CSU Senior Design Project: NASA Lunabotics Competition

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Abstract
The purpose of the annual NASA Lunabotics competition is to engage with engineering students through the development of prototypes for robots capable of harvesting water on the moon. This is important because water will be vital to the operation of future lunar bases and astronomically more cost effective to mine locally than transport from Earth. The design challenges this year stem from a reduction in size and mass limits of the robot and the observed shortcomings from last year’s competition runs. In order to reduce the size of the robot, the wheels and the configuration of their motors and axles have been changed. The autonomy of the robot was completely revamped with a powerful new CPU and sensor suite that will enable it to complete all objectives with no human intervention. Additionally, failure risks have been analyzed and evaluated based on previous and predicted performance, with the highest priority risks being mitigated in the design.

1. Introduction

NASA’s Artemis program aims to put mankind back on the moon by 2024[1] and has recently been approved by President Trump in 2017. In order to support a permanent human presence on the moon a great deal of water is required. To solve this problem NASA plans to utilize autonomous robots to harvest ice that has been found below the surface on both the Moon and Mars (Figure 1). The Moon is planned to be used as a launch point for future missions and it would be unfeasible to have the amounts of water necessary to be shipped from Earth. This harvesting of water from the moon is called an In-Situ Resource Utilization (IRSU).

Site collected water could be used for many things from personal hygiene, agriculture, and drinking water to the synthesis of rocket fuel. The availability of an extraterrestrial rocket fuel station is essential for deep space travel and the possibility of an expedition to Mars, especially since a large majority of fuel is expended in escaping Earth’s strong gravitational pull.

In 2010 NASA created the Lunabotics Robotic Mining Competition, tasking university students to design and construct a mining robot capable of navigating simulated lunar terrain, mining icy regolith simulant, and returning the collected payload to a designated area, simulating the conditions and requirements of an ISRU mission.

The competition itself takes place at the Kennedy Space Center every year. The current form of the competition involves an arena where two robots can compete side by side, as seen in Figure 2. Each team has two 15-minute attempts to harvest as much icy regolith, represented by buried gravel, from a designated mining zone as they can and deposit it into a collection bin.

Figure 1. Subsurface ice on Mars [2]
The teams are scored based on a variety of factors that are designed to reflect the goals and constraints of an actual mission. Points are added for the degree of autonomy, amount of regolith collected, and degree of dust protection. Points are deducted for the quantities of robot mass, data transmitted, and energy consumed.

Prior to this year’s competition, the objectives were based on a hypothetical mission to Mars. This year however they have been adjusted to reflect the constraints of the Artemis program launches. This means that the size constraints have been reduced to two thirds of the previous year, now 0.5m x 0.5m x 1m, and the total weight limit has been reduced to 60kg from 80kg. Though exceeding these does not disqualify a team it does impose harsh penalties.

2. Main text

This year’s team has taken an iterative design approach, choosing to revise the previous years’ design and improve on its known weaknesses. The robot consists of an auger as the chosen mining device, with a rectangular chassis made from aluminum T-slots. This chassis allows the team to shift locations of motors, wheels, sensors, control modules, and any other brackets that need to be implemented into the robotic system with ease. The augur is mounted on a rod that is perpendicular to the augur’s axis and allows it to pivot from horizontal to vertical and plunge into the soil. The plunging action is made possible by the mounting of the auger on a lead screw which pushes the augur in the direction of its axis when rotated. This design can be seen in Figure 3.

The auger is enclosed by six inch inner diameter PVC tubing and is turned using a direct current (DC) motor capable of delivering over 1 kW of power. Its pitch is controlled by a linear actuator.
located at the back of the robot. The auger is advanced via a lead screw connected to another DC motor.

In the previous design the power was transmitted to the wheels via chain-and-sprocket. However this was improved by changing the mounting of the motors from parallel with the wheel axles to perpendicular and replacing the power transmission chain with a set of miter gears as seen in Figure 5.

![Figure 5. Miter gear drivetrain assembly](image)

Not shown however are some of the more recent improvements. The previous team’s wheels were made of PVC pipe sections for the rim and thick polycarbonate sheet cut-outs for the spokes. The initial design of the new smaller wheels also utilized PVC rims and plastic spokes but it became apparent that the low strength led to a high risk for failure. To remedy this, new wheels with similar overall dimensions but less volume were designed to be casted with either aluminum or magnesium alloy. These new all-metal wheels would reduce the risk of failure and improve overall mass and ease of assembly by eliminating the many steel fasteners used.

In order to reduce mass further, the bulky one-inch diameter aluminum axles and their accompanying ball bearings, shown above in the horizontal position in Figure 5, were redesigned. The new axles were made with a stronger alloy (7075 vs. 6061), and a half-inch diameter. The smaller diameter allowed for replacement of the bearings with smaller, lighter, and more convenient bearings.

All DC motors and linear actuators are powered using an array of motor drivers which are in turn controlled by a single main computer. This main computer either conveys data from a remote manual operator or runs missions autonomously processing data from the onboard sensor suite. These controllers are all housed in a centrally located box, seen below in Figure 6, for both wiring convenience and dust protection. The back of the box has been cut out and replaced with an aluminum plate to allow for heat conduction from the electrical components to the chassis. This is important because active cooling via fans is disallowed at the competition as the Moon’s atmosphere is far too thin for it to function properly.

![Figure 6. Robot control box](image)

Manual operation is counterintuitive to one of the primary goals of this competition, however it has been implemented so that certain scenarios could be easily recreated during testing. Ideally the robot will have the capability to operate with complete autonomy, thus allowing site operators to complete useful work while the robot is on mission to collect water.

The primary navigation sensors are a LIDAR scanner and radio ranging modules. The robot utilizes a single 360 degree LIDAR scanner that is mounted at an angle on a podium at the front of the unit (Figure 7). The purpose of this sensor is obstacle detection, and aids in creating a 2D visualization of the robot’s surroundings. The LIDAR is mounted at an angle towards the ground so that as the robot advances forward the cumulative data from the scanner can be used to effectively create a 3D space to identify obstacles such as boulders and craters.

An array of radio ranging modules are used in this unit to triangulate its position during navigation. There are two modules attached to the collection bin/home base position that serve as
beaconing points for the mobile unit. There are
another two modules that are fixed to the back of the
robot. Since there are two stationary “beacons” and
two dynamic modules, the position and orientation
relative to home base can be determined at any time
during the robot’s journey. The combination of both
the radio ranging modules and the LIDAR scanner
allow the robot to feasibly conduct an autonomous
mining run.

![Figure 7. Mounted LIDAR unit](image)

Figure 7. Mounted LIDAR unit

The software control suite is a bespoke
platform based in Python and C++. All libraries
utilized are free and open-source software (FOSS) to
ensure availability of documentation and to maximize
modularity, expandability, platform independence,
and overall modifiability.

A passive skid steering technique is used to
take advantage of the independent wheel control.
Skid steering works through the forward rotation of
the left side wheels and reverse rotation of the right
side wheels, or vice versa. Thinner, smaller wheels
have been implemented and the wheelbase length has
been chosen to enable successful skid steering that
was not previously functional. The motors have been
moved slightly to ensure full engagement of the bevel
gears and to minimize losses in the system.

The auger system operated well in previous
competitions, although there was much room for
improvement. With the old auger support spacing, the
maximum depth of mining achieved was limited to
only 30 cm. This was just short of the 30.5 cm
minimum mining depth to reach the icy gravel layer
under the Black Point 1 (BP-1) simulant. This has
been addressed in the new design with an adjustment
of front auger support. Additional changes to the
mining system include no longer storing regolith in
the auger itself. Mined material is now carried out of
the auger tube into a collection bin onboard the rover.
This bin allows the sorting of regolith from simulant
as it is being mined, reducing the collection of
non-scoring material. This increases the capacity of
regolith that can be transported in a single traversal of
the obstacle course, improving time and power

efficiency.

The testing facility has also been completely
rebuilt, to accommodate the new testing soil. Similar
to NASA’s BP-1 this soil, called Azomite, comes
from volcanic geological sources and is a much
closer substitute for lunar soil than the diatomaceous
earth used for testing by the 2019 CSU team. The
new testing facility consists of a half meter deep
mining area and a shallower elevated navigation area
(Figure 8). This allows for testing of the mining,
movement, and autonomous navigation systems in
conditions very similar to the competition without the
financial burden of purchasing several tons of
simulant. The entire facility is surrounded by plastic
tarps with a ventilation system to create negative
pressure in order to keep any small Azomite particles
from escaping.

![Figure 8. Test pit for new simulant](image)

Figure 8. Test pit for new simulant

3. Conclusion

The overarching goal of this team was to
contribute sacrifices to our robot overlords, so they
would bless us with a young, lunar expeditionist. It is
rumored that once the robot overlords are satisfied
with our sacrifices, they will send down a prodigy
bearing the name C.A.M. to travel with us to the
mythical lands of Flo Rida. It is said in the prophecy
that C.A.M. will aid us in defeating the evil,
tyrannical rule of Alabama University. Once C.A.M.
has accomplished the prophecy he will ascend to the
heavens to provide life giving substances for weary travelers. This is our goal.

Also, the team aimed to meet current competition specifications while improving existing functionality. Current specifications that have been met include restrictions on volume, weight, and hardware (no pressure vessels, hydraulics, GPS systems). Systems that have been improved this year include: drivetrain, wheels, chassis, mining device, storage, and autonomy. While most of these systems have seen significant improvements given the new constraints, some brought new issues that have gone unresolved due to the cancelation of the Lunabotics RMC. These problems stem from interferences at system interfaces. This is largely due to the new size constraint which leaves little room for adjustment.

4. References

