Multi-stage Ice Drilling and Extraction System

"MIDaES"

RASC-AL Special Edition: Mars Ice Challenge

Technical Report

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Introduction:

As the question continues to rise about the possibility of colonizing planets beyond Earth, an important reality to face is that our destinations do not contain the resources necessary in the form that we as humans require. The Multi-stage Ice Drilling and Extraction System (MIDaES) is a key in refining one of the basic building blocks of life: water. While the design may seem simple, key components lengthen the lifespan and reduce the chances of failure, while allowing the extraction of Martian subsurface ice by the means of a multi-stage drilling system from a depth of zero to one meter. The ice is then melted in place and transported up through the drill shaft as water and exported to an external source.

System Description:

- Mounting System

The system is mounted to the container by four bolts. This was done to make the attachment of the MIDaES to be as simple as possible to allow easy integration onto other systems. One of the first considerations made was for the ability of this device to be placed on a rover. The bolts can be moved to any part of the frame to attach to a different device, but they were designed to attach to the box specified in the competition details.

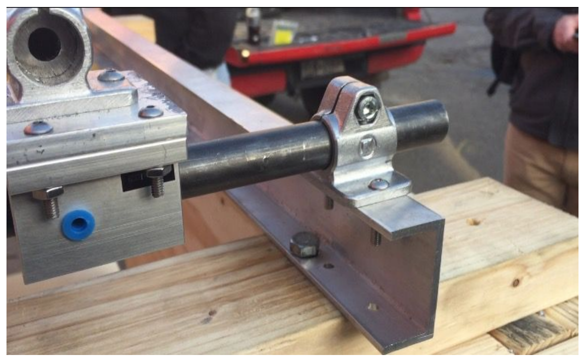


Fig. 1: Mounting System

- System Excavation Operations

The system begins by acquiring data to get its orientation with respect to the x and y axes. Once the sensors have determined the position of the drill, the x and y motors will move to the predefined path to the drill site. Then, the outer auger motor will turn on and the z motion motor will lower the outer auger and the system will begin drilling. The outer auger will continue to run until it has reached the ice. Once the ice layer has been reached, the inner drill will turn on, and the heating coil will turn on. The inner drill will continue down until a predetermined depth is reached. The thought behind using two drills to excavate the ice is that we can keep almost all of the overburden from contaminating the water collecting at the end of the system.

Fig. 2: System in Operation

- Water Extraction System/Technique

Once this point is reached, the pump will be turned on and the water will be extracted. When the water is finished being extracted, the pump and heating coil will turn off, and the drills will retract from the hole. Then, they will move to the next predefined position and repeat the cycle. The water extraction system is integrated into the inner drill from the excavation process. There are holes at the bottom of the inner shaft, just above the drill bit to extract the water. The location of the holes on the inner auger has been set to be the closest to the bottom of where the water reservoir would be forming to allow us to collect the largest amount of water from each hole.

Fig. 3: Water Extraction

- Filtration and Water Collection

The water will be passed through a filter at the end of the pump. The pump has a nozzle that can attach directly to the output hose. While we don't need to filter out a large amount of particulates, we still want to get any small amount of overburden that could fall through the outer auger out from the water. Through testing it was found that melting the ice where the drill is also helped the drill with jamming issues.

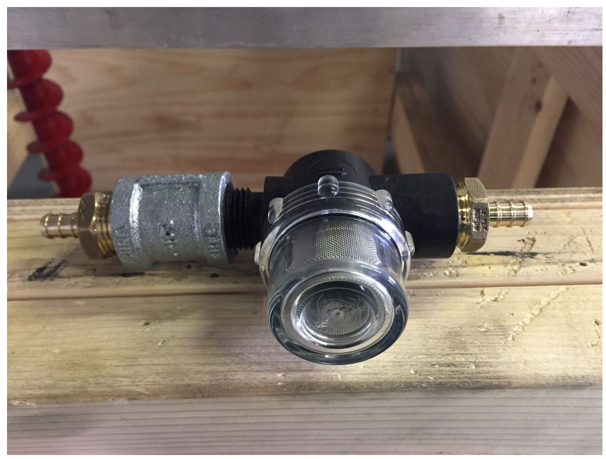


Fig. 4: Filtration

- Solution to Deal with the Overburden

The MIDaES system utilizes a dual-drill system to handle the overburden. This system keeps the unwanted substances and particulates away from the ice. The ice is melted a distance beneath the overburden to ensure that the ice does not collapse upon itself. Once the ice is melted, it is pumped through a hole just above the drill bit, in the inner auger shaft. To deal with any possible small amounts of dirt falling into the melted water in the hole, a filter is attached near the top of the system. The hole in the ice would have dirt in it after the drills have retracted however, so if the drill had to be retracted before the cycle is complete, a new hole would need to be drilled. The presumption was made that because the surface that is being drilled is relatively large, emphasis on individual drilling sites is of lesser concern, while a focus on collecting the largest quantity of water overall

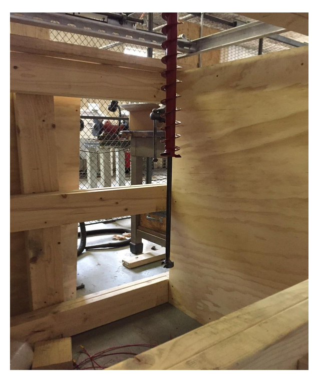


Fig. 5: Overburden Solution

was the primary mission.

- Process For Managing Temperature Changes to Prevent Drill From Freezing in the Ice

The process for melting the ice utilizing the MIDaES system begins when the drill reaches the ice region. A heating coil is wrapped around the inner drill to heat and ultimately melt the ice. This heating coil is placed in a casing of an electrical insulator to prevent a short circuit from the coil touching the inner drill, which is exposed to the ice and water mixture. In addition to allowing us to transport exclusively water up through the drill shaft, it keeps the drill from freezing in place while in the ice region.

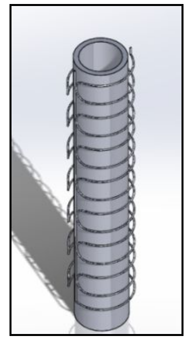


Fig. 6: Drill Freezing Prevention

- Control and Communication System

The core of the control system is a Raspberry Pi. The Raspberry Pi is a microcontroller through which all of the commands are received and distributed. Connected to the microcontroller are four drivers, and four relays. Each of the drivers are connected to the x,y, and two z motors. The relays are connected to the heating coil, pump, and the two drill motors. In addition, there is a load cell connected to the microcontroller to ensure that we do not exceed the 100 newton force for the weight-on-bit requirement. The Raspberry Pi was chosen because of its familiarity to the staff, as they have used it in other projects. Each of the motors had to be evaluated based on their specific task. We knew that the positional (x,y, and two z) motors required precision to determine the exact location of the drill, both during the drilling process, and when the drill is being moved from one excavation location to the next. This meant that these motors had to be stepper motors and they required drivers.The drill motors can operate at a constant RPM and torque, so they did only needed a relay to control them. The pump and heating coil similarly only needed to be toggled on and off, so they are controlled by a relay.

Fig. 7: Control System

- Datalogger

The Raspberry Pi integrated into our system exports a .txt file that records everything that appears on the screen during operation to our control computer. This allows for a more in-depth analysis of performance.

Technical Specifications:

The maximum weight on bit of the system is specified at 100 Newtons, and the maximum overall mass of the system is limited at 120 kg. Since the system can move around in the frame, the volume is best quantified by the total volume that it can cover which would be 2 cubic meters. The length of the outer auger is 21 inches and the drill bit itself is ½ inch in diameter. The rated load of the overall system is under ten amps. The drill motors have a maximum RPM of 2500 and a torque of 0.35 Newton-meters. Our onboard computer system includes a Raspberry Pi which has the Raspbian operating system and is coded using Python. The Arduino that controls the load cell is running C++. The communications interface for the Raspberry Pi is a SSH and a com port for the Arduino. Input commands are given utilizing a laptop computer. Power for the system is converted from the 120 VAC from the outlet to a 24 V DC system.

Design Changes/Improvements:

We have decided to use an Arduino to gather data from the load cell. With the Arduino, we were able to use already existing libraries to read the load cell. Additionally, we are able to monitor the load cell's reading in real time.

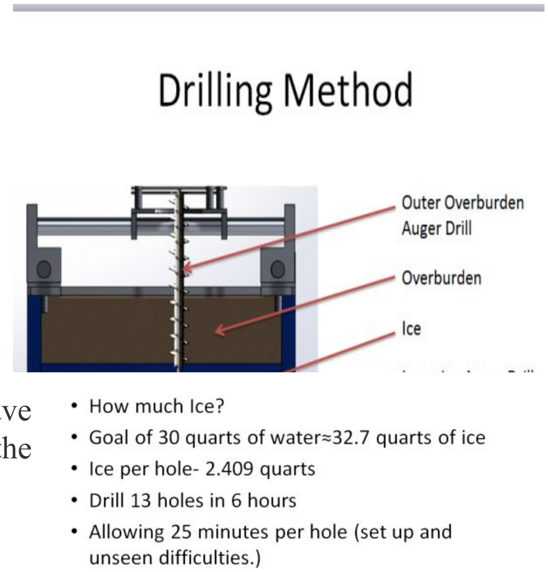
Challenges:

We encountered several challenges during the manufacturing process. Due to the complexity of some of the parts we designed, we found it challenging to manufacture the parts to the standards that we needed utilizing only the school's machine shop. Additionally, we could have allowed more time for testing if we had some of the more complex parts fabricated elsewhere.

Additionally, we encountered challenges in dealing with vibrations on the multi-drill system. Our original design used a chain and sprocket to drive the drills, but decided to change our design due to the continual slipping of the chain during testing. As well, this loose fit produced vibrations which caused the drill to have difficulty catching the ice when starting a new hole. To solve this issue, we switched to 90° bevel gears. This allowed us to get as close to a direct drive as possible, as we could not use a direct drive due to our design to pumping water through the shaft that holds the inner drill. The bevel gears, combined with the two bearings keep the drill shafts from reaching critical vibration levels.

Some of the issues we encountered from the electrical system included controlling the load cell. This proved to be too difficult given the time constraints we were given, so to mitigate this, we decided to use an Arduino in conjunction with the Raspberry Pi. We also had a minor issue with one of our smaller relays, but we were able to revert to the larger relays that we were previously using.

Overall Strategy for the Competition:



Our strategy for the competition is to utilize our ability to move the drill in the test area to excavate the ice from multiple holes. We plan to put a small filter at the end of the pump to filter out any minor sediment that could contaminate the water. The majority of the overburden will be trapped above, with the outer auger shielding the ice below. Each hole will take approximately twenty five minutes to drill and we expect to have approximately 30 quarts of water at the end of the competition.

Summary of Integration and Test Plan:

Currently, the aluminum frame for the system has been completed. The parts that hold the outer auger drill and the pump have been integrated. Our team has completed construction of the mounting and support system for the linear x, y, and z motion. We also have the inner drill and outer auger in place. We have the pump, heating coil, and filtration system integrated at this time. All of the wiring has been completed for the system. We will be spending the next couple weeks before the competition performing continued testing on the system and making minor programming tweaks.

We have tested several different gauges of nichrome wire to determine which would best suit our needs. We could not change the length of the wire because it needed to fit inside the drill bit. During our testing, we found that the 20g and 24g wire were glowing red and were much too hot for our purposes. So we chose the 36g wire for our purposes.

We also tested different types of drill bits for our project. They were tested by observing which drill bits fit certain criteria. They were tested by their torque required to penetrate the ice, as well as the time each one took to drill through a length of ice and the amount of ice we gathered from each bit. We concluded that the Forstner bit is the optimal drill bit for our purposes.

Tactical Plan for Contingencies/Redundancies:

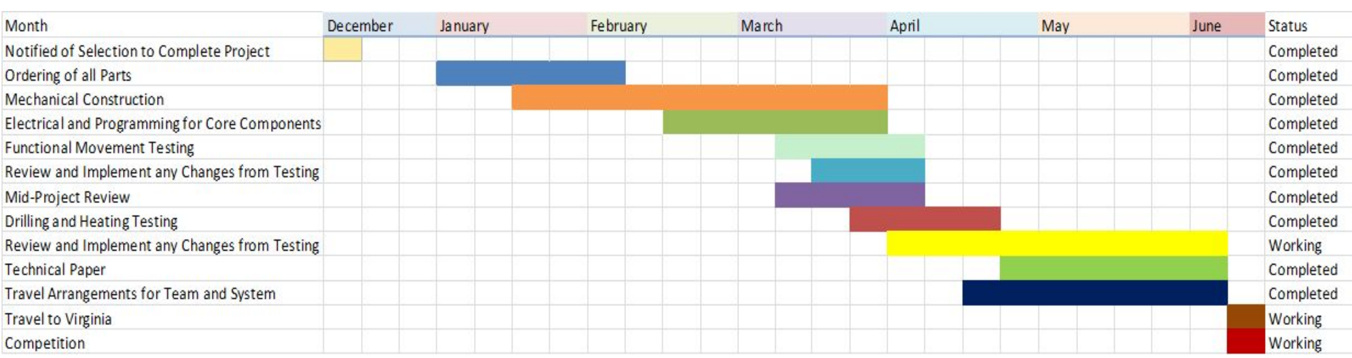
The areas where we foresee needed redundancies are the motors, the microcontroller and the drills. We have additional motors and an additional microprocessor. During our research on extraterrestrial drilling, we found that even in the cases where humans were directly controlling the drill, jamming was a big issue. As such, we have a secondary inner and outer drill system in the unlikely event the first one should be damaged.

Risk	Severity	Effect	Mitigation
Control and Communications Power Failure	High	Loss of control for the drilling apparatus, resulting in an unsafe condition	Redundant control method via ethernet connection, program motors to stop if control is lost
Pump Failure	High	The drill could become clogged, not allowing for more extraction of materials	Testing of the vacuum system to ensure it can handle the load
Heating Coil Failure	Moderate	The system could take longer to melt the ice	Testing of the heating system to ensure it can handle the load
Motor Failure	Moderate	Lowered lifetime of the moving parts of the drilling apparatus	Utilize separate drivers for each stepper motor

Item	Process
Linear Motion x	Independent of other items
Linear Motion y	Independent of other items
Linear Motion z outside auger	Run simultaneously as inside auger
Linear Motion z inside auger	Run simultaneously as outside auger
Outside auger spindle	Independent of other items
Inside auger spindle	Independent of other items
Heating element	Run simultaneously as pump
Pump	Run simultaneously as heating element

Fig. 8: Redundancy Analysis

Project Timeline:



Safety Plan:

The MIDaES system uses no hazardous materials in its processing of the overburden and ice/water. Personal protective equipment (PPE), such as gloves or electrical shock protection is required when performing maintenance on the system, but during operation PPE is not required. During operation of the system, safety goggles are required to protect from any small bits of debris.

Path-to-Flight:

- Concept Development

When we were first developing concepts for the water extraction system, we placed a large amount of emphasis on handling the overburden. We looked at what excavation techniques we use on Earth and looked at their adaptability for use on Mars. We discussed various methods of excavating the overburden, including using a belt to transport the dirt away from the test area and coring the ice. This method had its advantages, but if you were to apply this method on Mars, we decided that too much of the ice that we were uncovering would sublimate. Another idea was to use a system similar to an endoscope in which we could move in any direction. This method was deemed to be too complicated to manufacture. In the end, we landed on a design similar to the one we have now. We decided that the two drill system could be more compact, and still be able to accomplish the tasks. We added a frame similar to that of a 3-D printer to allow for the drill to move around in the test bed without human intervention. We thought that the ability to move around in an area would allow the same amount of mass to be excavated from the testing area while saving mass from needing a large steel drill bit.

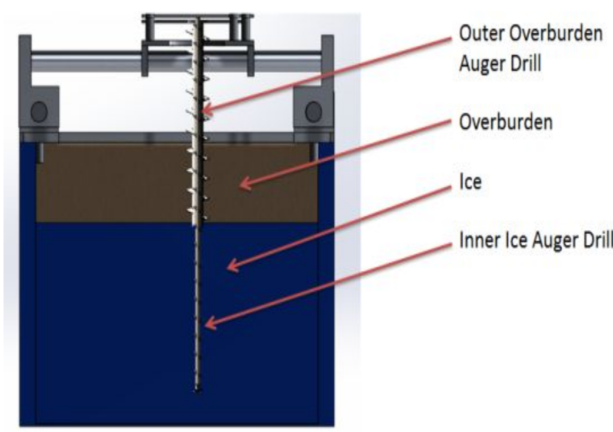


Fig. 9 Old Inner Drill (left) and New Inner Drill (right)

The design adapted as we were able to test it more and more. We realized that we could melt the ice before the drills have retracted. This would help us with the issue of the drill freezing in the ice. At the same time, this would increase the longevity of the system by having less fatigue without the inner auger grinding against the inside of the outer auger. We found that our initial design of using a chain and sprocket to drive the drill shafts was too loose for our needs and caused issues with vibrations. Switching to gears was the closest we could get to direct contact, while still allowing for torque corrections on our motor.

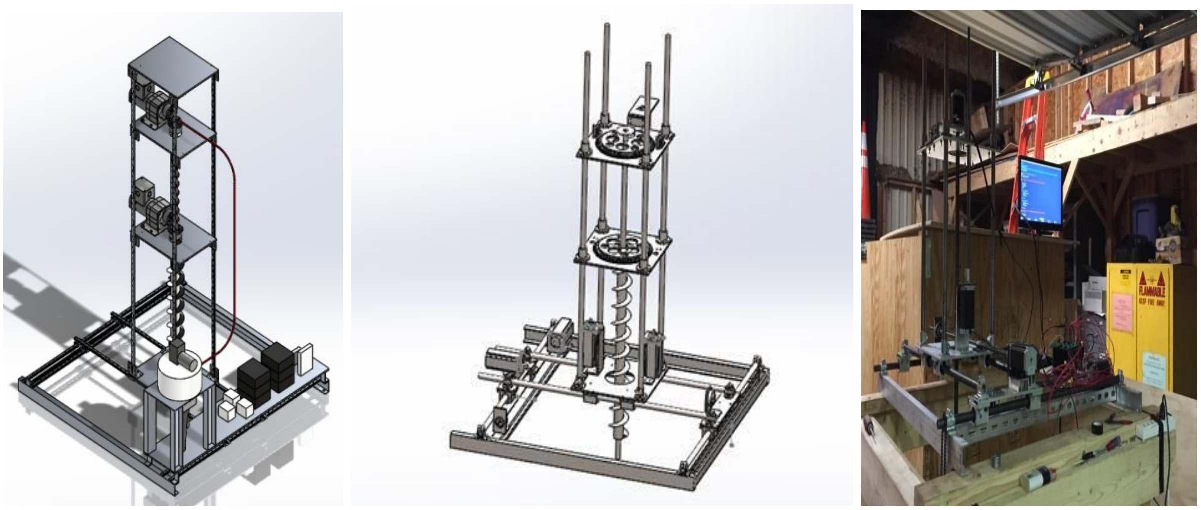


Fig. 10: Midterm Review Development

- Mechanical

The core of the differences between our system designed for the testing here on Earth and a system designed with Mars in mind are the pressure and temperature differences. As soon as the ice is uncovered on Mars, it will begin to sublimate. With our design, the uncovered ice would not be exposed to the atmosphere, so losses would not occur from there. Modifications would have to be made to ensure that an air-tight seal is created around any of the areas of the system exposed to the outside air.

The overall movement for the drill would be different if we were to utilize the system on Mars. If you wanted to gather any sizable amount of water, you would need the platform to be more mobile. The ideal situation is to place this on a rover. Placing the system on the top of a rover would allow for the system to be very mobile, but not make a person carry the system around on Mars, as the rig weighs 50 kg. This system would be incredibly inefficient without the ability to move the drilling apparatus beyond the small range we currently have. If MIDaES was mounted to a rover, then the x and y linear actuators would no longer be necessary, as the rover could move around externally instead of the drill needing to move internally. However, the ability to move around within an area could be useful for hard to reach areas.

It is important to keep in mind the form of energy that is available to use on Mars currently. There are two main sources of energy generation used on Mars today. They are solar energy and nuclear energy. If you could harness the heat energy given off from the plutonium in a nuclear thermoelectric radioisotope generator, you could save a lot of energy by directly using the heat energy, instead of converting it to electricity and then back into heat energy. This would create a much more efficient usage of energy in the system, which would allow for faster melting periods and a higher rate of water collection over time for the exchange of more complexity.

MIDaES' structure would need to be modified to anchor more securely to the ground. The mounting system is designed to be attached specifically to the testing box. While it would be possible to simply place the system on the ground, the vibrations caused by the drilling are enough to shift the system to the point where jamming can occur with the drills.

Several modifications will need to be made to the system for it to be able to extract liquid water on Mars. The first modification that would need to be made would be to change the vacuum pump system to a compressor/venturi system. This modification needs to be made because utilizing a vacuum pump on Mars is not feasible, as we cannot create a pressure differential great enough to raise a column of water using the vacuum pump method. However, by utilizing a venturi and a compressor, a pressure differential greater than that needed to lift a column of water can be obtained. To do this, piping modifications would need to be made to the existing Earth-ready system, and a venturi would need to be inserted between the compressors' outflow port and the internal collection vessel. The pump we have specified for the vacuum pump system can also be used for the compression/venturi system with only slight modifications being necessary. This would result in a slight weight increase, but would require no additional controls to be implemented. Another modification would be the types of polymers utilized in the piping and tubing used to transport the liquid water, the collection vessels, as well as the filters. For the Mars version, heating elements may be necessary to keep liquid water from freezing in the pipes, as well as in the internal collection vessel and filtering system. Due to this, the polymers will need to be able to withstand direct contact with heating elements, with minimal to no degradation in the plastics as a result. Lastly, a modification as to how the water flows after it has reached the initial collection vessel may be necessary on Mars. As the gravitational force on Mars is substantially less than that on Earth, a pressurized system may be required so as to force the water to flow through the filtration system. To do this, a diverter valve will need to be added to the outflowing side of the compressor so as to divert the compressed air so as to pressurize the filtration system.

The frame of the system could use strengthening at the top. While we have not found this to be an issue during any of our testing, we have concluded that the top of the frame should not be able to move around as much as it can. The conditions on Mars would put too much stress on the system while it is trying to move up and down if this issue were not corrected. This will be fixed by adding an extra plate at the top that is unable to move.

- Electrical

Heat transfer on Mars makes for a challenge when it comes to electronics. Electronics are designed to operate between certain temperatures and Mars' surface temperature falls well below these operating temperatures. Since the pressure on Mars is so low, it creates a situation where convection will not transfer most of the heat energy stored from the system or the environment. The system would need to be heated in key areas and heat would have to be distributed from other key areas. Most notably, the heat generated by the motors would need to be dissipated. This can be accomplished through using heat exchangers. A heat exchanger will allow for the heat to be distributed in an advantageous manner throughout the system. This would need to be integrated with the power source in mind. Heat exchangers would have a much more limited application with solar powered system.

The control system needs a fair amount of adaptation if it were to be utilized on Mars. Not only would we want to use radiation resistant memory to protect the computer's integrity, we would also want to have a second microcontroller. That way, if the primary microcontroller stops working, we can switch over to the secondary one to keep the system running. A camera would also need to be added to assist in the alignment of the drilling motors and give a better idea of the implications of any issued commands to the system.

Telecommunications is the largest adaptation that we would need to make on the current system. Adding deep space network compatibility would add a large amount of mass and power draw to the system. We would need a communications system similar to that of the Curiosity rover's, broadcasting at an ultra-high frequency (UHF). This would involve adding a UHF software defined radio to the control system. A low gain antenna and high gain antenna would be required to communicate directly with Earth. These adaptations would allow updates and commands to come from the deep space network instead of our control computer, which are essential to enable longevity on these deep space missions.

The usage of solid state electronics is also adversely affected by the low pressure and cosmic rays found on the Martian surface. The energy fluctuation caused by cosmic rays can cause failures to occur in solid state electronics. An analysis will have to be performed to determine which systems are critical to be solid state and their usage will be kept to a minimum. Adequate radiation shielding will be applied. Additionally, dust storms are a large concern on Mars. The electrical equipment would need protection to be able to withstand these harsh conditions. This is achieved through the addition of proper protection for all circuitry, as well as keeping debris away from all of the moving parts of the drilling apparatus. An aluminum casing would help to keep debris from the electronic equipment, as well as assist in shielding from cosmic rays.

- Programming

The programming would need to be modified to be compatible with the deep space network. It would have to be broken into two segments: downlink and uplink. The downlink telemetry received from the system has to be in the simplest form possible to be processed by a ground station. The uplink commands are slightly less strict in terms of bits, but the programming would need to be adjusted to handle a wider variety of commands. The commands that you would administer to the system might depend on the application. For example, if you wanted to utilize the water collected for fuel, you might not need to run the same processes that you would if you wanted to utilize the water for agriculture. The programming needs to be modified to allow diagnostics to be run on each part of the system. These diagnostics are critical for the mission. Completely automated systems are essential for any extra-terrestrial operation.

This would take rigorous testing to ensure that the rover would be more independent as it collects ice. A previously stated consideration would be the Martian dust storms. There would have to be a power conservation mode to prevent complete loss of control in the event of a prolonged storm. These dust storms cause the surface temperature on Mars to decrease drastically. Current electronic equipment on Mars has been left for multiple weeks at a time without being recharged due to these storms. MIDaES would need similar programming to compensate for this issue to only power essential systems, notably the telecommunications system.

Budget:

Description	Funding	Costs
NIA Awards	$11,200	
Bernstein Travel Fund from AU	$1,000	
Machine Shop Usage (In-kind)	$3,000	
Purchase Parts		$7568.45
Testing Cost		$637.02
Transportation of System		$200
Travel to Competition		$3,000

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