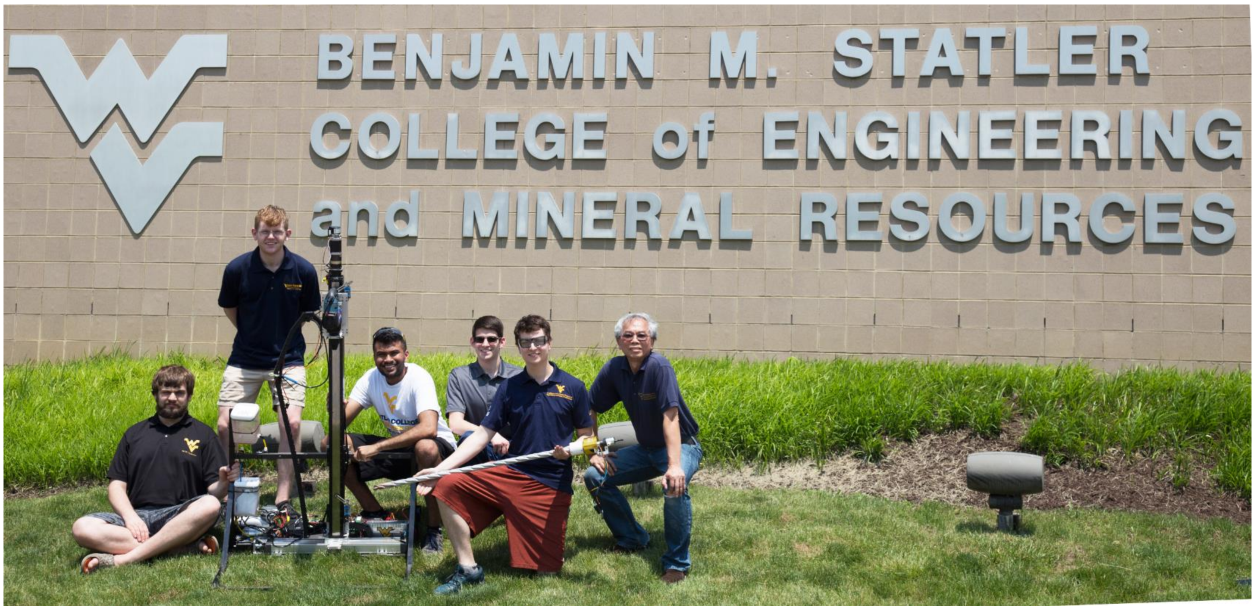
2019 RASC-AL Special Edition: Moon to Mars Ice & Prospecting Challenge

Technical Report



West Virginia University

Statler College of Engineering and Mineral Resources

The Mountaineer Robotics Team

Student Team: Ian Hostottle, Praveen Majjigapu, Nathan Owen, Samuel Price, Derek Roesch, Karan Sah, Bertrand Wieliczko (Team Lead), Jacob Winokur, and Joseph Yeager

Faculty Advisor: Dr. Powsiri Klinkhachorn (lead), and Dr. Ilkin Bilgesu,

1 Introduction

Liquid water provides many benefits for the exploration of the Moon, Mars, and other places past our terrestrial bounds. Benefits of extracting liquid water from the Lunar and Martian environment go beyond simply fulfilling the biological needs of human beings—water retrieved can be used for rocket fuel when split into hydrogen, and oxygen and can provide shielding from radiation. Extraction of liquid water, however, can be seen as an intricate task due to the characteristics of the Lunar and Martian environments such as their low temperature and pressure. Specially designed robotic systems can provide a solution to the formidable problem while maintaining low liabilities.

The Mountaineering Ice Drilling Automated System III (MIDAS III), developed by the West Virginia University Robotics Team, is completely redesigned from its 2017 & 2018 RASC-AL Mars Ice Drilling Challenge award winning predecessors the Mountaineer Ice Drilling Automated Systems (MIDAS I & II). Given the lessons learned from last year's competition, MIDAS III displays a unique process that can undermine the complications of retrieving liquid water from Martian ice deposits and profiling the contents of Martian and Lunar overburden. MIDAS III's functions will be demonstrated alongside other robots in the 2019 Revolution Aerospace Systems Concepts Academic Linkage (RASC-AL) Special Edition: Moon to Mars Ice and Prospecting Challenge at NASA's Langley Research Center (LaRC)

The process designed by the WVU Robotics team corroborates that a simple solution of working with the environment on Mars rather than fighting it can allow for the successful extraction of liquid water. It includes using a custom designed all in one heating and water extraction probe to drill into simulated Lunar and Martian regolith to retrieve water from ice deposits. The data collected while drilling into the regolith can be used to classify the hardness of soil and rock in the overburden. Once the ice has been reached, a heating probe will be used to create a pressurized Rodriguez well within the ice deposit. Liquid water can then be pumped out of the well due to the pressurization. Descriptions of Lunar and Martian operations are listed in detail, along with potential additions on the path to flight section of this paper. The rest of the paper describes the team's build details, challenges, and strategy to usher in a golden age of research and exploration with the completion of MIDAS III.

2 System Descriptions

2.1 Frame

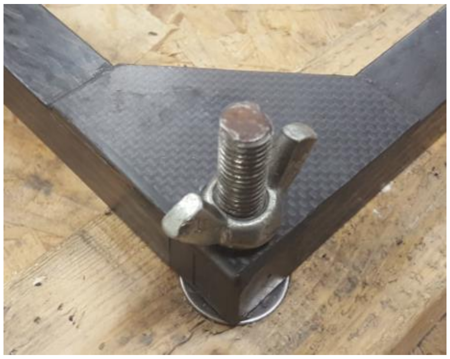


Figure 1: Carbon Fiber Mounting Joint

In order to reduce the weight of the overall rig while maintaining a structure rigid enough to handle vibrations and loads from drilling actions, carbon fiber tubing was used as the main building component of the rig instead of aluminum T-slots. The hollow 25mm by 25mm, 1.5mm wall thickness braided carbon fiber tubing is connected using nylon 80/20 quick connectors to form structure. Balsa and oak wood bars were placed in the tubing to prevent localized crushing of the carbon fiber. Gussets made from 2mm and 3mm carbon fiber sheets were used to support each joint. Pliogrip panel 90 adhesive was used to connect all the components together permanently. As shown in in Figure 1, MIDAS III is anchored via holes drilled into each corner of the frame. MIDAS is held in place with wingnuts. Final dimensions of the rig are shown in Figure 2. The entire system weighs 57.5 kg.

Physical flexural tests as well as Finite Element Analysis (FEA) on RFEM was done to validate the use of carbon fiber vs. aluminum t-slot. The carbon fiber tube was measured to have a moment of inertia of 0.0344 in^4. Based on the load vs position data from flexural testing up to 87 lbs at a 24" span, the carbon fiber tube was found to have a modulus of elasticity of 13.9 million psi. The aluminum T slot tested in flexural at the same span was found to have a modulus of 7.6 million psi. The stiffness (modulus x moment of inertia) of the carbon tube is 479,736 lb-in2 compared to 335,867 lb-in2 for the aluminum track, a 43% increase in stiffness.

Results from the FEA, as shown in figure 3, showed that the most critical member for the left, M26, and the most critical member for the right both had a critical load of 7425 psi. This is well below the modulus of elasticity for carbon fiber. Carbon fiber can then be justified as a building component.

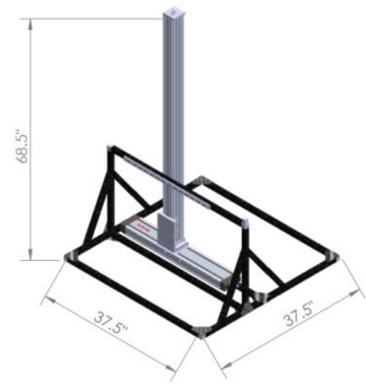


Figure 2: Dimensions of MIDAS III

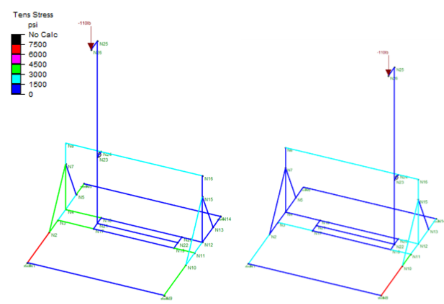


Figure 3: FEA Shear Testing Images

2.2 All-In-One Probe (AIOP) Excavation and Extraction System

MIDAS III, similar to MIDAS II, will only employ one probe, the AIOP, to go through the overburden and melt/collect ice from beneath the overburdens layers for the excavation and extraction process. The motive of the single probe methodology is to keep operations as simple as possible and that the use of one bit during Martian operations decreases the chance of losing water to sublimation. Unlike MIDAS II, MIDAS III's AIOP will use a rotating action when going through the overburden because a ramming action alone would be insufficient to penetrate various hard layers. The rotating action is provided by a Bosch SDS Rotary Hamer Drill that can provide 110 ft-lb of torque and drill at up to 900 rpm. The AIOP system includes a main pipe made from aluminum and a copper heater housing. Spiral lands/flutes, which are groves along the body of a drill structure, will permit the removal of overburden material from the end tip of the drill during excavation. A Polycrystalline Diamond Compact (PDC) Anchor Shank Bit is located at the tip of the AIOP. A slip-ring and water swivel will ensure the connection of heating elements and water line. The heating element in the tip regulates high temperature as the AIOP plunges to ensure that it won't freeze. After multiple tests in overburden layers, which include drywall, aerated concrete, crushed concrete, and red clay, the MRT is confident in the design decision. A bit stabilizer was designed to mitigate any unwanted movement by the bit during operation. When the ice is reached MIDAS's AIOP will begin extraction and undergo a heating cycle in hopes of creating an inverted bell shaped Rodrigiez Well. Creation of such well will insure no overburden collapse. Once enough water is collected in the Rodriguez Well, water can be pumped into the filtration and then the collection system through the AIOP's water line. The MRT was fortunate enough to get a service grant from Protolabs, a professional manufacturing company, to fabricate the AIOP. The final bit is shown in Figure 4. It is 42 inches long.

Figure 4: All-in-One-Probe

2.3 Filtration System

The ARES (Aluminum Reactor Electrocoagulation System) is MRT's solution to filtering the water recovered by MIDAS. ARES works in two stages; stage one is the electrocoagulation chamber and stage two is the mechanical filter. The water is directly pumped from the sample to the first stage of ARES where the reactor separates the water from the particles. The components of the filtration process are shown in the process and instrumentation diagram in Figure 5.

The electrocoagulation system works by having parallel aluminum plates set up in an alternating pattern of "anode, cathode, anode…" and having them set up in parallel electrical configuration. The wiring of this plate pattern is shown in Figure 6. By passing a current through

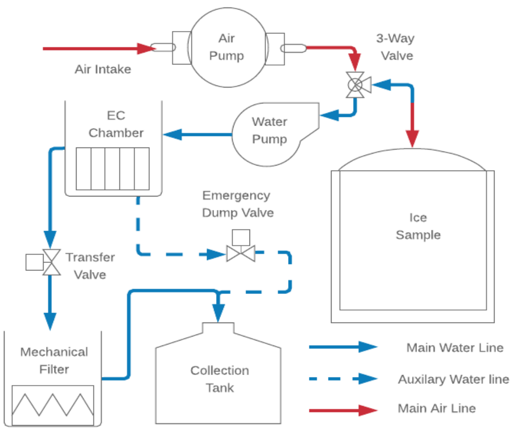


Figure 5: MIDAS III Process and Instrumentation Diagram

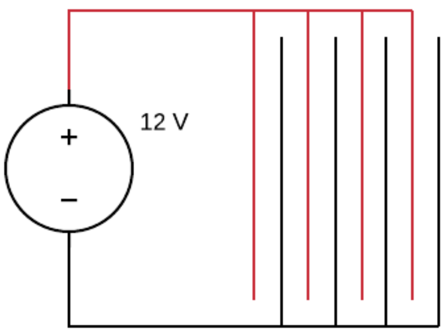


Figure 6: Parallel Plate System for Electrocoagulation

theses plates, electrolysis takes place, passing ions from cathode to anode. This passing of ions is the main source of the separation. These ions catch floating particles, dissolved metals, and oils in the water and depending on their composition, make them either sink or rise to the top of the container leaving cleaner water in the middle. This water in the middle will be transferred to the mechanical filter where any particles that float through will get caught and removed. After the second stage, the water is dumped into the collection tank.

2.4 Subsurface Prospecting Method

MIDAS III can create a digital core of the subsurface soil and rock sample by performing a Cone Penetration Test (CPT) while drilling into the sample. A CPT consists of pushing a probe through different layers of overburden while recording the weight on bit (WOB) and depth of the probe. The trend in the WOB data is then compared to prerecorded data and trends of tests performed in different soil, gravel, concrete, and clay to determine the material present in the overburden at each depth. While a typical CPT includes a testing instrument with two load cells, one for tip resistance, and one for side friction, MIDAS III will measure the total resistance on the bit through its load cell where the drill is mounted. Position data will be recorded using a quadrature encoder mounted in line with the vertical stepper motor.

MIDAS III makes use of a different bit when subsurface prospecting instead of excavating and instructing. A 0.5x39 inch concrete bit is used instead of the AIOP because it is smaller and can penetrate the overburden more efficiently. The CPT procedure of MIDAS III begins with turning on the drill. The vertical stepper motor then moves the drilling bit down into the sample. While the drill bit plunges into the sample, filtered WOB data is recorded through the load cell. Position data is also recorded to match WOB trends with their corresponding depth. The drill will plunge until the bottom is reached, at which point, the stepper motors will stop moving the drill bit down. The WOB and position data is then exported for interpretation.

The preliminary result of one such CPT test is shown in Figure 7. The test was performed using the method specified above through an overburden sample of drywall, a clay-sand mix, aerated concrete, clay with gravel, and chunks of crushed concrete. While the drill plunged through the drywall, WOB peaks occurred at each new drywall layer due to the resistance of the paper covering each drywall layer's face. MIDAS III recorded 9 such WOB spikes, which matched up with the number of drywall layers in the sample. The WOB remained low and consistent throughout the clay-sand layer, and then the WOB spiked a small amount when the drill hit the aerated concrete. In the clay and gravel layer, the WOB was low with several spikes, which were caused by the resistance from the scattered gravel pieces. Finally, The WOB spiked again through the crushed concrete level. The weight on bit is highest at this point because the crushed concrete has the highest density of all materials in this sample.

While MIDAS III does not perform traditional CPT Testing with a bit resistance sensor and a sleeve resistance sensor, the results matchup very well. The actual sample consisted of 4.5" of drywall, followed by 8.5" of clay and sand, with 6.5" of aerated concrete after that. Then, there was 7" of clay and gravel, followed by 3" of crushed concrete. By measuring the changes in WOB as MIDAS III plunges, the estimated densities and layers of different materials in the overburden sample can be obtained.

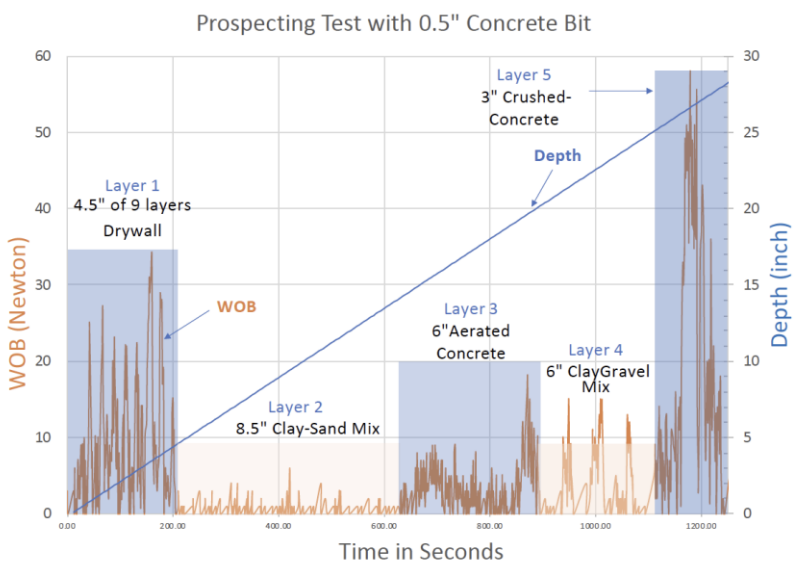


Figure 7: Prospecting test graph showing different overburden layers

2.5 Electrical System

The Electrical System is divided into several key components that allow MIDAS III to properly function. Power comes in through a 120V wall socket, which goes through a 9A fuse. The AC power supply powers the pump, the heater, the solenoid valves, and the blower through high-current relays, and the electronic drill speed controller. The AC power supply is also fed into a 12V and 24V DC power supply. The 12V power supplies power to the electrocoagulation filter. The 24V DC supply powers the Programmable Logic Controller (PLC), along with the stepper motor controllers, temperature sensor, current sensor, force sensor, limit switches, and panel display. The PLC communicates with all the relays, stepper motor controllers, sensors and panel display to exchange information and control the drill rig. The stepper motor controllers allow the PLC to send pulses and direction information to move the drill on the linear rail axes. Most of the electrical control system is secured on a DIN rail for organization. A diagram of the electrical system is shown in Figure 9 and a photo of the electrical system is shown in Figure 8.

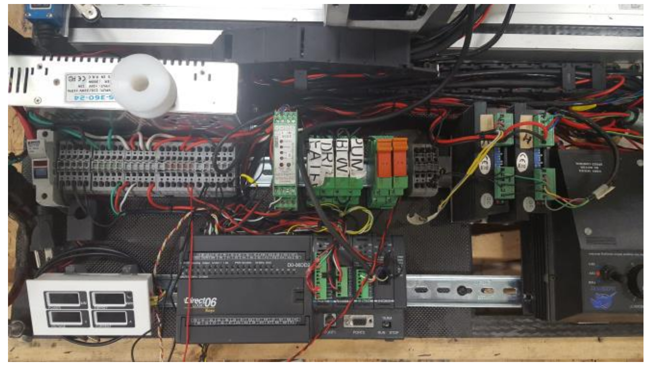


Figure 8: Electrical and Control System

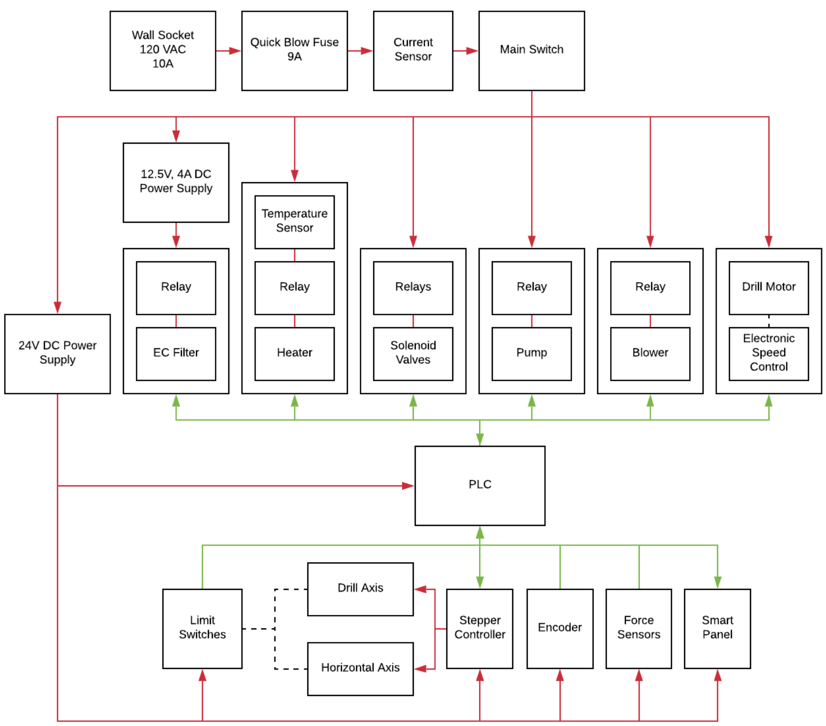


Figure 9: MIDAS III's Electrical System

2.5.1 Sensory System

MIDAS III's electrical system has a series of sensors to monitor important system functions. The first of these sensors is an AC current and voltage sensor that keeps track of the current and power usage of MIDAS III. This data is logged throughout the entirety of MIDAS III's function in a MATLAB script via USB. Safety Limit switches ensure that rig does not travel beyond its parameters and serve to home the drill/probe during initialization. A quadrature encoder is attached to the vertical stepper motor to keep track of the drill's vertical position. The S-Shaped load cell connecting the drill mount to the linear rail measures the weight on bit as it plunges into the sample. The load cell can read 200 lbs safely up to 150% with a drill rating of 4000bpm. This weight on bit information is monitored by the PLC at all times to ensure that the 150N WOB maximum is not reached. A thermocouple will measure the temperature of the heater while the AIOP is heating and extracting water from the ice.

2.5.2 PLC and Communications

Like last year, a PLC will be used to control the functions of MIDAS III. PLCs are heavily used in industry for process automation, and they operate using ladder logic. An AutomationDirect DL06 is the PLC that controls MIDAS III. The rig is controlled through an LCD operator interface panel. The LCD display has been upgraded from last year, and an AutomationDirect EA9-T10WCL, which is a 10" touch screen display, is now being used. The new menu screen is shown below in Figure 10. This larger display will allow more information and functions to be displayed for ease of use and understanding. Through the interface panel, the user will be able to set and view parameters and run both manual and automatic functions. The manual and automatic functions are controlled by the PLC through its output ports. The PLC can also display trends of information on the LCD, such as weight on bit, vertical position, heater temperature, and current usage.

Figure 10: LCD Screen Menu

2.6 Software

The PLC is programmed using ladder logic code in Automation Direct DirectSOFT 6. Operator commands are given through the operator display, which is programmed with C-More. Figure 11 depicts preliminary software flow diagram. The code first goes through an initialization phase, and then waits in standby for user commands through a control panel LCD display. The manual setting controls allow the PLC to input parameter values such as desired weight on bit and temperature. Additionally, manual controls can turn on MIDAS III's movement, drilling, pumping, blowing, and heating operations. The user also has two options of automatic processes to run: drilling and prospecting.

The automatic drilling mode allows MIDAS III to perform its drilling and water extraction cycle without constant user input. First, the drill goes through homing and centers on the drilling location. The drill then turns on and begins drilling down until a desired depth is reached. The rate of drilling is controlled by using load cell data as a process variable within a PID loop. From there, the heater is switched on, and the pump is turned on and off at regular intervals to extract the water from the ice sample. The bit temperature is also regulated within a PID loop in order to prevent the AIOP form freezing. The process will stop when the extraction of water is finished.

During the automatic prospecting function, MIDAS III will plunge the CPT probe into the sample at a constant rate while constantly monitoring bit resistance to form conclusions about the makeup of materials in the sample. When this process is first selected, the speed for the linear actuators is set, and the probe will move into the sample. MIDAS III is recording data from WOB load cell during this mode. When the probe reaches the bottom of the sample, the linear actuator is turned off, and the data is exported to be analyzed.

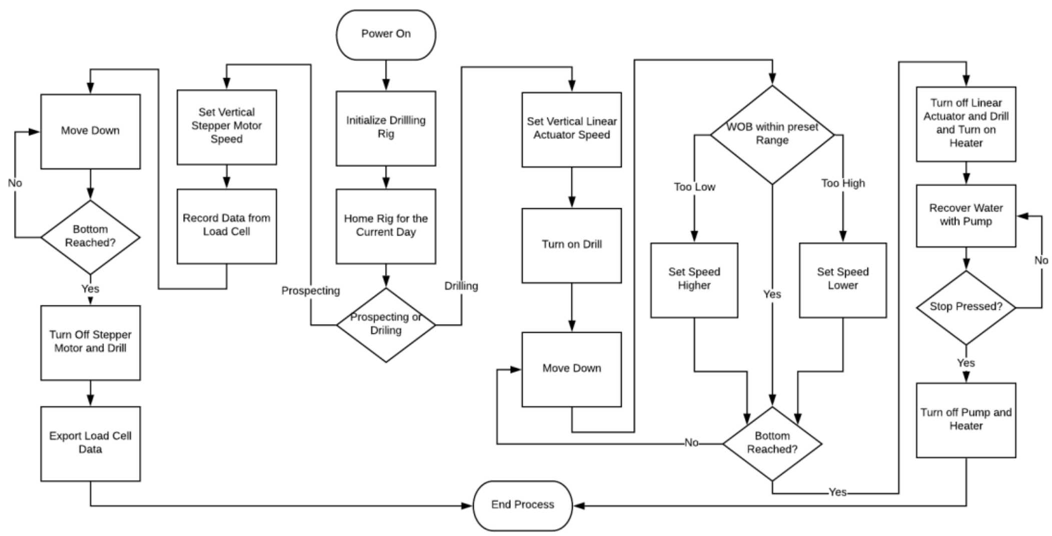


Figure 11: MIDAS III Program Flowchart

3 Integration and Operational Test Plan

Testing for MIDAS III is extremely important because it verifies the rig's ability to function properly in the simulated Mars subsurface conditions. Additionally, the test plan for MIDAS III allows for optimization of process variables based on the outcome of the test, which will tune MIDAS III to operate at peak performance. For testing, samples are prepared within a capped PVC pipe. These samples have a variety of overburden compositions that consist of combinations of ice, clay, mud, gravel, crushed concrete, and aerated concrete. When making a sample, water is first poured into the PVC pipe, and then the sample is frozen and the thickness of the ice layer is recorded. Then the layers of overburden material are added to the sample, and the thickness and position of each layer is also recorded. The sample is then frozen again to simulate the cold conditions of the Moon and Mars.

Before testing MIDAS III on a sample, process variables such as heating temperature, desired WOB, and plunging speed are set and recorded. MIDAS III's drill bit is then brought to the surface of the sample, and its depth and timer are reset. MIDAS III then begins plunging and drilling through the sample while temperature and WOB data is recorded. MIDAS III can be seen drilling into an ice sample in Figure 12. While MIDAS III is plunging, a blower is turned on to clear the water channel of debris that might clog it. Special care is also taken while testing to ensure that MIDAS III is running safely. When MIDAS III reaches the bottom sample, the drill probe stops plunging and drilling and it then begins its heating cycle. Once a Rod-Well with a sufficient amount of water is believed to have been created, MIDAS III begins the water extraction process by blowing air through the drill bit to clear any obstructions blocking the water line. The blower is then turned off while the pump is turned on to extract the water into the filtration system. When no water is flowing into the filtration system, or if the filtration system becomes temporarily full, the pump is turned off. Power is then provided to the electrocoagulation filter, and the filter is ran for 6-10 minutes to separate particles from the water. When this process is complete, a valve is opened that allows the water to flow into the mechanical filter. After the water goes into the mechanical filter, it is sent to the collection bottle outside of the system. This process of heating, pumping, and filtering continues until no more water can be extracted or the operator stops the extraction process. The drill is then turned back on, and the probe is withdrawn back up through the sample.

Figure 12: AIOP Drilling into Ice Sample

After testing, data such as the bit temperature and WOB graphs along with the amount of water collected are analyzed to tune performance strategies and process variables. The sample is also dumped in order to view the ice inside. The shape of the ice can help determine if the amount of heat applied to the ice was effective for creating a Rod-Well. One attempt at Rod-Well creation is shown in Figure 13. The WOB graph vs time and depth is also processed to generate a graphical makeup of the sample. Some data that was collected from an integrated test run is shown below. A WOB vs time graph while prospecting is shown in Figure 14. A WOB vs Depth graph from another prospecting test can be viewed in Figure 7 in section 2.4: Subsurface prospecting method.

Figure 13: Ice Cavity Created During Testing

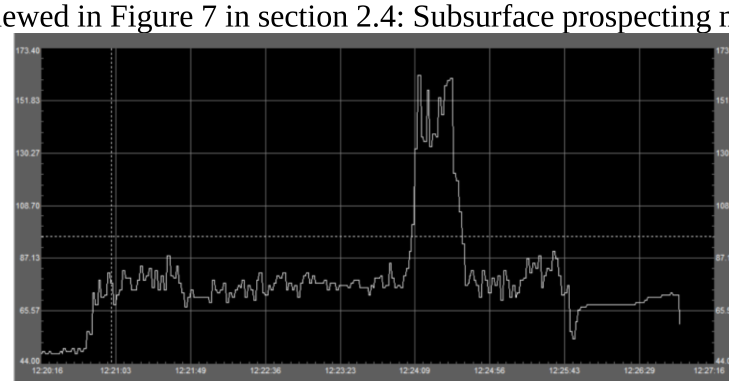


Figure 14: WOB while Prospecting

4 Competition Strategy

On the first day of the competition, the team plans to first install the 0.5 inch concrete bit to perform prospecting in the sample. On one of the far edges of the sample box, a prospecting test will be performed in order to profile the contents of the overburden. Then, the bit will be extracted, and the prospecting data will be processed to give insights into the makeup of the sample. After prospecting, the team will install the AIOP on MIDAS III and enter hands free operation. The AIOP will then plunge into a different area of the sample from the prospecting bit until the probe reaches its target depth in the ice. The temperature will then be turned up to a higher setting to begin melting the ice. Once a Rod-Well has been created, extraction of the water will begin. When as much water as possible has been collected from the well, the AIOP will be retracted from the overburden, and the excavation and extraction process will be repeated in another location. The excavation and extraction strategy on the same day of the competition will remain the same. WOB data will still be collected when plunging the AIOP in order to confirm or reject the initial prospecting findings.

5 Challenges

One early challenge that set the MRT back was an incident in January where the sprinklers in the lab froze and flooded the lab and everything in it. Two weeks of construction were replaced with water cleanup to minimize damage to MIDAS and lab equipment. Another challenge faced by MIDAS III was its heavy weight. While the linear rails provide smooth and reliable movement, they are extremely heavy. In order to counteract the weight from the new vertical linear rail, a carbon fiber frame was created to replace the heavier aluminum frame.

6 Design Changes/Improvements

The largest design change from the midpoint was changing the construction of MIDAS III's frame from aluminum T-slots to carbon fiber. MIDAS III was overweight with the aluminum frame, so it was replaced with carbon fiber as a lighter option. This new construction reduced the frame's weight by 5 kg. Additionally, MIDAS III's aluminum frame was prone to shaking during operation. The new carbon fiber frame was constructed to be more rigid while drilling.
Another small improvement from MIDAS III is that the vertical stepper motors' micro stepping ratio has changed. We have increased it by 4 times in order to reduce the plunging speed and WOB as the AIOP drills into the ice sample during prospecting mode. The stepper motors now require 3200 pulses per rotation instead of 800. In our testing so far, this reduces our average prospecting WOB from around 110 to 90. We will continue to experiment with new microstepping ratios.

7 Tactical Contingency Plan and Redundancies

The MRT will be taking many precautions in order to overcome unforeseen and expected setbacks at the competition. Firstly, to combat hardware failure, we will be bringing a spare part of every electronic component on the rig. If any mechanical or electrical parts fail during operation, we will halt the current process and initiate hands on mode to fix the problem. Once the problem has been fixed, we will resume drilling in hands-on operation in case the part should fail again.

MIDAS III also has several built-in contingencies. The AIOP contains two heater elements. If one fails, the other should still be able to operate, but the overall heat output will be reduced. MIDAS III also has two separate valves built into the electrocoagulation filtration system. If too much sediment blocks one valve, the other can be opened to bypass the excess sediment.

8 Project Timeline

The project Gantt chart is shown in Figure 15. Black stars represent milestones already reached by the team and green stars are milestones that the team will be extensively working towards the RASCAL competition.

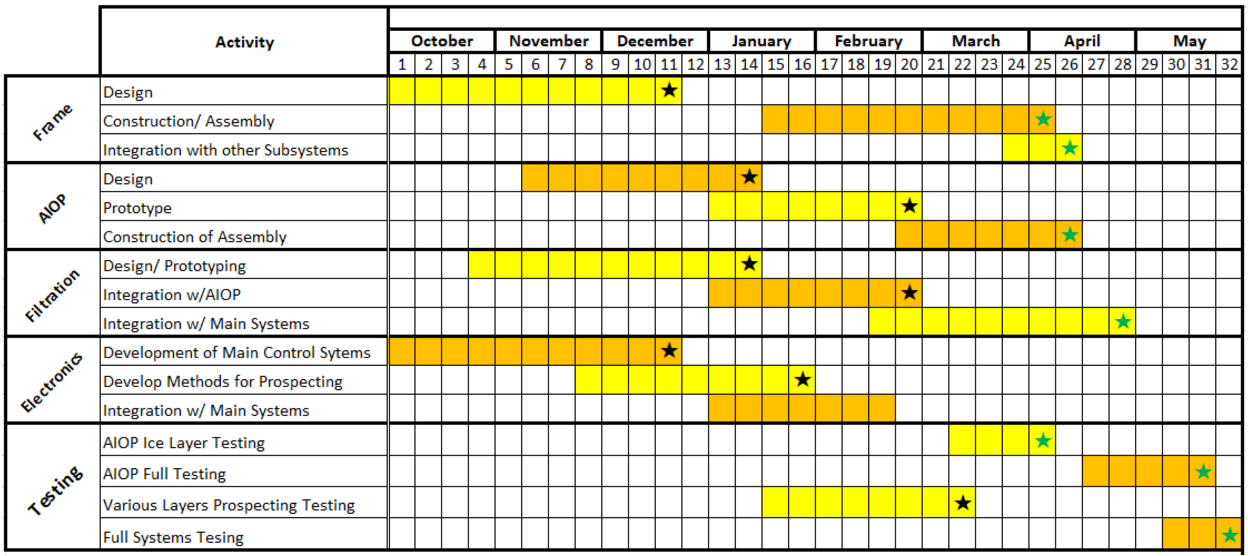


Figure 15: Team Gantt Chart

9 Safety Plan

During the fabrication and testing process MRT ensured that all members wore the proper attire when on site. Safety glass were required for all participates; including spectators while any machine was running in the shop. When working with carbon fiber additional measurements were instituted. In addition to eye protection; a mouth guard and latex gloves were worn to prevent fibers from causing injuries during the fabrication process. When using the Pliogrip panel 90 adhesive a minimum of three members were on site to assist with cleaning, mixing and applying to the joints of the frame to reduce the mess and time the adhesive normally takes. In the testing process MRT has everyone on site wear both eye and hearing protection, as the system is excruciatingly loud for long durations and even though unlikely, could still possibly toss material.

10 Paths-to-Flight

10.1 Mars

There are considerations that need to be made when designing devices for space operations. What works on Earth does not necessarily work on Mars or the moon. Any devices sent to space must survive exposure to high levels of radiation and elemental challenges unique to the location. MIDAS III in its current form is not capable of withstanding the environments of the Moon and Mars. Largely analyzed are critical components of MIDAS. Namely its structure, drilling capabilities, water filtration methods. It is assumed that providing electrical power for the drill rig's operations is already well researched and techniques for shielded computers are well practiced. PLC's as the computing source for a stationary ice drilling rig and prospecting platform will be examined.

PLCs will provide suitable control for drilling rigs on Mars and the Moon due to their durability and reliability in performing simple, repeatable automated tasks. Industrial screens for interfacing with the PLC can provide a simple and easy to understand control method for a drilling operator during all stages of water extraction. An operator will be necessary while drilling down into an ice deposit to ensure that the drill is functioning safely and properly. However, once the drill has reached a suitable depth for ice extraction, the PLC will be able to operate without any user control due to the repetitive water extraction process. Similar feats have already been performed by PLC systems in industry, as PLCs are often used for controlling remote oil and gas drilling and extraction.

The structure of MIDAS is primarily carbon fiber. Carbon fiber on Earth is a lightweight structural material. MIDAS has demonstrated that carbon fiber handles the continuous strain caused by hammer drilling. For Mars application there are additional factors that can affect the structure that do not affect it on Earth. First, Mars' gravitational pull is only about one-third of that on Earth. This is a benefit as the rig does not put as much force on itself as it does on Earth. Second, dust protection is a must. Mars is well known for having large planet-wide dust storms. This poses a risk to carbon fiber similar to what is on MIDAS III. Once the protective lacquer is worn away and the fibers are exposed, the structural integrity quickly erodes. Third, the temperature on Mars can range from -125 degrees Celsius to 20 degrees Celsius depending on where you are on the planet. Carbon fiber has been shown to have a higher shear strength as the temperature drops [1]. Rate of change in temperature can damage carbon fiber in the form of micro cracks. If the temperature drops too quickly micro cracks can form [1]. It is shown that carbon fiber tends to generate many micro cracks as it is cooling down and over time this may result in an overall weakness that could lead to failure of the structure. Some method to maintain a constant temperature is advised for Martian and especially lunar operation. If a nuclear based power system is equipped, excess heat can be used to keep the device's temperature constant. Carbon fiber appears to be useful material for structures that are to

Temp (°C)	No. of samples	Shear strength S_H (psi)	Deflection at peak load (in)	Standard deviation	% Standard deviation
-100	5	23633	0.046	783.87	3.317
-50	5	17733	0.035	1578.64	8.902
-5	5	14525	0.032	161.06	1.109
23	5	11286	0.029	3247.29	28.774
50	5	11280	0.030	107.41	0.952

Figure 17: Sheer Strength of Carbon Fiber Samples [1]

Samples	Temp °C	Total no. of events on decreasing the temp.	Total no. of events on warming to room temp.
1	-154	1930	33
2	-150	1280	186
3	-150	3789	82
4	-150	3495	249

Figure 16: Acoustic Events Detected Indicating the Formation of Micro Cracks [1]

be installed on Mars. Further research into looking at the stability of the carbon fiber when exposed to radiation on Mars is recommended before moving forward.

Currently MIDAS uses a pneumatic hammer drill. Hammer action has been demonstrated to be a necessity when drilling through harder surfaces efficiently and is not something worth sacrificing. A pneumatic drill will not work in a Martian environment. As an alternative a mechanical hammer drill or an electrical solenoid-based hammer drill can be used. The PDC anchor shank drill bit equipped on MIDAS III is well used in the coal and oil industry. Designed for high speed low weight on bit operation these bits are almost ideal for Martian environments where subterranean rocks have presented issues for landers looking to explore below the Martian surface (InSight). PDC bits do have a large flaw that comes in the form of heat generation. As the temperature from the drilling increases the risk of permanent damage to the bit increases. Things like the thermal conductivity and thermal diffusivity of the Martian rocks will play a major role in the rate that the drill bit heats up. Heat generated from the PDC bit presents another issue when it contacts ice. If the ice is heated rapidly and due to the low-pressure environment, there is a risk for a steam explosion which may damage the drilling rig. MIDAS III is currently equipped with a thermocouple that measures the temperature of the tip. While in practice this device is used with the onboard heater, the device can easily be used to make sure that the tip does not reach dangerous temperatures. To reduce heat buildup on Earth water is often pumped down and a slurry is produced that not only cools the bit but also aids in the removal of debris. Pumping water or another liquid is not an option on Mars so air may be a suitable replacement. The atmospheric pressure on Mars is around 4.5 Torr compared to 760 on Earth. Even with low atmospheric pressure a compressor can be installed that periodically compresses air to store for drilling operations. When pressure is low drilling stops, pressure is increased, drilling resumes.

To extend the PDC bit's life measures must be made to prevent detrimental events that damage the PDC bit or negatively affect the drilling operation [2]. "Bit whirling" occurs when the center of the drill bit begins to circle around the center of the hole. Whirling produces harmful vibrations that can chip the PDC bit. Three factors affect the bit whirling; operating parameters (WOB, Rate of penetration, Rotation speed), bit geometry, and rock properties. An anti-whirl bit is recommended to help reduce the bit whirling and sensors that detect when the bit begins to whirl and adjusts the operating parameters to reduce or eliminate the whirling. "Bit Balling" happens when material become trapped or attach to the bit. Material that becomes attached to the PDC bit reduces the rate of penetration and can increase the temperature of the bit. As discussed earlier some form of liquid or air will aid in clearing the debris as well as the geometry of the bit. An on-board bit cleaning unit would be beneficial to prepare the bit if multiple holes are needed. [cite reference here]

The electrocoagulation unit installed on MIDAS III may require the least amount of changes. It can be placed within a shielded container and operate properly. The only downside to electrocoagulation is that the anodes and cathodes require replacement over time. Spares must be brought along adding unnecessary weight.

With its current size MIDAS III is not suitable for Martian operation as a stationary rig. The ideal design for MIDAS III is a larger stationary rig located near or within a habitat or a rover with the AIOP system. With MIDAS III as part of a habitat system the rig can be located outside the habitat or within the habitat. The drilling process only happens once with MIDAS. Once the drilling is completed the Rodwell is formed and the system maintains the Rodwell from there and the drill bit is only used to heat the water. If the rig is located within the habitat atmospheric pressure and temperature do not pose a problem. If the habitat happens to be NASA's concept of an Ice home, MIDAS could supply the water to the dome first and then provide water for other functions. Large scale stationary drill rigs are not practical to end without humans. Using a rover equipped with the AIOP system small Ice deposits can be located and recovered. An electrocoagulation system can be installed onboard to perform filtration operations. However, due to the low atmospheric pressure, the ice will vaporize, and the vapor can be captured and stored with no need for filtration producing water that is free from toxins such as perchlorates which have been found in Martian soil. In the case of a large stationary rig electrocoagulation can provide quick water filtration but it requires that the electrodes be replaced regularly. A more ideal system would be a slow sand filter that is made with material found on Mars. The common design of a sand filter is shown in Figure 18. Slow sand filters 5 cm in diameter and 210 cm in height have been demonstrated to filter the secondary effluent of and activated sludge wastewater treatment plant and meet the requirements for excellent bathing water quality [3]. Slow sand filters can be scaled up and allow for the recycling of water placing less strain on the supply from the Rodwell.

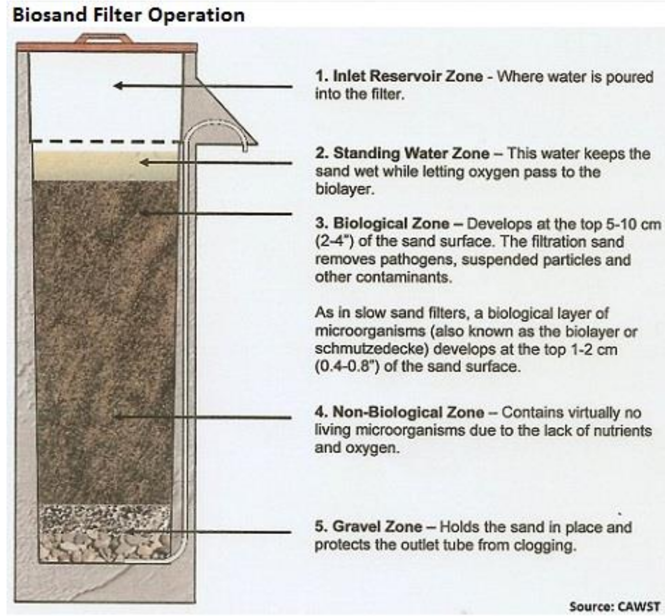


Figure 18: Construction of Sand Filter

10.2 Moon

MIDAS III's prospecting system's straight forward design reduces the number of modifications that are needed for a prospecting mission on the Moon and turns the prospecting system into an add-on for another mission. Regardless of how simple the system is, there are a couple of severe threats that my affect MIDAS III's prospecting reliability. The first of the challenges is the lunar regolith. Lunar regolith is a fine dust like particle that is electrically charged [4]. It can get into any open part of the machine and poses a threat to the electronics on board. The system must be completely enclosed to prevent the regolith from causing damage. Regolith also has a habit of staying attached to surfaces for a long time. Our robots that competed in the 2015 Robotic Mining Challenge still wears trace amounts of the simulated regolith material several years after competition. During drilling operations, regolith can attach to the drill bit and begin to build up causing the drill to heat up faster potentially affecting the drilling and measurement results. There is no temperature monitoring system nor a temperature reduction system currently in MIDAS III's prospecting bit and a bit with a high temperature is at risk of causing a rapid evaporation of frozen gasses causing an explosion that could damage the rig. With no atmosphere there is no air that can be compressed to use to cool the bit and natural cooling takes far longer in a vacuum. A method to negate the heat buildup of the drill bit will need to be made or at least a temperature monitoring system to cease drilling operation if the temperature reaches a critical level.

The Apollo 17 mission included missions to retrieve geological samples of the Moon. Apollo 17's deep drill which was 3 m in depth was deployed near the Moon's Camelot and Central Cluster craters [5]. This drill included rotary-percussion action 280rpm, 2270 blows/minute @ 40 in-pounds/blow [6]. Fluted walls outside of the core of the drill insured that the drill could penetrate deep surfaces. Figure X displays the drill's rod. This mechanism was successful in retrieving data for scientific use.

To expands MIDAS III capabilities on the Moon, similar strategies as the deep drill can be taken. This may include replacing MIDAS III's drill with one similar to Apollo 17's deep drill. Flutes on MIDAS III's rod can be made to better act on lunar regolith as well. This may require testing and validation via Earth based tests.

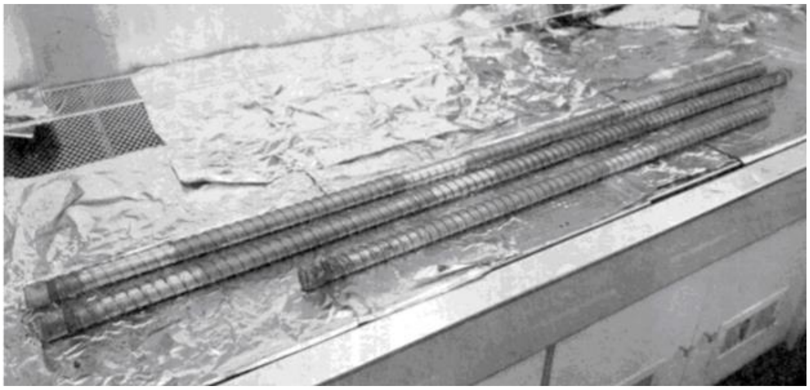


Figure 19: Sections of Apollo 17's Deep Drill

11 Budget

The estimated expenses for MIDAS III's construction, equipment, and supplies total to $9500. Travel expenses and registration fees total to $5000. Also, an $8000 service grant was received from Protolabs to make the AIOP. Other sponsors include the Benjamin M. Statler College of Engineering and Mineral Resources, the Lane Department of Computer Science and Electrical Engineering, the College of Petroleum and Natural Gas Engineering, the WVU Honors College, and the WV Space Grant Consortium.

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