Alfred University's RASC-ALFRED team presents Sub-surface Archimedes Screw System "SSASS"

RASC-AL Special Edition: Mars Ice Challenge

Technical Report

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University: Alfred University

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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 Sub-Surface Archimedes Screw System (SSASS) 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 simple drilling system to a depth of several meters. The ice is then extracted and melted in a collection hopper and sent through a filter.

System Description:

- Mounting System

The system is mounted to the container by four bolts. This was done to make the attachment of the SSASS 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.

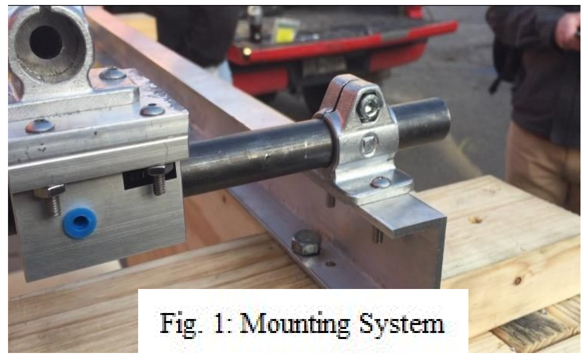


Fig. 1: Mounting System

- System Excavation Operations

The system begins by drilling a shallow hole for the auger to rest in when it drills at an angle. The first servo will tilt the drill assembly and the second servo motor will lower the auger and the system will begin drilling. The auger will continue to run until it has reached our specified depth so as not to hit the bottom of the ice chest. Once the ice layer has been reached, the hopper will be opened and allow it to fall into the filter system, and the heating coil will turn on. By using this drill at an angle it allows us a very simple and robust system capable of drawing the ice up to a hopper to be melted which is definitely preferred.

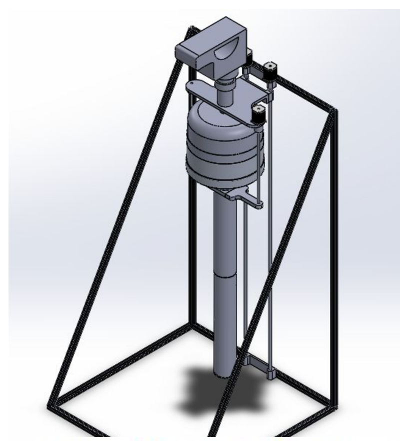
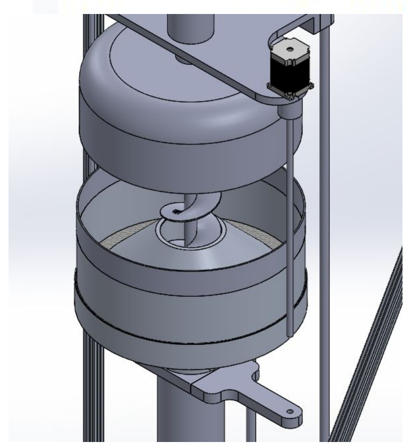


Fig. 2: System in Operation

- Water Extraction System/Technique

Once this point is reached, the heating coils will be turned on and the ice will be melted. As the ice is being melted it will flow through gravity fed filters. The filters for the water get progressively more fine to catch smaller particles.



- Filtration and Water Collection

The water will be passed through filters by gravity. The bottom of the collection hopper 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 debris that could fall in from the overburden.

- Solution to Deal with the Overburden

The SSASS system utilizes a "tilted drill" system to handle the overburden. This system keeps the unwanted substances and particulates away from the ice. The ice is brought up to the hopper after allowing the overburden to fall off the drill assembly and melted by direct current, once the ice is melted, it is gravity fed through a filter. The filter system should be able to catch most of the overburden big or small if it does make it through.

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

With the friction of constant drilling, our ability to control the drills angle, and a relatively powerful drill we are not concerned with the auger freezing as it should not affect our system.

- Control and Communication System

The core of the control system is an Arduino. The Arduino is a microcontroller through which all of the commands are received and distributed. Connected to the microcontroller are three drivers, and two relays. Each of the drivers are connected to the servo motors. The relays are connected to the heating coil and the drill motor. In addition, there is a load cell connected to the microcontroller to ensure that we do not exceed the 150 newton force for the weight-on-bit requirement. The Arduino 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 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 servo motors and they required drivers. The drill motor can operate at a constant RPM and torque, so it only needed a relay to control it. The heating coil similarly only needed to be toggled on and off, so it's controlled by a relay.

- Datalogger

The arduino 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 150 Newtons, and the maximum overall mass of the system is limited at 60 kg. Since the system can tilt outside the frame, the volume is best quantified by the total volume while stationary which would be 2 cubic meters. The length of the auger is 21 inches and the drill bit itself is 4 inches 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 480 in.lbs. Our onboard computer system includes an Arduino and is coded using C and C++. it also controls the load cell. The communications interface for the Raspberry Pi is a serial cable and a com port for the Arduino. Input commands are given utilizing a laptop computer. Power for the system uses 120 VAC and uses 48 VDC converted from the 120 VAC.

Design Changes/Improvements:

We changed a few things with the orientation of the frame members but the only effective change was going to a chain driven system to tilt the drill.

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 scheduling with fellow teammates. Balancing school work and a project as large scale as this as you rapidly approach finals week is a challenge but doable.

Some of the issues we encountered from the electrical system included controlling the load cell. This proved to be difficult given the time constraints we were given, so to mitigate this, we decided to use an Arduino. 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 start a pilot hole with the drill vertical and then drill at an angle so the drill is more stable. We plan to put a small filter at the end of the pump to filter out any minor sediment that could contaminate the water. Most of the overburden will be shed at the top of the hopper with the collection entrance closed. The 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 auger and hopper have been integrated. Our team has completed construction of the mounting and support system for the up and down motion as well as the angle of the drill. We have the 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.

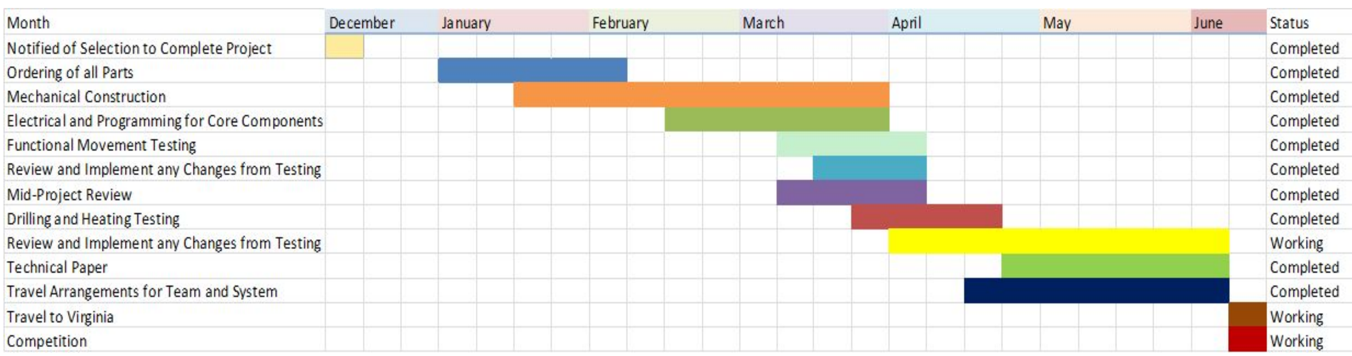
We also tested different types of drill bits for our project. They were tested by observing which drill bits fit certain criteria. They were tested by their torque required to penetrate the ice, as well as the time each one took to drill through a length of ice and the amount of ice we gathered from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

Project Timeline:



Safety Plan:

The SSASS 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 single drill system with a hopper could be more compact, and still be able to accomplish the tasks. We added an A-frame for max strength and lightness. We thought that the ability to tilt the drill 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.

The design adapted as we were able to test it more and more. We realized that we could melt the ice once in the hopper. At the same time, this would increase the longevity of the system by having less fatigue without the auger grinding against the inside of the sheathe. We found that our initial design of using a direct drive to the tilt mechanism had to be changed to a chain and sprocket..

- Mechanical

Servo motors were used for angling the drill outwards as well as lowering it into the ground while a step motor would be used to engage the hopper. We decided to go with the servo motors to do the majority of the work because we needed to be able to track the amount of rotations that the servos would turn that would allow the drill to be lowered and angled out. In order to fit the power budget that the competition states, we calculated that if we were to run a one motor at a time while continuously running the drill, load cell, and Arduino that going with the ACM602V36 servo motor would be the way to go. It runs on 200 watts which is enough power to move the drill but not enough to take away from powering the drill itself. It has a peak torque of 1.91 N-m which is more than enough torque to lower and swing out the drill. The ACS806 servo driver was needed in order to take the signal from the Arduino, amplify it, and send that signal to the motor in the form of an electrical current. This is crucial for getting the motor to turn how we wanted it to. As for the step motor, it doesn't have the capability to track and orient itself so a simple task such as engaging the hopper when we tell it to is why we went with the step motor for that function.

The drill will operate in two different modes. The first to remove overburden, the second to extract ice and collect it in a water for further processing. To start the drilling process the drill will start at an angle of 90 degrees to drill a pilot hole. Once a pilot hole has been started, the drill will tilt to 45 degrees. Once it is angled properly it will begin to extract overburden and pull it away from the borehole. When extraction of the overburden is complete, and ice is visible at level of the hopper, the hopper will swing into place over the sheath collection hole, and collection will begin.

The speed between drill modes will vary to account for different drilling mediums, and speed will also vary based on feedback of drill pressure. The pressure of the drill will be measured using a load cell attached to the drill shaft. A single point load cell from OMEGA rated for 100kg of force provided more than enough strength and durability to withstand the pressure that the drill bit will exert onto the strain gage itself. As pressure it applied to the auger, the rotation of the bit will slow down depending on the output of the load cell. If the measured downward force exceeds (140 N), the downward movement of the drill will stop to ensure the (150 N) limit is not exceeded.

To save weight, aluminum framework was used. To ensure that it would remain structurally sound throughout the drilling process, vibration dampening measures were taken. Vibration of the system was a significant concern and many different measures were taken to counter it so as it would not affect the mechanical structures or the electrical components of the system

- 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 "guiding" of the drilling 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. SSASS would need similar programming to compensate for this issue to only power essential systems, notably the telecommunications system.

Budget:

Description	Funding	Costs
NIA Awards	$10,000	
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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