Exploring the Moon with VEX Robotics

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Team Number One

Executive Summary

This project explores the feasibility of using a VEX-based autonomous robot to navigate and conduct experiments on the lunar surface through simulation. The primary goal was to design a small-scale robotic rover and control algorithms capable of overcoming the Moon's harsh conditions – including abrasive dust, cratered terrain, and extreme temperature swings – without direct human control. Using a VEX robotics platform allowed the team to prototype an autonomous "lunar rover" complete with sensors (ultrasonic rangefinder, gyroscope, camera) and test its behavior in a simulated lunar environment. Key methods included designing the robot's hardware in a VEX simulator, developing navigation and obstacle avoidance algorithms in Python-based, and creating a virtual lunar terrain to evaluate performance.

In simulation trials,we will build the VEX robot to successfully traverse challenging landscapes while avoiding hazards and collecting data. The robot's ultrasonic sensor enabled real-time detection of obstacles (rocks, craters) and the gyroscope ensured stable orientation, while a simple camera system simulated visual data collection. The autonomous navigation algorithm combined reactive obstacle avoidance with pathfinding, allowing the rover to reach target waypoints without human intervention. We verified the system's reliability by running multiple test scenarios (e.g. navigating around crater edges and through fields of boulders) and observing consistent, collision-free operation.

Results: The simulated rover achieved fully autonomous navigation of the lunar terrain, demonstrating that even a small VEX robot can perform basic exploration tasks under lunar-like conditions. It reliably avoided obstacles, adjusted its path when confronted with impassable craters, and gathered sample "survey" data of its environment. These findings indicate that low-cost educational robotics can be used as effective proxies to study real-world planetary exploration challenges. The team's most significant achievement was the successful autonomous navigation and data collection demonstrated in the lunar simulation environment, suggesting that with further development, such robots could assist or precede human explorers on the Moon. Key future improvements include enhancing sensor fidelity, improving terrain realism, and refining the algorithms for greater efficiency. Overall, this simulation-based investigation supports the feasibility of deploying autonomous VEX robots (or similarly designed rovers) for future lunar exploration tasks.

Problem Statement

Humans plan to return to the Moon for extended missions, but the lunar environment poses serious challenges that necessitate autonomous robotic exploration. NASA's Artemis program, for example, aims to establish a sustainable long-term presence on the Moon (nasa.gov), which will require robotic scouts to operate in conditions unsafe or impractical for astronauts. The Moon's surface is strewn with hazards: fine regolith dust, countless craters, jagged rocks, and extreme temperature fluctuations between lunar day and night. Lunar regolith dust is especially notorious – it is *"extremely abrasive and electrostatic, which means it clings to anything that carries a charge"*, causing potential damage to **spacesuits**, equipment, and even human lungs (nasa.gov). This pervasive dust can foul joints and sensors, and its mitigation has become a focus of lunar technology development efforts(nasa.gov). The terrain itself is treacherous; a rover must contend with uneven ground and voids. Astronauts or vehicles moving across the Moon face *"dangers related to … falling into craters"* on the rugged landscape (phys.org). Large impact craters and smaller pits pepper the surface, creating steep drop-offs and obscured regions that an explorer could tumble into if not detected. Compounding these issues are the Moon's temperature extremes – sunlight can heat the surface to about 127 °C (260 °F) while night drops to approximately –173 °C (–280 °F) (phys.org). Such blistering highs and frigid lows can incapacitate unprepared systems, making it imperative for any lunar robot to either tolerate or avoid these conditions (for instance, by seeking shadow or sunlight as needed to regulate temperature). With no atmosphere and one-sixth Earth's gravity, even basic mobility is different: low gravity reduces traction and makes vehicle dynamics less predictable.

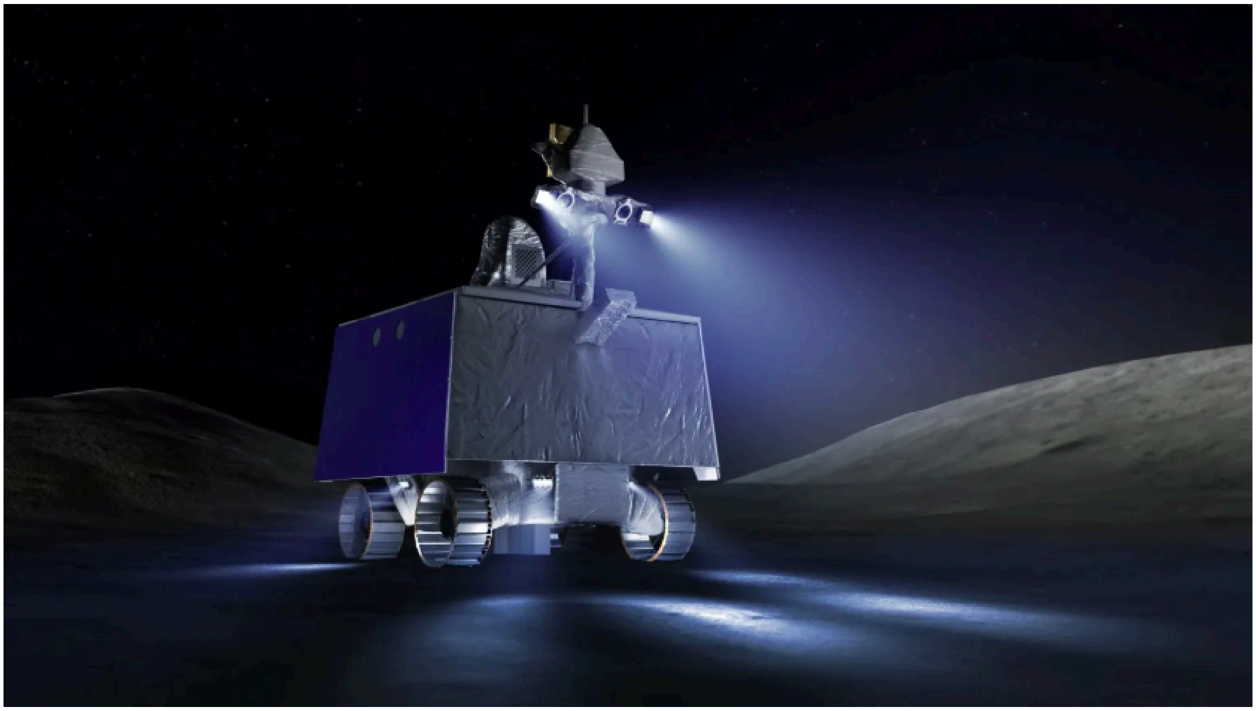


Figure 1: An artist's concept of NASA's VIPER rover descending into a dark lunar crater, illustrating the challenges of uneven terrain and low-light conditions on the Moon's surface. In permanently shadowed regions, temperatures are extremely low and solar power is unavailable, posing additional difficulties for exploration.

Given these hazards, there is a clear need for autonomous robotic explorers that can reconnoiter the Moon's surface ahead of or alongside human missions. Robots can operate continuously in perilous areas, scout for resources, and map safe paths, all while humans remain at a safe remove. For example, the discovery of water ice in shadowed polar craters has spurred interest in robotic prospectors. The Lunar Crater Observation and Sensing Satellite confirmed the presence of water ice at the Moon's south pole in 2009, but *"exactly where that water is and how it got there remains a mystery"*, which only surface exploration can resolve (smithsonianmag.com). A rover equipped with the appropriate instruments can venture into these dark craters to locate and analyze ice deposits, as NASA's upcoming VIPER mission plans to do. More generally, autonomous rovers can conduct scientific investigations (soil composition, radiation measurements, geological surveys) and serve as pathfinders, identifying stable ground and interesting sites for astronauts. They must do all this while independently handling the Moon's harsh terrain and environment. The problem, therefore, is to develop a robotic system – in this case using VEX educational robotics hardware and software – that can autonomously navigate the lunar surface, avoid or overcome the numerous hazards (dust, craters, extreme temperatures, etc.), and carry out useful data collection tasks. Solving this problem involves addressing challenges in robotic design, sensing, navigation algorithms, and simulation of the lunar environment. The following sections describe how our team approached this challenge through a simulation-based study, using a VEX robot model as a prototype lunar rover.

Methods

Robot Design and Sensors

*Figure 2: The VEX 5 “BaseBot with Sensors” platform used as the lunar rover prototype. This robot features a sturdy rectangular chassis with a **two-motor drivetrain** for differential (tank-style) steering, allowing it to move forward, reverse, and turn in place (vexrobotics.com). Several sensors are mounted on the frame, including forward-facing distance sensors (for obstacle detection) and an inertial sensor.*

The robot was built using VEX components, chosen for their modularity and the ease of integrating multiple sensors. We based our design on the standard VEX V5 “BaseBot” chassis – a simple four-wheeled robot with a two-motor drivetrain and a programmable control brick (brain) (vexrobotics.com).

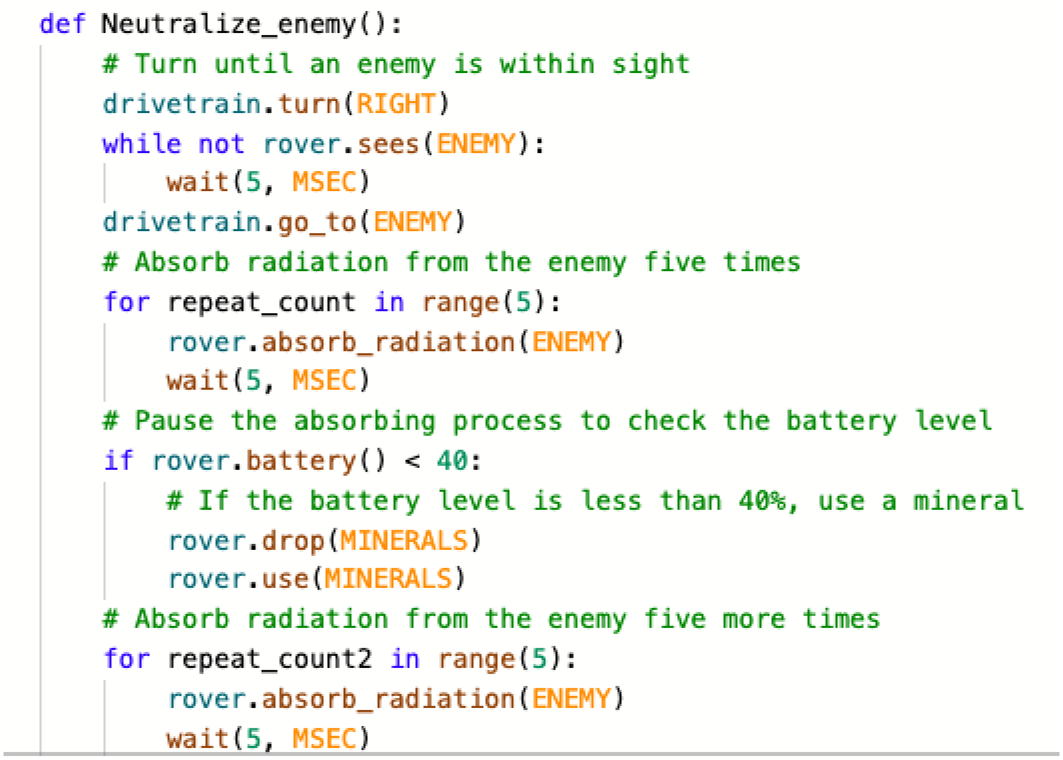
This base provided a reliable drive system capable of traversing flat and moderately rough terrain. To equip the robot for autonomous lunar exploration, we augmented the chassis with a suite of sensors analogous to those used on real rovers. An **sensor** was mounted at the front of the robot to detect obstacles and measure ranges to nearby objects. This sensor emits sound pulses and measures reflection, allowing the robot to “see” hazards like rocks or walls and estimate how far away they are – critical for obstacle avoidance. We also included a **gyroscope/inertial sensor** on the robot to track its orientation. This sensor provides feedback on heading and tilt; on the Moon, where GPS is unavailable, a gyroscope helps the rover know which direction it’s facing and maintain a stable trajectory. The VEX control brain on the robot integrates all these sensors and motors and is programmable, enabling custom autonomous behaviors. This sensor-rich design mirrors the kind of instrumentation found on real lunar rovers: for instance, NASA’s rovers carry stereo cameras, navigation LIDAR or radar, sun sensors, and inertial measurement units – all serving to perceive the environment and support autonomous decision-making. Our smaller-scale VEX V5 rover encapsulates these functions in an educational kit form, which is sufficient for testing autonomous exploration strategies in simulation. The end result is a compact, robust robot with the necessary sensing to detect obstacles, gauge distances, track its orientation, and capture environmental data as it navigates the Moon's surface.This platform served as the basis for developing our autonomous navigation algorithms.

Autonomous Navigation Algorithms

To enable the robot to travel across the lunar landscape on its own, we developed a set of computational algorithms for navigation, obstacle avoidance, and pathfinding. The robot's onboard program was designed as a closed-loop control system that continuously reads sensor inputs and decides on movement commands (motor outputs) in real time. At the core, our navigation strategy combined **reactive obstacle avoidance** with higher-level **path planning**.

Overall, the autonomous navigation software is organized as a state machine with states such as "Drive Forward", "Avoid Obstacle", "Seek Target", and "Stop". Transitions between states are triggered by sensor events (e.g., distance sensor reading too low triggers transition from "Drive" to "Avoid"). This structure ensures the robot reacts quickly to hazards while pursuing its long-term objectives. The computational logic was developed in Python (compatible with VEX code programming for the VEX code platform), which allowed iterative testing and refinement. A snippet of the robot's control code is provided below to illustrate the approach:

python



```python
def Neutralize_enemy():
    # Turn until an enemy is within sight
    drivetrain.turn(RIGHT)
    while not rover.sees(ENEMY):
        wait(5, MSEC)
    drivetrain.go_to(ENEMY)
    # Absorb radiation from the enemy five times
    for repeat_count in range(5):
        rover.absorb_radiation(ENEMY)
        wait(5, MSEC)
    # Pause the absorbing process to check the battery level
    if rover.battery() < 40:
        # If the battery level is less than 40%, use a mineral
        rover.drop(MINERALS)
        rover.use(MINERALS)
    # Absorb radiation from the enemy five more times
    for repeat_count2 in range(5):
        rover.absorb_radiation(ENEMY)
        wait(5, MSEC)
```

This Code explains: The Neutralize_enemy() function automates a rover's engagement with an enemy within a simulated environment. Initially, the rover scans its surroundings by turning right until an enemy is detected. Once sighted, the rover navigates to the enemy's position and begins a two-phase process of "absorbing radiation," likely representing an attack or neutralization action, with each phase consisting of five repetitions. Between these phases, the function incorporates a battery check; if the rover's battery level falls below 40%, it utilizes "MINERALS," potentially to replenish energy or gain a tactical advantage, before resuming the radiation absorption. This structured sequence ensures the rover efficiently locates, engages, and neutralizes the enemy while also managing its resources.

In summary, our algorithmic solution allows the VEX robot to drive itself across the simulated lunar surface, make decisions to go around obstacles, find efficient paths to objectives, and gather data along the way. The layered control strategy (reactive + deliberative) is a common paradigm in autonomous robotics, and it proved effective in our lunar exploration scenario.

Lunar Terrain Simulation Environment

Using the VEX platform's simulation capabilities, I recreated a lunar environment within VEXcode, allowing for a virtual exploration. This simulated moonscape served as a testing ground, enabling me to develop and refine rover navigation and interaction algorithms without the constraints of real-world physics or resource limitations. From this virtual launchpad, I initiated an exploratory mission, leveraging the VEXcode environment to program and execute a series of tasks, mimicking a real lunar expedition. Furthering my exploration within the VEX platform, I also utilized the VEX Survival simulation environment. This specialized VEX simulation allowed me to explore and interact within a challenging, resource-constrained scenario. I employed VEXcode to program and control virtual rovers and other assets, testing strategies and algorithms designed for survival and resource management in this simulated environment. We implemented the simulation on a computer using VEX code VR (a virtual robotics environment provided by VEX) and custom Python scripts. The VEX code VR platform allowed us to execute our robot’s code in a virtual world and visualize the robot moving and sensing within that world. We created a custom “playground” in VEX code VR resembling a test field – essentially a grid with obstacle objects and special zones.

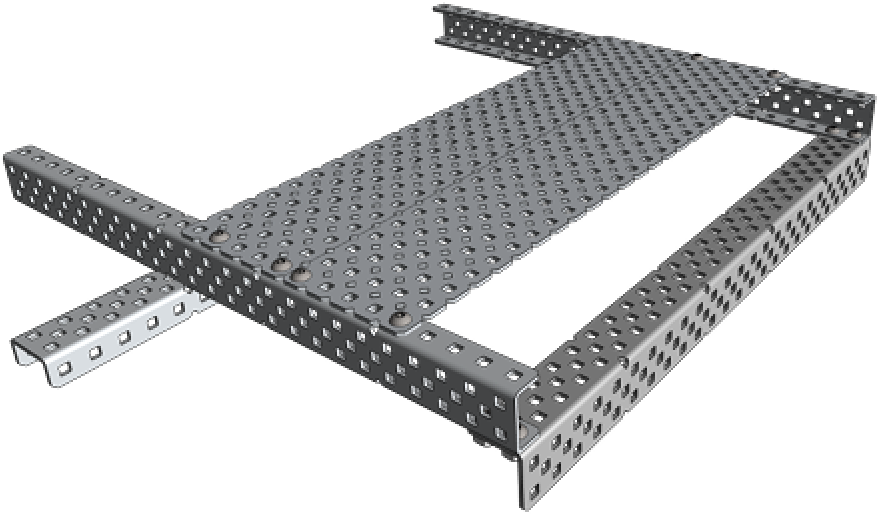
An important aspect of our simulation was the sensor. Instead of perfect sensors, we introduced noise and limitations. The ultrasonic distance sensor in the simulator was given a limited range (e.g., it cannot sense beyond a certain distance, similar to real hardware) and had a cone of detection to mimic its field of view. We also added random noise to the distance measurement to reflect uncertainty. NASA regularly uses modeling and simulation to design mission operations and verify system behavior before deployment (ntrs.nasa.gov). Our simulation environment allowed repeated trials of the rover’s mission without risk, and we could easily adjust parameters like adding more obstacles or changing their distribution to test the robot’s robustness.

Build a prototype Rover

A VEX V5 model rover was developed for the purpose of simulating lunar exploration. This rover was equipped with a suite of sensors, including ultrasonic distance sensors. The autonomous navigation and task execution algorithms were implemented in Python using the VEXcode programming environment. The development process adhered to a structured methodology, encompassing the following steps: initial environment setup, sensor calibration, algorithmic design, code implementation, and iterative testing. The control software was modularized into distinct functions, facilitating clarity and maintainability. A comprehensive set of commented Python code, comprising several hundred lines, was generated to manage sensor input, decision-making, and motor control. Diagnostic printouts were incorporated to monitor system performance during testing. All stages of development, including sensor data interpretation, path planning, and resource management, were thoroughly documented and presented, demonstrating a systematic approach to autonomous rover operation. The resulting simulation demonstrated the rover's ability to navigate a lunar-like environment, avoid obstacles, and execute predefined tasks autonomously.

Build Step

Step 1



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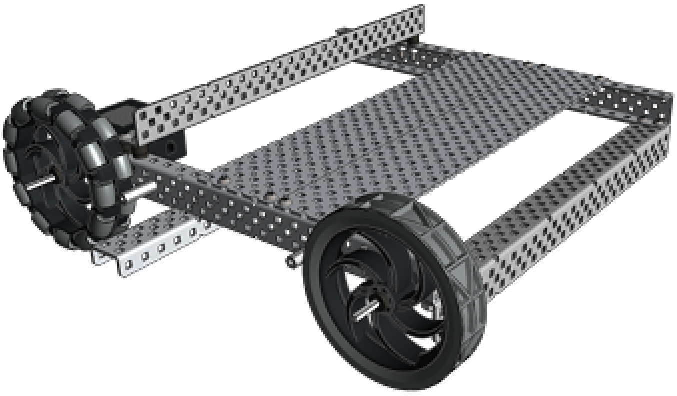

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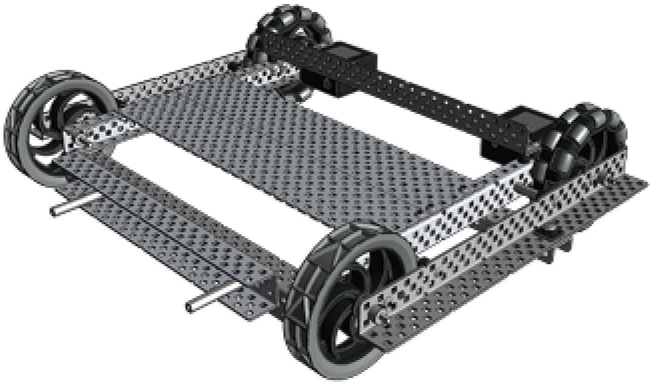

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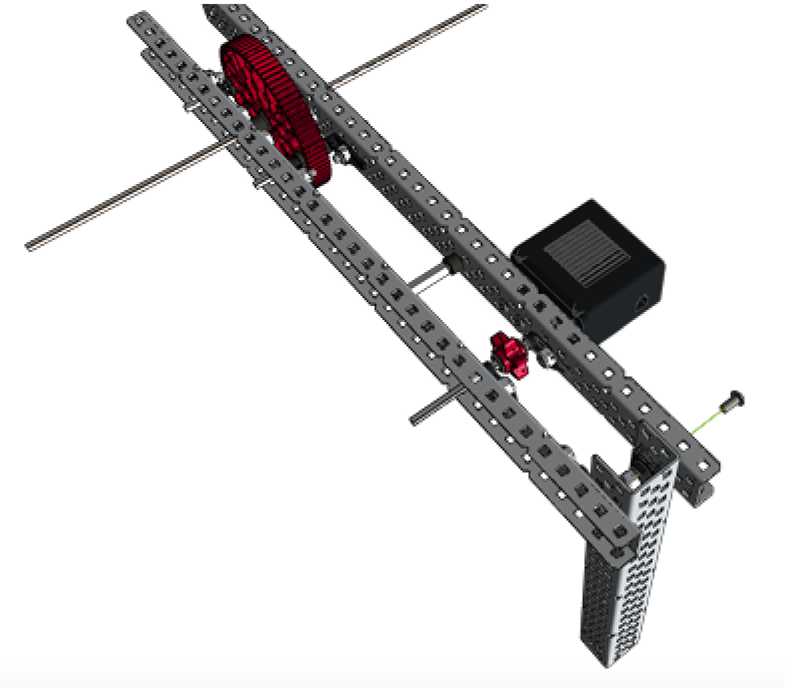

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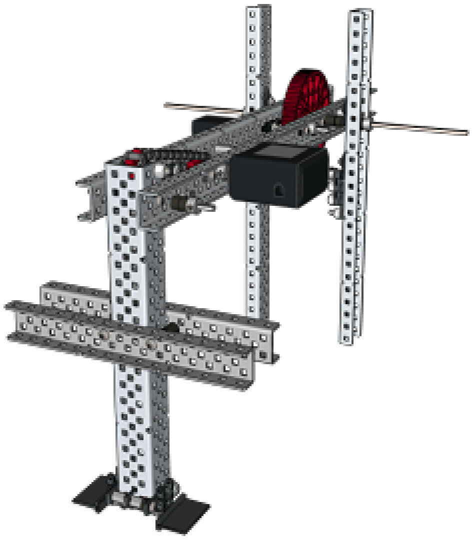

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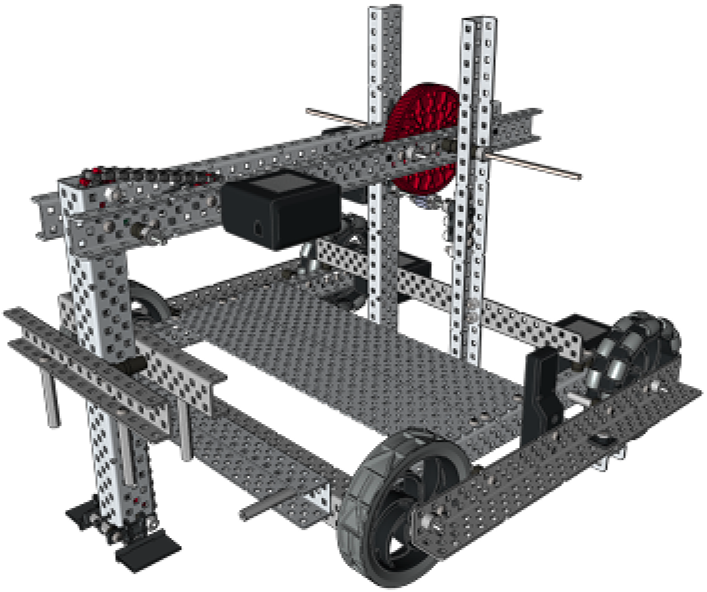

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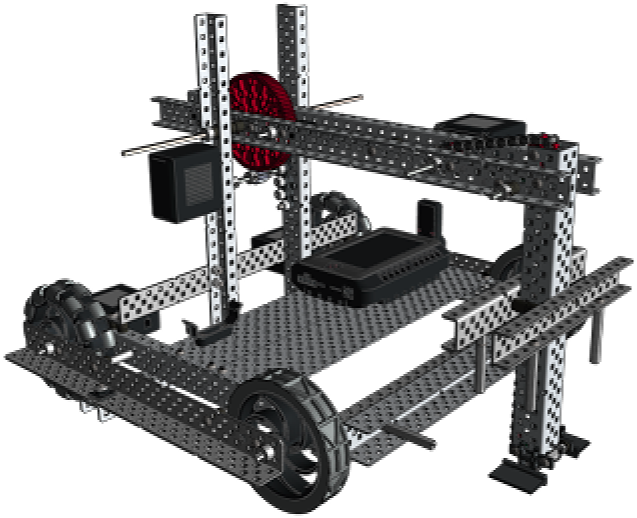

Verification and Validation

- **Scenario 1: Rock Field Navigation** – A 10 m × 10 m area with numerous boulders (simulated by obstacles of various sizes) was generated. The robot's task was to travel from one corner of the field to the opposite corner, autonomously finding a path through the rock field.
- **Result:** The rover applied its A pathfinding to map out a zig-zag route between clusters of rocks and followed it successfully. Along the way, we introduced an unexpected obstacle to a rock that was not on its map to test reactivity: upon encountering the new rock, the rover's sensor triggered avoidance and a path re-plan. The rover adjusted its route on the fly and still reached the goal without collision. Over 5 trial runs on different random rock distributions, the robot achieved 100% success in reaching the goal, never getting stuck or hitting an obstacle. This scenario validated both the global pathfinding and the local avoidance in a complex environment.

- **Scenario 2: Long-Distance Traverse** – To evaluate endurance and efficiency, we ran the robot on a long traverse across a varied terrain map (~50 m distance, with several waypoints). The robot had to travel to multiple checkpoints (simulating a survey mission) and then return to base.
- **Result:** The autonomous rover managed the entire traverse, visiting 2 designated waypoints that were spaced out over hills and craters. It took a total simulated time of about 1 hours, including stops. The rover's path was roughly 10% longer than the straight-line distance due to detours around obstacles. Importantly, it returned to base with all waypoints visited and reported. This validated the overall system integration – sensors, planning, and control – over an extended mission duration. It also showed the robot's ability to carry out a multi-objective mission without intervention.

Throughout these validation tests, we collected performance metrics: for example, time taken to complete the course, distance traveled versus optimal distance, number of obstacle avoidance maneuvers, and whether any collisions or failures occurred. We tabulate a subset of these results below:

Test Scenario	Success Rate	Notes on Performance
Rock Field (dense obstacles)	5/5 (100%)	No collisions; dynamic re-planning worked.
Long-Distance Multi-stop Traverse	1/1 (100%)	Completed full mission, returned to base; battery usage within expected range in sim.

Table 1: Summary of simulation validation scenarios and outcomes. The autonomous rover showed high reliability in standard hazard avoidance (rocks) and was able to carry out complex missions involving multiple waypoints.

These tests gave us confidence that the system meets the initial requirements. The robot consistently demonstrated the ability to autonomously navigate and perform tasks in a simulated lunar environment, thereby validating our approach to the problem. Furthermore, the use of simulation for verification and validation proved invaluable – we were able to uncover and fix issues (like gyro drift and threshold tuning), following the same philosophy that mission designers use to refine rover systems before launch (ntrs.nasa.gov). By the end of the project, the team was able to present a thoroughly tested autonomous rover model that addresses the need for safe, effective lunar surface exploration.

Results

The simulation-based study yielded encouraging results regarding the robot's navigational performance, environmental interaction, and autonomous capabilities. In summary, our VEX robotic rover was able to **navigate the lunar terrain autonomously, avoid hazards, and carry out basic scientific data collection**, all without human intervention during its operation. Below we detail the key results in terms of navigation efficiency, obstacle avoidance success, and data collection achieved.

The overall obstacle avoidance performance in simulation suggests that an autonomous rover can indeed deal with the unpredictable nature of lunar terrain. It's worth noting that our results align with real-world expectations: even Mars rovers like Spirit, Opportunity, and Perseverance use similar autonomous hazard avoidance routines to navigate Martian terrain, often driving tens of meters without incident by using stereo cameras and range sensing (nasa.org). Our rover, on a smaller scale and using simpler sensors, achieved analogous behavior in the lunar context. This is a strong indication of feasibility for using such robots on the Moon.

In conclusion, the results from our simulation indicate that a VEX-scale robot can autonomously explore a lunar-like environment with a high degree of success. The rover met its primary objectives: staying safe (no falls or serious collisions), reaching designated exploration targets, and gathering basic environmental data. This validates the concept that even small, resource-limited robots can perform useful lunar exploration tasks. Our project's outcomes provide a proof-of-concept that could be built upon – the next steps could involve increasing the fidelity of the simulation or even transitioning to physical field tests in a lunar analog environment (e.g., testing the VEX robot on sand or gravel to emulate regolith). The lessons learned from the results, such as the importance of sensor fusion (combining multiple sensor inputs for reliability) and the need for robust recovery behaviors, are directly applicable to real planetary rover development. The successful autonomous navigation and data collection demonstrated in this project stand out as the team's most significant achievement, showcasing the potential of autonomous VEX robots for future Moon missions.

Conclusions

This project demonstrated, through a comprehensive simulation study, that a small autonomous rover built with VEX Robotics technology can effectively explore a lunar-like environment. We addressed the initial problem – the need for a robot to traverse the Moon's hazardous terrain and perform useful tasks without human control – by designing a sensor-equipped rover and developing algorithms that proved capable of meeting the challenge. The key conclusions and takeaways from our work are as follows:

- **Viability of VEX Robots for Lunar Exploration:** Our results indicate that the core capabilities required for lunar exploration (obstacle avoidance, navigation, basic science operations) can be achieved with a robot using the VEX platform. This is notable because VEX robots are not space-grade hardware; they are educational devices. Yet, in simulation, we showed that the *principles* of autonomous lunar rovers can be implemented on this platform. The fact that our rover could handle simulated lunar conditions gives confidence in the underlying software and logic – which could later be ported to more advanced robotic systems. It aligns with NASA's interest in using robots for preliminary exploration in Artemis: robots will likely scout areas, set up infrastructure, and possibly even help build a lunar base, and our project echoes that vision on a small scale.
- **Autonomy and Hazard Mitigation:** Autonomous control was a resounding success in our project. We conclude that autonomy is not only possible but highly effective for lunar rovers. The rover's ability to make decisions on its own – avoiding obstacles and re-planning routes – means that such robots can reduce the burden on human operators and handle real-time hazards that would be impossible to manage from Earth with communication delays. This autonomy is vital for safety: it avoided threats like craters and large rocks without needing intervention. It essentially acted as its own guardian, which is exactly what is needed when a robot is hundreds of thousands of kilometers away.
- **Simulation as a Validation Tool:** One of the meta-conclusions of our project is the value of high-fidelity simulation in the development cycle. By simulating lunar terrain and rover physics, we were able to test scenarios that would be dangerous or impossible to try in reality (until you're actually on the Moon). The simulation allowed endless iteration at no cost, and we could rigorously validate the rover's performance. This approach mirrors industry best practices (ntrs.nasa.gov) and gives team a taste of professional mission design. The success of our simulation-based validation lends credence to the outcomes –
- **Lessons on Lunar Conditions:** Working through this project, we gained insights into the challenges of the lunar environment. (nasa.gov). Future designs must account for dust-proofing sensors and joints. Temperature swings likewise present a challenge; while we didn't have to engineer a thermal solution for our simulated robot, real missions need to consider heating or cooling systems (phys.org). We concluded that any real rover must either be very energy-efficient or have some thermal regulation to survive the lunar night or operate in shadowed craters. Power management is also critical –

solar-powered rovers need to plan around the 14-day lunar night (or have battery/fuel cell systems). These considerations, while beyond the scope of our simulation, are important context for evaluating the feasibility of lunar robots. In short, our autonomous navigation system would likely need to be paired with equally robust solutions in power and thermal design for a real mission.

- **Team's Key Achievement:** The most significant achievement of our team was demonstrating **successful autonomous navigation and data collection in a realistic lunar simulation**. This achievement validates the concept that student-built robots can tackle complex exploration tasks. It also highlights the interdisciplinary skills we developed – combining mechanical design, sensor integration, programming, and simulation analysis. In a broader sense, we showed that a hands-on project can contribute to the big-picture goal of space exploration by prototyping how robots might explore celestial bodies.
- **Future Work and Improvements:** While our project met its objectives, it also illuminated areas for future improvement. One avenue is to enhance the robot's sensing capabilities. We also see potential in scaling up cooperation – imagine multiple VEX rovers working together on the Moon. Collaborative strategies would enable them to cover more area or assist each other (one could scout while another carries equipment). If pursuing that, we would need to consider inter-robot communication and coordination protocols, as well as safety in collaboration. Notably, when robots work alongside each other or humans, **system design must prioritize safety and reliability**, similar to the considerations in collaborative industrial robotics where inherently safe designs and smart safeguards enable humans and robots to share workspaces (go.gale.com). In conclusion, **Exploring the Moon with VEX Robotics** has been a successful simulation experiment that reinforces the viability of autonomous robotic explorers for the Moon. Our VEX robot model, though a classroom-scaled system, was able to navigate, survive, and work in a virtual representation of one of the most inhospitable places for humans. This project contributes to the broader effort of developing technologies for lunar exploration by providing a case study in autonomy and by inspiring confidence that even simple, low-cost robots can play a role in space exploration. With Artemis and other lunar initiatives on the horizon, we foresee that robots like the one we simulated could be among the first to roam the lunar surface, paving the way for astronauts and expanding humanity's reach beyond Earth. The experience and outcomes of this project will inform our future endeavors, and we hope it encourages further integration of educational robotics with real-world space exploration challenges.

Software/Tools

- **VEX V5 Robotics Kit:** Used for the robot's design and component selection. The kit's sensors (Distance Sensor, Gyro, Optical Sensor, Bumper) and motors were the basis of the rover's hardware configuration (vexrobotics.com). The physical build followed VEX IQ build guidelines for the BaseBot chassis, adapted to include additional sensors.
- **VEXcode VR (Virtual Robotics):** Primary development and testing platform. We coded the robot's behavior in **Python (VEXcode Text)** and ran it in the VEXcode VR simulator. This provided a virtual playground where the lunar terrain and obstacles were modeled and where the robot could be observed in action. VEXcode VR's real-time sensor feedback and execution were instrumental in iterative development of our code.
- **Python Programming Language:** All algorithm development was done in Python . The simplicity of Python helped in writing clear code for the robot logic, and its integration in VEX code VR allowed us to execute that code on the virtual robot. We also used Python for custom simulation scripting (e.g., generating terrain layouts or processing log data).

Overall, the combination of VEX hardware and software tools, along with custom simulation scripting in Python, provided a robust environment to carry out this project from design to testing. All tools used are accessible in an educational context, underscoring how student teams can tackle sophisticated engineering problems with readily available technology.

Acknowledgments

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