MAY 16, 2018

TINAD

This Is Not a Drill

RASC-AL 2018

MARS: SPECIAL EDITION ICE CHALLENGE

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1. Introduction

As space technology progresses, the idea of a permanent human settlement on Mars is no longer fiction. The discovery of subsurface Martian ice deposits has prompted experts to evaluate the viability of using this native resource as means to aid exploration efforts. The ability to reliably harvest water provides foundational support for Martian based mass agriculture, oxygen generation, drinking water, and polymer and propellent production. However, these abilities are only possible if the technology for in-situ water collection is thoroughly researched and developed. In response to the Mars Ice Challenge issued by the National Institute of Aerospace and NASA, a prototype device to accomplish the task of Martian ice extraction was developed over the course of 9 months. Described below is the University of Tennessee Knoxville's design, TINAD, that offers a unique dual tool head system capable of removing, harvesting, and filtering water from a simulated test environment.

2. System Description

The TINAD mining prototype is comprised of five main subsystems shown in *Figure 1*. Two of these subsystems are tool heads used for the removal of overburden and the harvesting of ice. These device's names are the overburden excavation system and the Ice Melting Device (IMD) respectively. The remaining subsystems are to address the filtration system, the chassis and drive system, and the electronics. The following section describes in detail these subsystems.

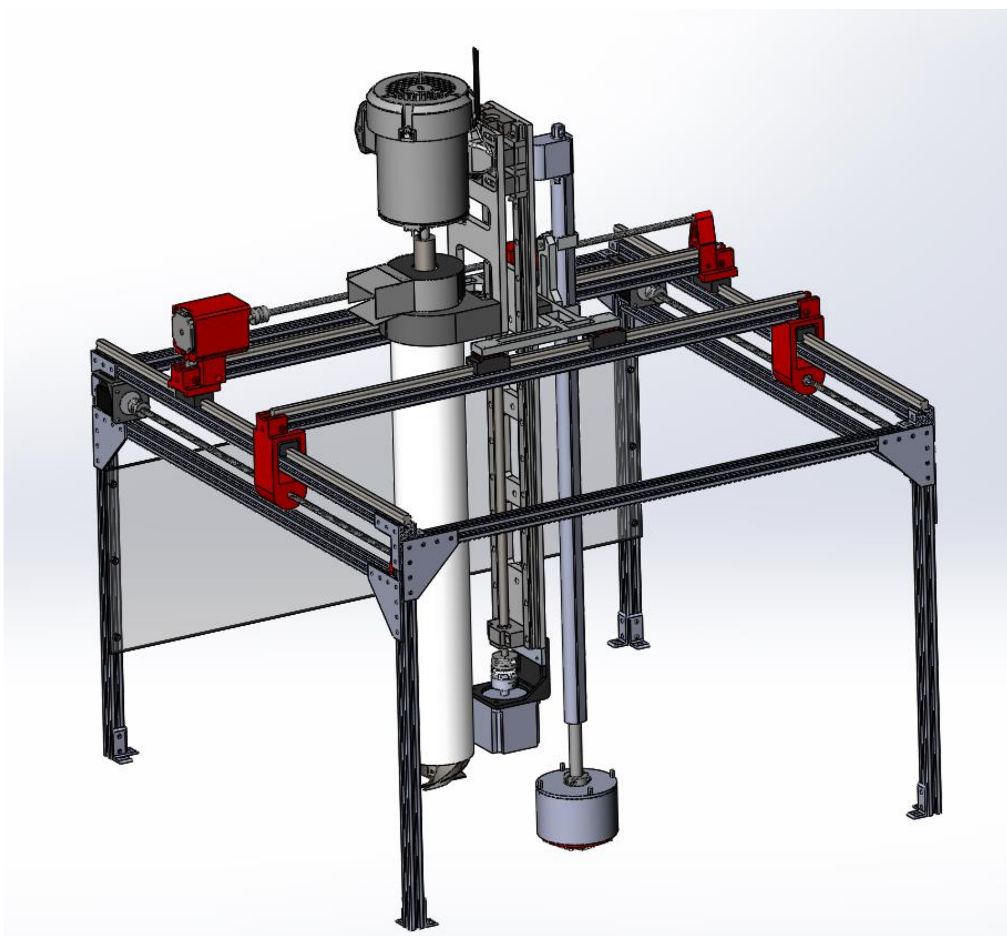

Figure 1: TINAD Martian Ice Miner computer generated model. Filtration and details of electronics board not shown.

2.1 Chassis and Drive System

When in operation, the overburden extraction system produces significant vibrational and static weight loads to the system. To combat these loads, the chassis had to be constructed from a strong material with very rigid joints while remaining light enough to meet competition constraints. The chassis is the basis of structure for the prototype. To allow tool head clearance to position themselves in the largest area possible, the chassis had to maximize its area in the horizontal plane. After four iterations, a final lightweight chassis that does not sacrifice rigidity was fabricated

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The final iteration is constructed out of 25 series aluminum extrusion. Aluminum extrusion was chosen due to its low density and strong cross-sectional profile. Aluminum is also corrosion resistant allowing the frame to be subjected to water and overburden without damage. The frame dimensions are 960mm x 960mm, allowing tool heads to access the most amount of testing environment while still allowing for a 40mm tolerance on either side. The maximum length of a horizontal member in the prototype is 960mm. This aluminum extrusion is rated to a yield strength of 241.1 $\frac{N}{mm^2}$ [1]. To prove its strength in the chassis, a simulation was performed *Figure 2* shows a fixed end, centrally applied force simulation on this maximum length of extrusion. Results show that with a 100 lb. applied force, the member only deflects 1.73mm [2].

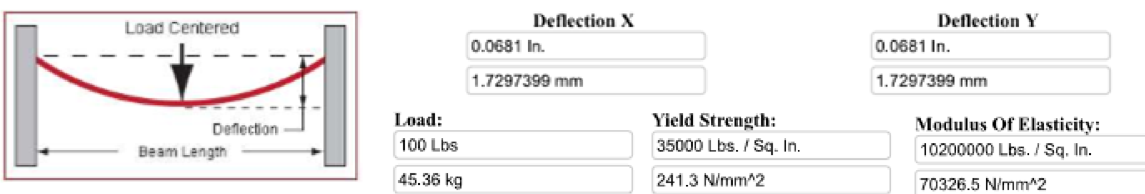


Figure 2: Aluminum extrusion load simulation with 100 lb. applied load.

A total of 12 members were used in the chassis construction. These members are secured using external fastening brackets. External mountings are not the strongest methods of connecting extrusion members, but they are the most adaptable when undergoing multiple design iterations. In total, 18 external brackets were used to secure the members together.

The drive system secured to the chassis assembly is capable of controlling motion in both horizontal directions. Each tool head has independent vertical motion control, the details of which are described later. Both tool heads are mounted to a central quarter inch thick aluminum plate called the “Carriage.” The Carriage is mounted to linear motion drive rails in the X and Y horizontal directions. The guide rails offer a platform for low friction linear motion while being able to support a significant load. The X direction is driven by dual NEMA 23 stepper motor ball screw assemblies. The Y direction is driven by a solitary NEMA 24 stepper motor ball screw assembly. Ball screw drive was chosen over belt drive for increased positioning accuracy and rigidity. The total drive system assembly is also shown by *Figure 1*.

Additionally, 3D printing was used extensively in the fabrication of this drive system. The extremely fast time from design to physical part was essential for quick design changes post testing. These parts allowed for complex internal geometries for components such as ball screw, linear guide rail carriage, and aluminum extrusion integration.

2.2 Mounting

The drilling system uses two right angle brackets on each of its four legs to mount directly into two standard 2x4 wooden boards that are connected to the test stand. In total, eight large wood screws are driven through the brackets to create a secure, static connection to the test stand. Testing has proven that this mounting solution can withstand the vibrations produced by drive system and auger operation. The mounting brackets can be viewed in the computer model of the prototype in *Figure 1*.

2.3 Digging Device

The overburden excavation system, shown by *Figure 3.1*, is comprised of two primary subsystems: the motor-auger subsystem, and the independent z-axis linear actuator. These subsystems, when combined, allow for the efficient removal of overburden by means of sweeping the excavation system over a given target area via the chassis' drive system. This type of overburden removal system was determined to be the most effective method of excavating and transporting Martian simulant regolith due to its power, durability and reliability.

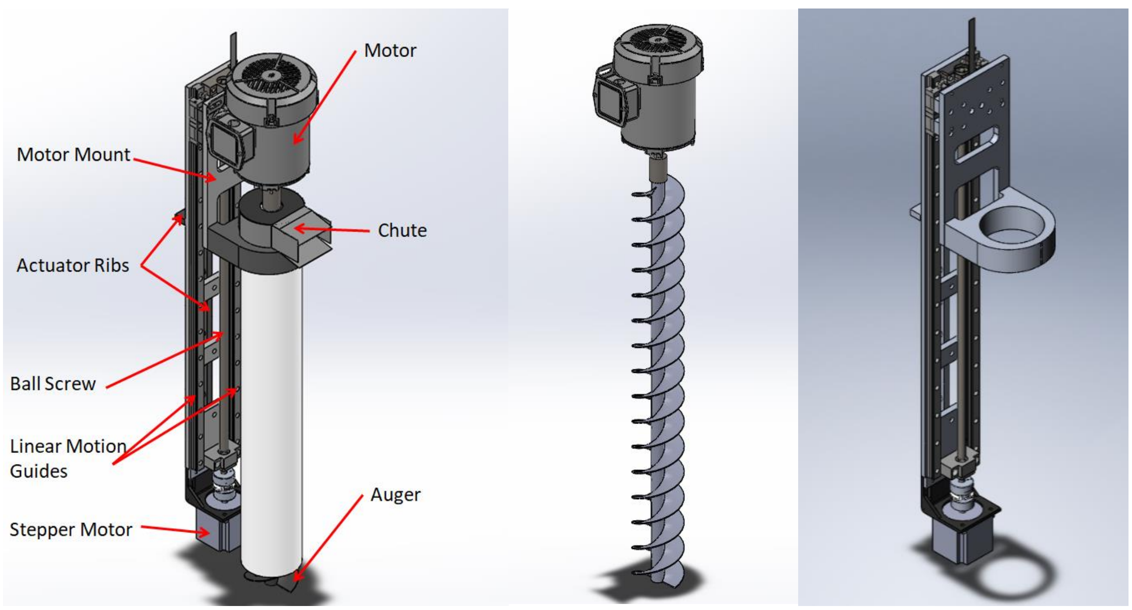


Figure 3.1, Figure 3.2, Figure 3.3: Overburden excavation system assembly, motor-auger subsystem, and vertical linear actuator subsystem.

The motor-auger subsystem is composed of a ½ HP AC motor and a machined auger shown by *Figure 3.2*. It is an earth proven technique of dirt excavation and testing of this system has shown promising results for Martian applications. The myriad of electronic and weight constraints placed on the motor was an initial challenge when trying to source a motor. In the end however, a more than acceptable motor was found meeting all competition constraints.

Similarly to a typical auger, this system uses a metal spiral to transport overburden upwards. The end of the spiral is exposed allowing it to collect overburden while passing. This overburden is later ejected from the auger spiral at the top of the shaft. While operating, imperfections in manufacturing cause a significant vibration in the system. This vibration is absorbed by the chassis but is also transmitted into the overburden. This acts as a supplemental percussion tool helping to break apart overburden before extraction.

After the overburden is spun to the top of the Auger, it is ejected out of a gap in the Auger's tube and into a sheet metal chute labeled in *Figure 3.1*. This chute slows down fast-moving debris and guides it into a controlled stream. This stream will eject overburden onto the lid of the test stand and the tarp around the testing environment. Some overburden will not be ejected all the way out of the testing environment and land back inside. This overburden will simply be picked up on another pass of the Auger and be ejected again.

The independent z-axis linear actuator subsystem *Figure 3.3* vertically mounts the motor-auger subsystem and allows for the auger to be raised and lowered independently of the drive system to allow for optimal regolith removal. The primary features of this subsystem include: a ball screw, stepper motor, linear motion guides, motor mount, and actuator ribs. The linear actuator is powered by a NEMA 34 stepper motor that has control of the auger's digging depth. This is combined with high quality linear motion guides, which provide stability, accuracy, and minimal friction for the motor/Auger system as it traverses vertically. This relieves great amounts of stress off of the linear actuator itself and adds necessary rigidity to the system. The motor mount provides an integration point for the two subsystems, and also attaches the tube which surrounds the auger. The actuator ribs, fabricated out of 6061-T6 Aluminum and anchor into the drive system, are the integration point between the excavation system and chassis. These ribs are fashioned in both the vertical and horizontal direction in an effort to mitigate deflection from weight and excessive operating vibration to the assembly. Collectively, an advantage of incorporating an independent z-axis linear actuator system is that if the auger becomes jammed or damaged in some way, the IMD is unaffected.

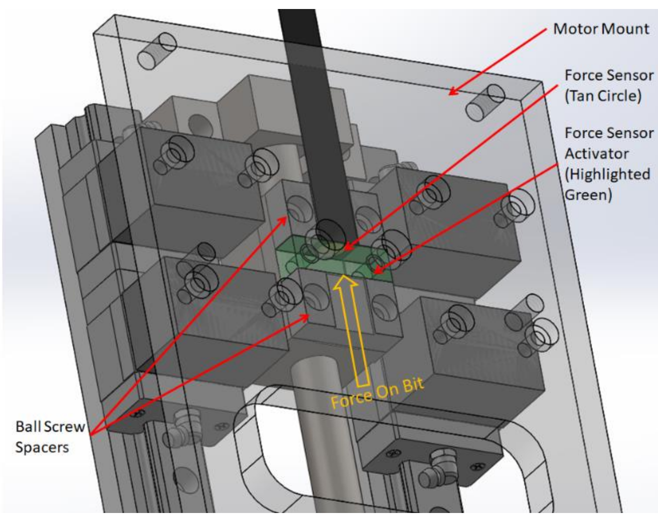


Figure 4: Overburden extraction system's weight on bit sensor diagram.

In order to measure weight on bit, a FlexiForce sensor is sandwiched in between the force sensor activator and the ball screw spacers shown by *Figure 4*. The force sensor activator is directly attached to the motor mount and not the ball screw. When the ball screw traverses down, the top ball screw spacer pushes against the force sensor activator and moves the entire motor and auger assembly with it. When a force is pushed vertically against the auger, the force is transferred through the auger and into the force sensor activator. The force sensor activator then exerts that force on the force sensor. Software prevents excessive force exerted by the auger by retracting the system if force readings get too high.

2.4 Ice Melting Device

The Ice Melting Device, or IMD, is the next iteration of the water harvesting device first conceived by this team in the 2017 Mars Ice Challenge. It is the second tool head of the system and is inspired by a coffee can. In layman's terms, the IMD is a heated metal cylinder that is lowered into the test bed to initiate a phase change from solid ice to liquid water. A full CAD model of this system is shown by *Figure 5*. The IMD is heated via conduction of a mica resistive heating element. The outer shell and the lid of the IMD is fabricated from stainless steel. The remaining structure is made from solid copper due to its high heat conductivity properties (390 $\frac{W}{mK}$) [3]. To prevent heat loss from the ambient air temperature, Pink Panther fiberglass insulation is packed inside of the heated cylinder.

Because the copper has a much higher thermal conductivity compared to stainless steel (16.2 $\frac{W}{mK}$) and fiberglass insulation (0.034 $\frac{W}{mK}$),the majority of the heat transfer is concentrated to the bottom of the IMD where it makes direct contact with the ice surface [4]. To maximize ice surface contact, copper pin fins are secured to the bottom of the IMD. These pin fins also help to account for uneven surface either during testing, or on Mars. $\frac{W}{mK}$

The IMD is attached to the chassis and driven vertically using a linear actuator. The IMD connects to the actuator shaft using two shaft collars that clamp the lid of the IMD together. A small gap between the top shaft collar and the lid of the IMD is left to fit a FlexiForce© sensor that records the weight on bit force for this tool head. The actuator is capable of pressing down with 222 N, but software will prevent the actuator from exerting past 150 N. The stroke of the actuator is 1 meter. Due to the 7-13 cm gap between the bottom of the chassis and the overburden, the IMD will not contact the bottom of the testing environment.

One noted problem and solution is the heating element can reach a maximum temperature of 600 °C. The fiberglass insulation is only rated to 540°C. Exceeding this temperature creates a fire hazard and could cause damage to the system. To correct for this issue, power to the heating element will be controlled manually while monitoring temperature output from an embed thermocouple.

To extract the liquid water, a peristaltic pump is connected into the top of the IMD. To improve the downstream filtration process, water will not be pumped directly from the bottom of the melted ice pocket where most of the heavy contaminants are expected to settle. This pump was chosen due to its unique ability to pump dry and to pump very turbid liquids. This pump is also cable of pumping vertically up to 25 feet. The only significant drawback of this pump is its low volume flow rate capable of only pumping 0.1 liters per minute.

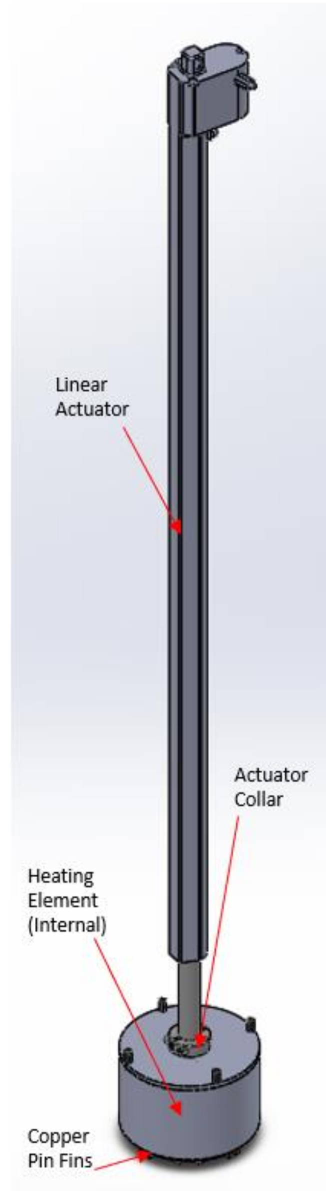


Figure 5: IMD diagram

2.5 Temperature Considerations:

In the simulated Martian surface, overburden can experience temperatures as low as -10°C. Both the Auger and the IMD are capable of sustaining operation in this temperature condition in different ways. The Auger is not susceptible to freezing damage due to the high amounts of friction it generates both by contacting the overburden, and its containment tube. The heat output from the friction is expected to offset any cooling done by the environment's temperature. The Auger is programmed to return to home above the surface when not in use to prevent freezing.

The IMD is designed to heat itself and its environment. The heat output by its resistive heating elements is more than enough to counter the effects of the cold environment. In addition to this, the IMD contains no moving parts that are susceptible to freezing damage. The water extraction system, however, will be unable to pump water if not in liquid form.

2.6 Filtration

Once water passes through the peristaltic pump it is deposited into a simple gravity fed filtration system. This system is housed in a clear acrylic tube mounted to the corner of the chassis. The acrylic construction allows for operators to view water levels inside the system to prevent backups due to excessive water flow. The filtration system is divided into two separate stages. Stage one uses a funnel sieve filled with a non-homogenous mixture of sand and zeolite pebbles to remove larger particulates from the water. Stage two is designed to filter the remaining impurities. Research shows that clay particles are typically around 2μm in diameter [5]. 3D printed supports are used to house 2 layers of laboratory grade filtration paper capable of removing particles less than 2μm in diameter. Testing of this system has proven this system capable of producing a visually clear water output from an extremely turbid water input.

2.7 Electronics and Controls

The TINAD control system consists of two main parts. Direct control of the system is done through an Arduino Mega coded in C++. This Arduino has direct control over all electronic components in the system. The second part of the system is a MATLAB front end that gives an operator control of the system. Control inputs are connected to the MATLAB code which then forwards commands to the Arduino. This is shown graphically by *Figure 6:*

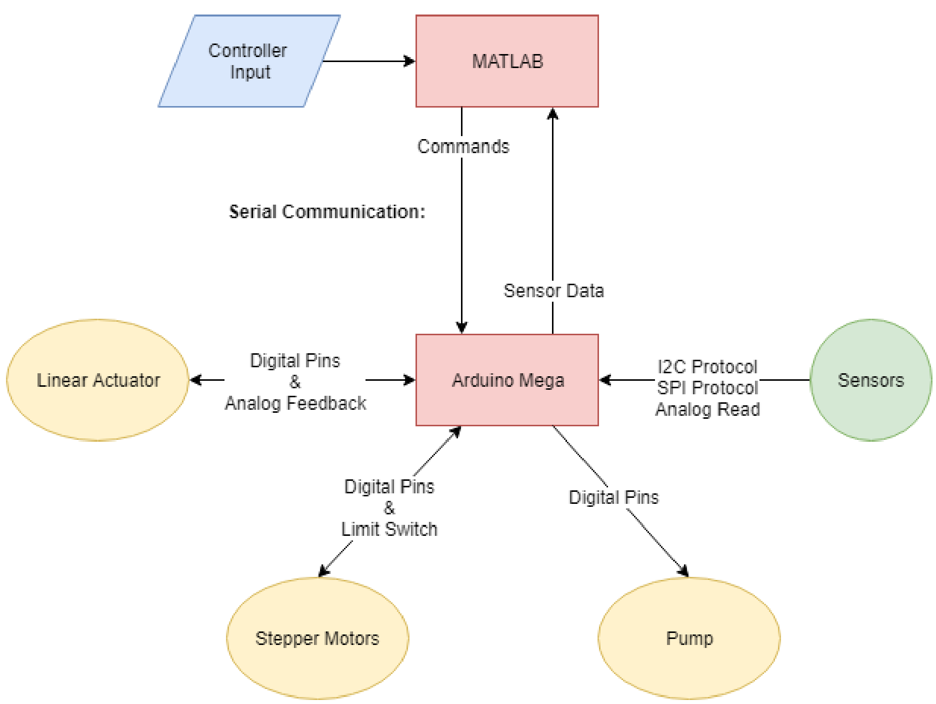


Figure 6: Electronics and programming layout diagram.

The operator controls the system using a combination of button and analog stick inputs from an Xbox controller. Additional system inputs are given by an external control board. This control board houses a potentiometer for digging operation and an emergency stop button. The combination of these input methods yields a precise and simplistic control system for the operator. The MATLAB code also produces real-time graphs of current draw, weight on bit measurements for both tool heads, and IMD temperature. All of these variables are recorded and stored with a timestamp to the computer's hard drive and can be referenced later.

2.8 Technical Specifications

Table 1 tabulates the TINAD drilling system's technical specifications. Please note, system mass and volume were recorded at the time of report submission. These have been fluid numbers and are both expected to drop before the competition.

Table 1: Subsystem technical specifications.

2018 Mars Ice Challenge TINAD Technical Specifications:	
System Specifications:	
System Mass:	67.7 kg
System Volume:	1.765 m^3
Chassis and Drive System Specifications:	
Maximum Chassis Load (Vertical):	11516 lbs.
Expected Chassis Load (Vertical):	100-120 lbs.
Overburden Extraction System Specifications:	
Drill Bit Length:	835mm
Maximum Drilling Speed:	1700 RPM
Optimal Drilling Speed:	450-500 RPM
Drilling Torque:	2.6 ft-lbs.
Maximum Load:	100 lbs.
IMD Specifications:	
Maximum Temperature:	540 deg C
Maximum Load:	50 lbs.
Electronic and Programming Specifications:	
Onboard Computer:	Arduino Mega
Communications Interface:	Custom GUI and Xbox Controller
Software Used:	Solidworks, MATLAB, C++, and Qt
Minimum Power:	19.2 Watts
Maximum Power:	156 Watts

3. Design Changes/Improvements:

Since mid-project review, TINAD has undergone changes to improve IMD melting efficiency, reduce system mass, and improve system controllability. IMD insulation was initially designed to use a machinable ceramic, but testing proved that this would be of marginal benefit when compared to basic fiberglass insulation home insulation. Additionally, the walling of the IMD was changed to stainless steel 304 from copper to direct 12.6% more heat into the ice.

The idea of flocculation was crossed out due to limited operation time before maintenance. Carbon like filters and laboratory grade filtration paper has proved itself an effective alternative. By moving the pump intake up, less impurities are able to enter the system.

The initial proposed Auger motor has been changed to a 3-phase motor to allow for RPM control through a variable frequency drive. The variable frequency drive can also reverse direction to clear jams if needed. Many parts have received copious amounts of weight reduction driven design changes. To reduce complexity of overburden ejection, the chute has from the original collapsible slide design to a single small sheet metal component. To help reduce system vibration, the chassis height has also been lowered by 12 inches.

4. Challenges Encountered:

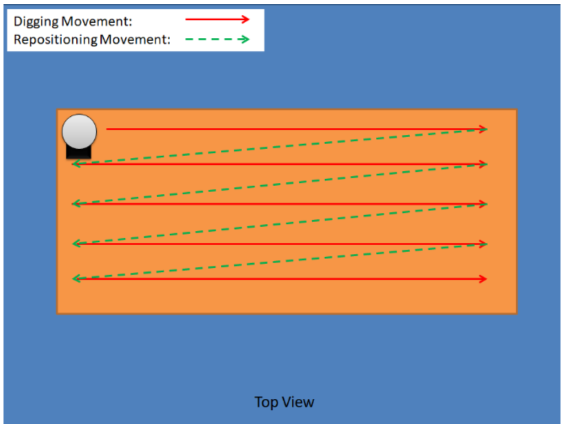
The main challenge encountered was weight. It has proved difficult to design complex mechanical systems that require such high rigidity and strength while remaining under a mass constraint. Many components have been changed to different materials or changed in size to reduce weight. 3D printed components were crucial to reducing weight. Infill percentages on these parts could be controlled to reduce weight.

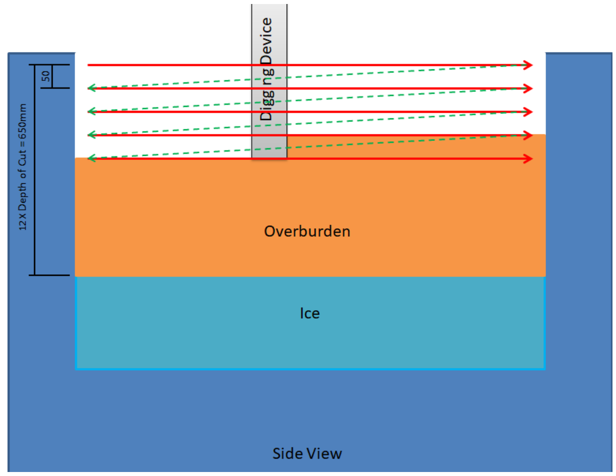
Another challenge encountered was the complexity of a dual tool head system. This was difficult to work with when operating in such a small area. The sizes of the tool heads had to be optimized so that each tool would be able to reach as much of the testing environment as possible. The current configuration and sizing does a good job of allowing as much movement as possible, but room for further optimization still exists.

The last significant challenge was due to a fabrication error in the auger spiral. A small bend in the central shaft caused a very serious vibration that had to be fixed. This was a serious slow down and pushed back testing. The final auger spiral still has slight defects and produces vibration. 3D printed damping pads were made to brace the carriage and absorb some of this vibration.

5. Competition Strategy:

The inspiration of the prototype, This Is Not A Drill, comes from the mining strategy. The auger sweeps across the overburden in rows removing approximately 2 inches of material at a time. The auger is then lowered to start a new layer. This process is repeated until ice is struck as detailed by *Figures 7.1 and 7.2*. Then the IMD begins to make cores into the ice, pumping water out as it goes.





Figures 7.1 and 7.2: Respective top down and side view of overburden removal device's path.

6. Integration and Testing:

Testing has been progressively preformed after each design iteration. Data has to used to aid the design of the following iteration. Each subsystem has undergone individual testing multiple times. An integrated test was performed where each system was mounted to the chassis and operated. The chassis had no support issues, the drive system was able to position tool heads accurately and quickly, the overburden extraction device reliably and efficiently removed regolith, and the IMD successfully harvested water. Pictures from this testing are shown by *Figures 8.1* and 8.*2*.

Figure 8.1 and 8.2: Overburden extraction device operating to remove regolith from a simulated test and The IMD harvest water from another simulated test respectively.

This integrated test suggested that a rubber damping pad be added to the back of the overburden extraction device's NEMA 34 stepper motor bracket to prevent the IMD from contacting it from vibration. The IMD also must be assembled using thread lock screws to prevent unwanted disassembly from vibration.

7. Contingencies and Redundancies:

It is in the nature of prototypes to have a high probability of failure during operation. Due to this issue, contingency plans have been developed to perform onsite maintenance, repairs, and replacements in necessary. Team members assigned to operate the prototype at competition were chose for their knowledge in each part of the system. Team tool sets and basic machining equipment will be brought to competition to assist in these efforts. Spare electronic components have also been purchased. It is expected that electronic problems yield the highest chance of failure in this system. Specifically, replacement stepper motors, stepper motor drivers, Auger motors, and Arduinos are on standby in case of breakdowns. Additionally, copies of all 3D printed components have been printed. Some mechanical component replacements have been purchased too, although these parts are less susceptible to failure. The Auger's tube is another specific possible failure point and additional material has been purchased to cover it.

Testing has made it obvious that manual control is the best route for control. The idea of an autonomous system was heavily debated, but the risk of failure in this system is too high to trust without human input. With rigorous testing and additional time, an autonomous system could be developed.

If the IMD heating system was to fail entirely, the Auger could be used as a means to scrape ice in small layers. The ice would be melted by friction and pumped up with a still functional peristaltic pump. This is an untested last resort method as this technique has a high chance of permanently damaging the Auger.

8. Safety:

There is an ever-existing possibility of mechanical or electrical failure in a dynamic prototype. Both mechanical and software-based safety methods are implemented in this system to ensure the well-being of operators and spectators. A physical, clearly labeled "Emergency Stop" button is wired into the electronics of the system that will disable any electricity to moving components. This button is well tested and proven to work. An additional software-based emergency stop is also programmed into the GUI of the control system. Some potential hazards during the operation of this system are detailed below.

The Auger is capable of operating at high rotational speeds while moving both laterally and vertically. The edges of the Auger's spiral shaft are sharp in places and can cause harm to any objects unfortunate enough to contact it. Thus, all team members and spectators must keep their distance from the machine during operation of the Auger.

There is a possibility of the Auger launching uncontrolled debris in the close vicinity of its operation. This uncontrolled debris is caused by the fast-moving tip of the Auger striking overburden in an unlikely way and should be differentiated from the debris that is purposefully ejected from the system in a controlled manner. Operators and spectators must be wearing safety glasses during operation. Please note that during testing of the Auger, any uncontrolled debris was contained by our simulated test bed and is expected to be contained during the competition.

The IMD is designed to reach high temperatures and remain hot during its use. It is hot enough to burn skin and melt some plastics. Non-insulated objects and tools should be kept away from the IMD during its operation. The operators have access to a digital temperature read-out in real time to know when the IMD is safe to handle.

9. Timeline:

Figure 9: TINAD development timeline.

10. Path-to-Flight:

The TINAD drilling system needs several modifications to be operable under Martian conditions. The majority of these changes are prompted by the properties of the Martian atmosphere. Specifically, the water extraction and filtration processes need a moderate degree of changes to adapt to the pressure and temperature differences. Other necessary system modifications include changes to the electronics housing and optimal motor RPM.

Mars's average atmospheric pressure is approximately 600 kPa, where water naturally exists only in its solid or gas phases [6]. *Figure 10* shows the water phase change graph. When ice is melted on Mars, it evaporates immediately. This happens because Mars' atmosphere is near the triple point of water [7]. However, by slightly increasing the pressure the ice is exposed to while being mined, the water will not become a gas. The TINAD drilling system needs to take advantage of this property to work on Mars. One method to control pressure is to have the IMD create a seal over the surface it is mining. This seal will close the system and allow the pressure to be control by the actuator. The water will

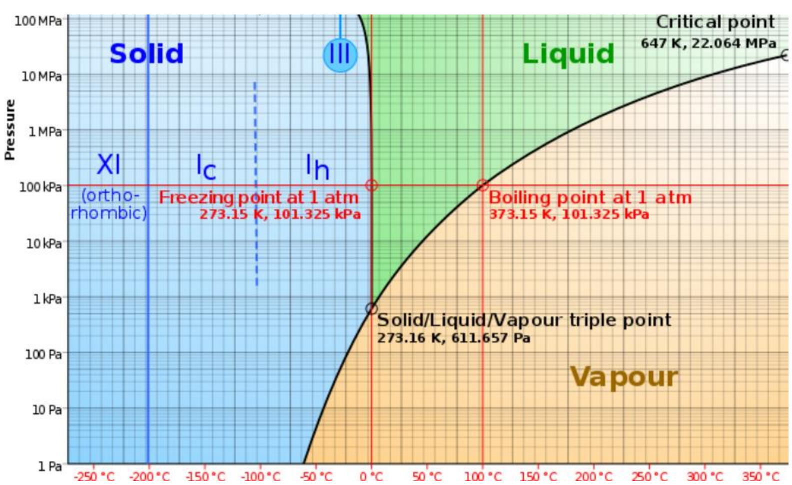


Figure 10: Water phase change diagram vs. pressure and temperature

be transported upwards by the peristaltic pump and through the filtration system before exiting to a pressurized holding tank. This tank could absorb UV light and release perchlorates in the water for sterilization from potential biological traces [8]. This additional cleaning process eliminates the need to evaporate and then condense the water again. Of course, other tank systems could be used for research of harvested water. It is important to note that the current filtration system is not sustainable for more than three months due to the filtration paper's life expectancy.

The use of redundant pump systems would help to improve this system's life-span. If one pump becomes compromised a valve system could divert harvested water an alternate route.

Extreme cold temperatures are expected to cause problems with the epoxies used in IMD fabrication. To prevent failures, further research and testing would be required to source more suitable composites. One idea if to use carbon fiber reinforced phenolic composites developed by NASA for heat shielding applications [9].

The competition allows for immediate device feedback, allowing for semi-autonomous and manual modes of the software control system. However, signal delay from Mars to Earth requires a highly-autonomous adaptation [10]. Programming would need to be modified for near fully autonomous operation. Additionally, electronics would need proper shielding from dust as well as a temperature regulated environment such as the Warm Electronics Box used on the Mars Exploration Rover. Advances in Radiation Hardened By Design, would need to be considered to protect electronics from long-term radiation exposure [11].

TINAD would also need a reliable energy source. Solar is not effective due to limited charging and energy storage options [12]. The most feasible option is to use an ASRG because of its efficiency of 26% and an operational lifespan of at least 17 years [13].

To help with sustainability to the electronics, self-diagnostics could be integrated to troubleshoot issues. Operations will be migrated to an autonomous framework to allow a smoother operation of troubleshooting programming. This would require the addition of more sensors for necessary self-diagnostics, as well as a camera for system monitoring by remote human communications. TINAD would also be outfitted with a proper channel to communicate with Earth similar to that of rovers, passing through the 2001 Mars Odyssey satellite to the Deep Space Network of Earth to maximize communication times [14].

Changes to the overburden extraction system are also necessary. *Equation 1* describes the minimal required rotational speed to elicit regolith movement up the auger [15].

$$Equation\ 1: N = \frac{30}{\pi}\sqrt{\frac{2g}{D}\frac{\tan(\alpha) + \mu_s}{\mu_w}}$$

μ_s stands for the coefficient of friction between the surface of the auger and the overburden. μ_w is defined as the coefficient of friction between the overburden and the auger tube. Alpha is the pitch angle of the auger. For efficient digging, the value of N needs to be reduced. Reducing N will decrease RPM of the system and inherently use less power. Applying low friction coatings to the auger spiral and reducing the pitch angle would help to reduce the RPM.

There are geographic locations on Mars that are preferable for TINAD due to the depth to the ice. The analysis of the planet's ice composition from Voyagers 1 and 2 determined these preferred locations lie at 50° latitude where continuous shallow ice was reported to be within 0.3 m [16]. Unfortunately, Mars' axis of rotation would leave TINAD most vulnerable to freezing during winter periods in these regions. To avoid the damage of the auger device from freezing, the inner auger would need to be made of metal while the outer sleeve is made of a composite. When introduced to extremely cold temperatures, the auger will contract within the sleeve, decreasing the efficiency of the dirt removal process but will continue to be operational. To avoid the adherence of water or vapor particles to TINAD that would cause freezing damage, a hydrophobic coating can be applied before deployment, such as resilient coatings used for insect adhesion mitigation on airplanes [17]. Additionally, with today's technology landing on elevation greater than 2 km is too risky [16]. This leaves limited regions of interest where finding ice lies within 5 m of overburden. Ultimately, depending on the purpose of the Mars mission, traveling to the shallower ice zones for water extraction may outweigh the cons.

To maximize the life span of the Auger, it would be wise to bore holes where the probability of digging through rocks while seeking ice is minimized. It was reported that using a 10 cm diameter Auger boring 0.5 cm in depth, the chances of encountering rocks is forty percent. To decrease these odds to ten percent, an Auger with a diameter of 5 cm would needed to be used. This change would decrease power required to operate the digging system, but also reduce the speed of digging.

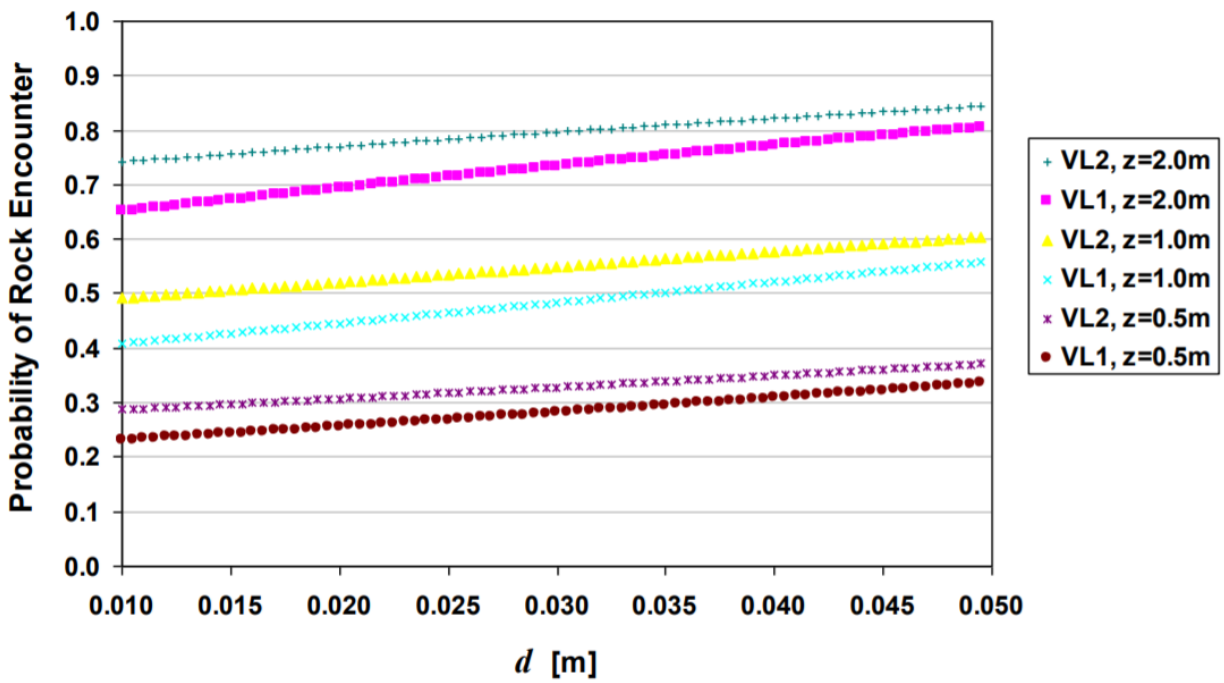


Figure 11: Probability of rock encounter vs. auger diameter.

Note that these probabilities were only recorded at Viking 1 (VL1) and Viking 2 (VL2) landing sites, where digging may not even be an option for the TINAD system. *Figure 11* shows that the probability of encountering rocks increases linearly with respect to the Auger's diameter [13].

11. Budget:

Table 2 shows a detailed breakdown of all team finances. From the 2017 Mars Ice Challenge, the team continued to use tools donated from the Mechanical, Aerospace and Biomedical Department at The University of Tennessee Knoxville. The value of these tools is $715.00. The team also reused a small number of items and materials purchased from the 2017 stipends. The cost of reused items is approximately $300. Additionally, the team applied for and received a generous grant from the Tennessee Space Grant

Consortium totaling $12,521.00. This additional funding allowed the team to purchase necessary tools, extra workshop facilities, and higher-grade materials used in the final prototype. The team also received a private donation of $300.00. Lastly, many university employees graciously donated their time and expertise to fabricate more complex components of the prototype. In total, the team's funding was $22,821.

Table 2: TINAD development financial breakdown.

2018 Mars Ice Challenge Finances:	
Income:	
Default Stipend	$10,000.00
Tennessee Space Grant	$12,521.00
Private Donation	$300.00
Expenses:	
Item:	Cost:
Chassis and Drive System	1500
Auger	4000
IMD	1000
Filtration	500
Electronics	2000
Workshop Upgrades and Additional Tools	5300
Competition Spares	2000
Item Shipping	3000
Travel	3500

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