Senior Design Team #19

**NASA Lunar Regolith Excavator**

3rd Deliverable: Needs Concept Development and Selection

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Group Members

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**Project Statement:**

The client in this case is NASA. They have requested that teams entering into the Lunar Excavation Challenge comply with a specific set of rules. These rules will be the guidelines for our project. NASA will be using information from this competition to design future aspects of lunar excavation robots. The competition focuses on excavation as a necessary first step towards extracting resources from the regolith and building bases on the moon. The unique physical properties of lunar regolith and the reduced 1/6th gravity, vacuum environment make excavation a difficult technical challenge. Advances in lunar regolith mining have the potential to contribute significantly towards our nation’s space vision and NASA space exploration operations. This particular project will focus on innovation more than invention to overcome the problems faced by previous excavation systems.

**Important Objectives:**

1. Using remote operation, move the robot across the simulated lunar landscape.
2. Collect regolith using the robot’s onboard excavation systems.
3. Return the robot across the lunar landscape and deposit the collected regolith.
4. Complete all the above objectives within 15 minutes.

**Results expected by NASA:**

A remote operated or semi autonomous robot capable of traversing across and excavating on the lunar surface which fits inside a box measuring 1.5m x 0.75m x 2m and weighs less than 80kg.

**Systems Based Design:**

We will use a systems based approach to design our robot. This involves breaking down the design challenge into separate subsystems and addressing these systems individually. The main systems of our robot are as follows:

1. Power Supply and Regulation
2. Motor Control and Actuation
3. Locomotion Platform
4. Excavation
5. Sample Offloading
6. Main Chassis
7. Control and Communication
8. Sensing and Observation

**Previous Designs:**

Design ideas for some subsystems can be gleaned from observations of subsystem performance in last year’s competition. Instead of estimation based decision methods, we can design our robot to perform better, where other robots failed in last year’s competition. Three of our eight subsystems can be designed using this approach.

**Locomotion:**

* Treads
* Wheels

**Excavation:**

* Bucket-Chain
* Bucket-Wheel
* Auger
* Bucket / Bulldozer

**Sample Offloading:**

* Four-bar linkage lift mechanism
* Auger
* Chain driven two-bar linkage system
* Pivoting Bucket

**Current Constraints:**

The physical design of the robot is primarily constrained by the allowable dimensions set by NASA. The robot must initially fit within a box measuring 1.5m x 0.75m x2m and cannot weigh more than 80kg without carrying any regolith. The robot may expand horizontally outwards after the competition round has begun, but at no point may it exceed 2m in height. The second constraint and the largest obstacle for the project is cost. While there is no limit to the amount of funds that may be used in constructing the robot, the majority of the funding must be procured by the team itself. A robot that meets the design criteria from NASA can only be built if the team is able to get the required funding to purchase the necessary parts. The team is free to design any means of locomotion and various excavation methods so long as it meets the NASA size limitations, with each of these methods determined by the availability of parts and funds to the project team.

**Design Selection:**

The focus of the competition is one of innovation of existing methods more than the invention of new techniques making it important to research methods that have been shown to be successful and improve upon them. By embracing this idea of building upon known success, a rather informal design process was used in the selection of the robotic subsystems, specifically locomotion and excavation. The team has spoken with several members, and is currently working alongside one of the members of the previous design team who had firsthand experience with the competition and witnessed the robot designs that were successful. In doing so, the team can immediately eliminate known design failures and focus on improving designs which worked.

1. **Power Supply & Regulation:**

In order to power our robot we will be implementing a battery pack, which type has not been confirmed as it ultimately depends on the required power of the motors. The power supply system for the power allocation must include the MCU, Motors, Sensors, On/Off Switch, Switching regulator, Emergency Stop switch, and Fuses to protect our electronics. Once the batteries are selected & purchased, the next step will be to test the batteries as well as the current draw of the motors. We considered several types of battery for our robot. Our estimated peak current draw for legged locomotion is 175 A split between three motors. This means that our battery system must be capable of very significant current discharge. Lead-Acid batteries have discharge capacities of up to 100 A per battery. However, because of weight constraints, they cannot be used for this project. We found a company that agreed to make us customized Lithium Iron Phosphate batteries for our project. They are customized because no readily available commercial battery had the current discharge per weight density that we needed.

1. **Motor Control and Actuation:**

Hexapedal robots require a very specific gait to run or walk stably. This means that the position of all hip motors must be precisely controlled. Encoders will be used to determine the position of the leg and they will be discussed in the sensor subsystem. Reading an encoder is not a trivial operation and no MCU has the ability to read six (or even four) incremental encoders. We will therefore be using motor controllers that have encoder inputs and can apply a control law to the hip motor to maintain accurate position. The other option is to apply an open loop control law emanating from the MCU, but this option is not feasible for stable robotic locomotion. Our motor controllers will not be simply spinning the running legs at a constant frequency; we need to implement a Buehler Clock to create stable locomotion gaits. A Buehler Clock describes the touchdown and lift off angles of the legs as well as the speed that the robot uses to transition in between these points.

1. **Locomotion Platform:**

The design team analyzed the success of the previously used methods of locomotion, being wheeled and treaded vehicles. This research coupled with firsthand experience from former competitors and the team’s association with the STRIDE lab, the team decided to use a previously ignored locomotive method: a legged robot. This new method will eliminate many of the problems arising from extremely close proximity to the regolith stimulant, which hindered all of the robots in the previous competition.

1. **Excavation:**

To select this subsystem, the team again researched previous methods that were shown to be successful. The two most successful systems were the bucket-chain and the bulldozer methods. The bucket-chain system is very compact and allows the collected regolith to be transported to a separate collection bin. Though it requires several continuously moving parts, it uses relatively little power and does not hinge its performance on the power of the motors. Alternately, the bulldozer design places the collected regolith in the collection bucket immediately and without any loss due to dust generation. However, a much larger motor is required to move this collection bucket during the offloading of the regolith and the locomotive motors must be strong enough to handle the resistance of the bucket during excavation. Of these two methods, the bucket-chain system was one that was incorporated by the wining team in the previous competition and is most compatible with the legged robot design.

1. **Sample Offloading:**

In order to select this subsystem, the team must understand the effect it will have on the performance of the other systems. It must be able to transport the excavated regolith to the collection bin without compromising performance during locomotion or excavation. Locomotion would be affected by altering the robots center of gravity, making it far more likely to tip over under the rocking motion generated by the legged robots walking gait. The placement of the driving motors and attachment points of the offloading system would affect excavation, as there is a limited amount of space available on the chassis. In addition, only small modifications may be made by raising the components above one another before the center of gravity begins to be affected as well.

To overcome these obstacles in best manner, a system that requires very little power and is able to be placed so that it does not affect the other systems must be implemented. This limits the offloading system to near vertical motion and placement on the end opposite the excavation system.

A lightweight system that works perfectly within these constraints is a power-screw lift system. This lift system would be comprised of a set of rotating, externally threaded rods, which each push an internally threaded bearing block along the rods length and is stabilized by a set of guide rails. The regolith will be contained within a pivoting bucket supported on each end by the bearing blocks.

1. **Chassis Concept:**

The design team determined that the main factor in consideration of designing the chassis of the robot is weight. With this being the case, lightweight materials such as low-density metals or composites appear favorable. Other, stronger materials such as steel were considered though the added weight to the robot made it an unusable option. Competitors from last year’s competition primarily worked with aluminum due to its high strength to weight ratio. With this in mind an aluminum base proves to be a very likely and high successful option, in addition to being light and strong it also serves as a heat sink for the electronics housed inside the frame of the robot.

To further reduce the weight of the chassis, carbon fiber will be used to create the top, or shell, of the robot. The carbon fiber can be custom molded and fitted for the robot while maintaining an extremely low weight. With the chassis taking up as little weight as possible the motors and gearboxes of the robot can be slightly heavier than originally expected.

1. **Control and Communication:**

The central computing unit of a robot is called its MCU. The MCU is the interface between the robot operating console and the robot, it applies the control laws, tells which motors to move when and our MCU will relay sensor data back to the operating console. Many MCU's could have been chosen.  At first, a PIC was considered for its ability to support visual basic, which is a very simple language.  However, the PIC is relatively slow, as is visual basic.  The LM3S9B96 development kit with ARM cortex processor nearly triples the PIC speed and supports the C language.  To move the hexapedal robot we could have moved the respective leg at a constant speed.  However, this does not allow for fluid and controlled movement so a Buehler clock will be implemented.  This allows for a slower speed while the leg is on the ground, and faster speed while moving through the air. This robot will be operated over a Wi-Fi interface and there are several options for this communication protocol. Several teams at last year’s competition hacked routers to communicate with NASA’s Wi-Fi network. A more robust option is to implement a Wi-Fi communication chip that is intended for use with mobile robots. One such chip is the Wi-Fly serial interface from SparkFun Electronics.

1. **Sensing and Observation:**

The robot will be operated from a separate control room where no direct observation of the robot is possible. NASA provides one overhead webcam view of the arena, but other than this, all vision and sensing needs to be provided by the robot itself. For vision of what the robot is seeing, we can implement webcams. The ideal placement of these sensors will be determined during practice sessions with the robot. Another necessary sensor is current sensors on all hip motors. We will need to monitor the current draw of these to ensure that our power system is not being overtaxed and that we will not be burning our motors out. A weight sensor will be an ideal option for our regolith collection system. Based on the increased weight of the robot, we can determine the optimum gait for moving with an increased mass. Our vision of the robot through webcams will not be perfect, so a good option to have will be collision sensors for the extremities of the robot.

**Resulting Design:**

After completing the preliminary research, the team has selected a design incorporating both new and previously successful subsystems. Thus, a legged robot using a bucket-chain excavation system and a power-screw lifting system will be designed and built for the purposes of the team’s competition. Comparing this design to robots in the previous competition as well as existing lunar and planetary exploration rovers, this particular robot will be able to traverse terrain that was hazardous or even impassible to wheeled and treaded vehicles. As the exact layout of the competition arena is not known until the competition begins, it is best to have a system that is not hindered by minor obstacles such as rocks and craters. Also, using a bucket-chain system limits the material being excavated primarily to loose, sand like surfaces and small rocks; however, since the competition disqualifies rocks found in the deposited regolith towards the final weight of material collected, this is an acceptable limitation.

**Cost Considerations:**

This being a multi-legged system, the majority of the ensuing cost will be due to the motors required to drive the legs and the electronic control systems for those motors. Aside from the motors, batteries, electronic controllers and basic mounting hardware, the team will fabricate all components of the subsystems.

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| **Category** | **Total** |
| Motors | **$3,550.00** |
| Excavation | **$150.00** |
| Batteries | **$2,400.00** |
| Electronics | **$5,160.00** |
| Raw Materials | **$1,050.00** |
| Travel | **$2,500.00** |
| Outreach | **$800.00** |
| Repair | **$1,100.00** |
| **Total** | **$16,610.00** |