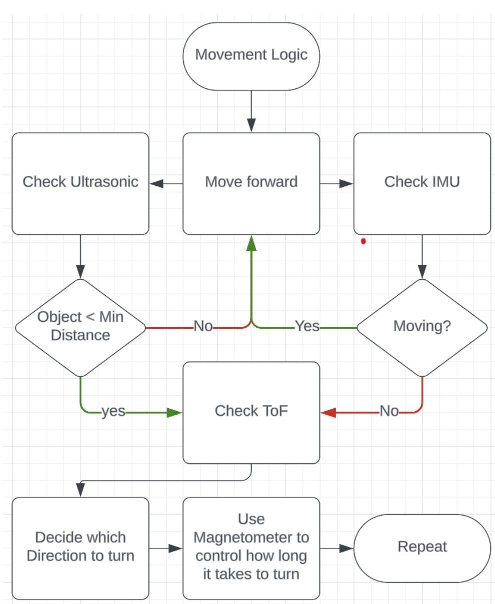
The next step in integration was to find a new plan for turning the rover. Initially, timed turns were to be used, even though they could be highly inaccurate due to sand and debris interference. In discussion with the team's advisor, David Stearns, it was suggested looking into a compass type sensor to avoid the inaccuracy of timed turns. The team tested and integrated the magnetometer which provided a successful solution to the turning problem. Testing was done by using serial communication to tell the rover which way to turn. The last problem to overcome, and integrate, was determining how the rover knew which way to turn. For that, a plan to use the time-of-flight sensor for path planning was developed.

Figure 5.1: Time of Flight Loop Code



Long before integration, the team intently focused on the ToF sensor and path planning. The first obstacle to overcome was the temperamental ToF sensor. The sensor would not write a new value to any zone unless it received a significantly different new value in that zone. This could be resolved by aiming the ToF at a very close plane to reset all zone values and then reorienting to take measurements of the scene in front of the rover. After this was resolved, code was finally integrated. The adjacent diagram is the loop that the code follows. Compared to earlier code, it heavily simplified the entire code logic, including movement function. Both of the normal code loops called on each other at different points and work together. This was fulfilled by heavily segmenting the code into functions that the loop in Arduino code format can call at different times.

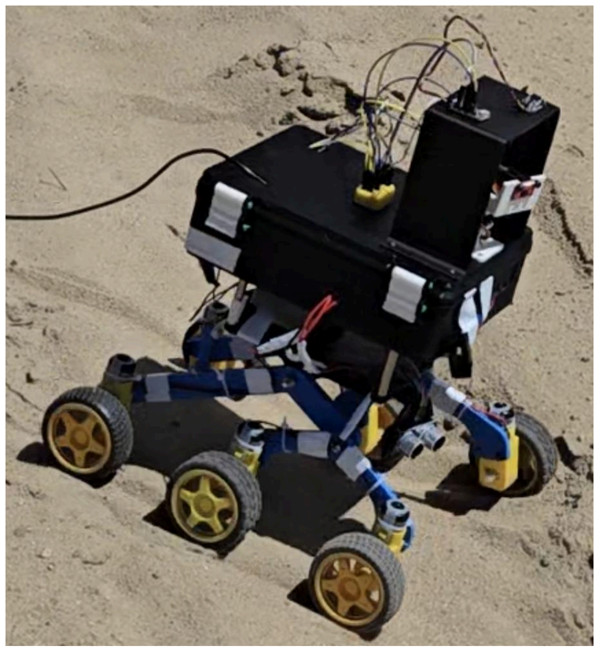
Figure 5.2: Movement Logic



The movement function repeatedly wanted to move forward while simultaneously querying the ultrasonic sensor and accelerometer to check if the rover had come close to an object in front of it or if it had gotten stuck. Then the ToF decided which direction to go and cued the movement forward until another object was detected or the rover got stuck. This is illustrated in detail in the adjacent block diagram.

Unfortunately, the xenomorph head was discovered to be too heavy and large for the rocker-bogie suspension. The team made the decision to have the xenomorph head be purely decorative, then removed once on the Sand Dunes for the Robotics Challenge. As the xenomorph head was going to be the close proximity plane to reset the ToF values, the team designed a cover to screw onto the top of the electronics box with the ToF servo mount located under it. This cover also helped to position the accelerometer and magnetometer far away enough from the batteries to prevent interference from electrical noise.

Figure 5.3: Final Design Without Xenomorph Exoskeleton



At this point, two versions of the Front Range Nostromo were being tested: the beta version and the final version. Upon arrival to the Sand Dunes, discrepancies were noticed between the beta and the final rovers wherein the beta was moving and detecting objects, while the final rover was not. Both rovers utilized the exact same code, and the team interchanged parts to test functionality. The team determined there were two main reasons for the dysfunction. The first was that the team did not have exactly identical motor drivers. They were both L298 motor drivers, but different brands and ages. The beta had significantly older motor drivers that were able to handle 2.5 amps per channel continuously, and up to three amps at peak. The final design's motor drivers could only handle two amps at peak. The second reason is that the FRCC Nostromo had four batteries hooked up to the motor drivers and the Beta only had two.This was supplying the motor drivers with nearly double the voltage and the motors were able to draw significantly more current than the motor drivers were rated for. Because of this, the FRCC Nostromo Beta was used at the Robotics Challenge.

Results & Conclusion

The Robotics Challenge

The FRCC Nostromo successfully completed three of the five test courses: Course One (progressing over sand, no obstacles), Course Two (navigating with stones and holes), and Course Three (navigating larger stones and ditches). The rover quickly drove over Course One with surprising speed, handling the sand without issue.

Course Two provided the first level of difficulty, with the rover failing its first run after hitting a barrier, then later getting stuck in sand and not moving one side of the motors. Swapping out the old batteries and replacing the immobile motor side fixed the problem. The rover went down the course, swerving to the other side and coasting alongside the barrier, before righting itself and navigating the rest without further issue.

Completing Course Three took the greatest amount of trial and error. Previous sand tests did not use large enough rocks to test the sensors. Several times, the rover either buried itself in the sand due to incursion with the motors, or got stuck on obstacles with the ultrasonic being as low as it was. Motors were cleaned, swapped out, and the ultrasonic was lifted. The speed of the rover was also reduced, as it was too fast for the sensors. After these fixes, the rover still was unable to complete the course, and the team realized its problem was with its ability to turn left and right. This was fixed by angling the time-of-flight more towards the ground which enabled it to see things closer to it. The team also lengthened the qualifying distance to detect an object. That means that items that were further away were getting counted as objects instead of being ignored. After many attempts and haphazard solutions, the rover finally navigated down the course and completed the third part of the challenge.

The FRCC Nostromo attempted the remaining courses, (climbing & navigating even larger obstacles), but failed. Despite that, and with a total of three challenges completed, the FRCC Nostromo managed to hit the majority of its target goals: pathing, real-time calculations, and becoming unstuck.

Discussion & Applications

The Front Range Community College team determined that the main reasons for the Nostromo's difficulty on the completed courses and inability to complete the more challenging ones lay mostly in design. While fixes to code and pathing are likely needed, with proper motors and wheels the Nostromo could have likely finished the later courses. The motors themselves were too weak to propel the rover, and ended up burying it further in the sand once it began to struggle on an incline. Additionally, the motors were too exposed and were frequently slowed down by sand. The wheels, despite their ease at traversing across sand, were too small and often could not roll over debris. Larger wheels and better tires could have smoothed out the process. The ultrasonic positioning needed to be higher to avoid hitting debris, and the time-of-flight needed to be lower to the ground. At its height, it was not completely efficient at navigating and pathing.

Despite these complications, the FRCC Nostromo is still a successful rover, and provided an inexperienced team a wealth of opportunity to learn and adapt to unexpected dilemmas. The Front Range team lost members, traveled frequently, and struggled with many problems remotely without having team members assist with troubleshooting. The team also gained hands-on experience with electrical engineering, mechanical engineering, and using industry standards such as GitHub and Visual Studio Code.

There is additional value in the accessibility of the Robotics Challenge, with all of it being completed locally and well under budget. The use of local makerspaces like Tinkermill, and access to experienced mentors willing to share their time, aided an enriching, small-scale investigation and experiment on how NASA's Mars Explorations function.

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Tarkoh, M. (2020, September 1). *A unified kinematics modeling, optimization and control of universal robots: from serial and parallel manipulators to walking, rolling and hybrid robots*. Research Gate. https://www.researchgate.net/figure/NASAs-Curiosity-Mars-rover-showing-passive-components-rocker-and-bogie-and-actuated_fig1_342942937