NASA RASC-AL

2020 Moon to Mars Ice and Prospecting Challenge, Mid Project Review

Sub-lunar Tap-Yielding eXplorer, STYX

Team Members

All student members are undergraduates studying Mechanical Engineering at the California Polytechnic State University, San Luis Obispo. This team was formed on 10/9/2019 and volunteered to take on this challenge as part of a capstone project.

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- *Programming, Controls, and Frame Design Lead*

Alex Krenitsky
- Thermal Systems, Linear Motion, and Tooling Lead

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- Water Processing and Tool Changer Lead

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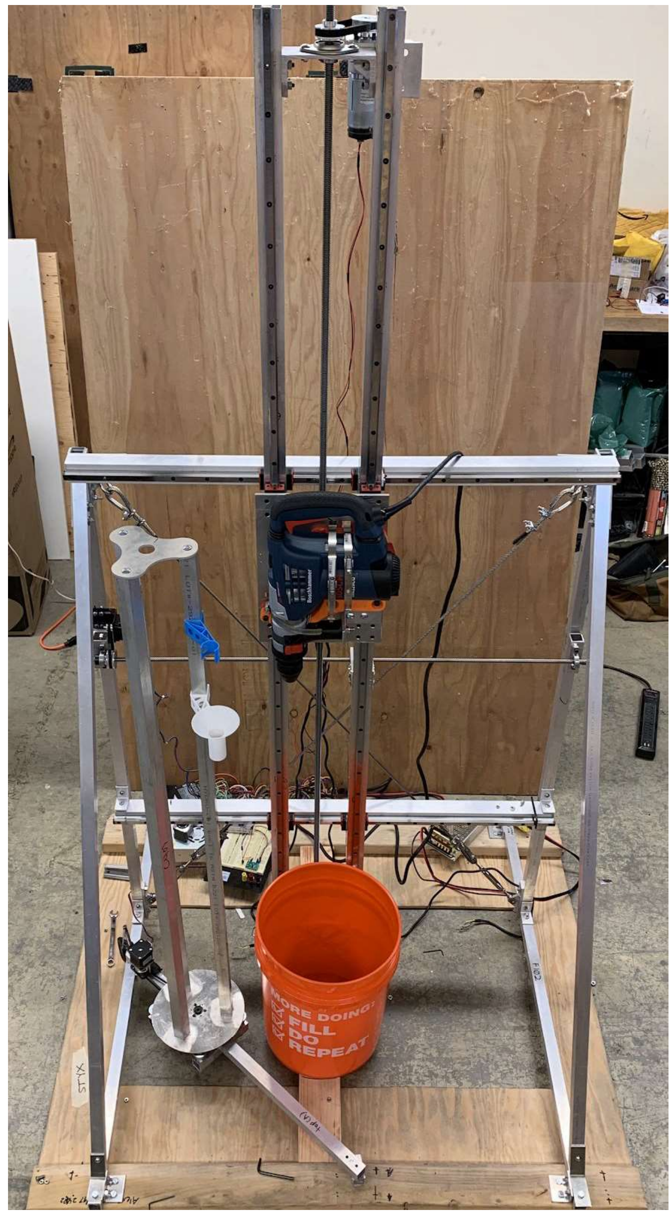

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I. INTRODUCTION

The STYX Team is confident that we will have a fully functional prototype in time for the June 1-4 competition. The following document, paired with a submitted video, is intended to provide the NASA RASC-AL competition with sufficient evidence that the Cal Poly STYX team has made significant design, build, and testing progress since the last progress report submitted in November of 2019. This document also serves to highlight future plans of the STYX team. The document first addresses all build progress by subsystem since the last submittal, focusing on the requested subsystems, then addressing others. Build challenges encountered by the STYX team and major design changes since the last submittal are also documented. The next section lays out all future testing plans for STYX subsystems; the document also discusses items such as the STYX team's tactical plan for contingencies and redundancies, the safety plan created for operation and use of the STYX equipment, and the updated timeline for all future STYX progress leading up to the competition.

II. Build Progress By System

By request of NASA for the mid project review, current build progress has been broken down by system: mounting, system control, drilling excavation, tool changer and miscellaneous systems.

A. *Mounting: Frame and Lid Interface*

All components of the frame for the STYX design have been completed and assembled with some preliminary stability and structural analysis and testing completed. This includes the linear rail and lead screw assembly for both X axis and Z axis motion. The frame has also been mounted to a temporary testbed fabricated out of plywood and 2x4s using 12 1/4in lag bolts. Alternative mounting locations have been added into the design of the frame footing to account for the uncertainty in the 2x4 positioning provided by NASA.

B. *System Control*

Preliminary programming code and control has been completed, giving the STYX team successful control over: X axis stepper motors, tool changer stepper motors, and Z axis DC motor. Load cells interfacing the Z-axis lead screw to the drill plate have been configured and calibrated, but will later be integrated into a closed-loop control system limiting Z-axis feed rate by maximum weight on bit. Encoders on the Z-axis will allow plunge depth to be tracked. Currently, data from load cells estimates weight on bit to within ~0.3 lbs, which has been comfortably within the 10% accuracy required by competition rules.

C. *Excavation: Drilling Operations*

As mentioned in the frame and system control sections above, Z-axis motion has been successfully completed. Linear motion in the Z direction is capable of guiding our drill into the excavation area. The STYX team is unfortunately still waiting on the delivery of a full size masonry drill bit to be used in the competition; therefore, a 18" drill bit was used to demonstrate the excavation abilities of the STYX system in the provided video. Concrete and ice were easily bored through using the hammer drill and Z-axis drive. Final penetration rates will be dependent on the implementation of the closed-loop control.

D. *Miscellaneous - Rotary Tool Changer*

The framework for the rotary tool changer has been completed and temporarily mounted to the frame for testing. An iterative design process has been completed for the tool holder 3D printed components. These components will be finalized and printed upon the manufacture of their respective tools. Through iterative design and testing, a finalized design has been completed for the tool holder clips that can successfully resist the load applied by tool changing operations. The final step for the tool changer is to mitigate deflection by stiffening the interface to the frame.

E. *Miscellaneous - Heater Probe*

The finalized heater probe will be manufactured in the coming weeks, but a 3D-printed prototype was created to rehearse assembly and demonstrate the desired actuating motion. The heater probe was printed at a 1:1 scale and was successfully actuated using its kevlar actuation string.

F. *Miscellaneous - Pump/Filter System Assembly*

The primary and secondary filters for the STYX system have been assembled, preliminarily tested, and are currently ready for endurance testing and system integration. The pump provides adequate head pressure and the tandem filters produce clear water from water that was polluted with concrete dust and dirt. The limiting portion of this system will be the maximum melting rate of ice and the potential of clogging a tube during endurance testing.

III. Build Challenges

The STYX team had to overcome typical manufacturing and assembly challenges as we pivoted from design to manufacturing. Common issues such as misaligned holes, problems with tool access, and errors in manufacturers' documentation required us to make several modifications. The final system's performance has not suffered, but some cleanup of the assembly may be in order before competition. We are pleased to say we have had very few issues so far.

IV. Major Design Changes Since Project Plan Submission

A. *Frame*

A major design change to the frame was the shift from using 8020 channel to thin walled aluminum square tube. The driving requirement for this change was weight, as the original 8020 frame weighed ~131lbs while the new frame weighs ~ 79lbs.

B. *Programming and Control System*

The programming language was changed from simulink to micropython. This is because hardware is difficult to integrate into simulink if modules are not already created, the microcontroller we have selected is too slow to allow simulink to drive an embedded system, and multitasking is more difficult to set up.

C. *Tool Changer*

The tool changer has been reduced in size and weight significantly. 8 Tool slots will be available for use and precise rotary actuation will be provided by a stepper motor with a 15.5:1 gear reduction.

D. *Induction Heater*

The induction heater was removed from the assembly. Our preliminary testing showed that it would be unlikely for the tools to become stuck in the ice. It appears more likely that they become stuck in the overburden and in this case, using the hammering action has freed the bit every time in testing. If heating of the tools becomes necessary in longer duration testing, we intend to heat our tools by touching them to the heater probe in the tool rack.

V. Integration and Operation Test Plan

A. *Mounting: Frame and Lid Interface*

Stability testing during extended drilling is currently the only required and planned test for the framing system. This test hopes to confirm sufficient structural strength and stiffness of frame members, joints, and mounts.

B. *System Control*

The control system has multiple safeties designed into it. The first is limit switches on the X-axis and Z-axis linear motion systems to prevent a crash into the frame or overburden. Next, ammeter sensors will be added into the system to allow for pre-emptive shutoff in the case of power overdraw. Thermocouples will be connected to the heater to prevent overheating, and temperature will be monitored such that power can be adjusted accordingly. In the case of a loss of connection while drilling, two emergency stops will interrupt power; one by the remote operator and the other on the machine. Exceptions will be included to allow programmatic pause if serial communication is lost. The task timing will be handled by a task scheduler and testing will ensure our latency does not exceed the limits required for stable closed loop control. A manual override platform will be created to allow each component to be easily moved in the case of autonomous system failure, but the goal is an entirely autonomous drilling, extracting, tool changing, and filtering operation. These control and safety systems will be repeatedly tested in all operating modes.

C. *Excavation: Drilling Operations*

The STYX team has already conducted sufficient testing to prove that the selected drill is capable of penetrating through all types of potential overburden. Further testing is necessary for the remaining tools: sheath, auger, heater probe, and camera probe.

D. *Rotary Tool Changer*

Several tests will be required for confirmation of proper rotary tool changer operations. The first necessary test will test the chuck depressing system to ensure the tool changer can properly engage and disengage the drill chuck allowing the tool changer operations. The second test will determine the relative accuracy of the programming control of the rotating base ensuring adequate alignment for tool changing operations and reliability of rotary actions.

E. *Heater Probe*

The motors driving actuation will need thorough endurance testing to ensure that they can be stalled for short periods of time without being damaged. Additionally, the maximum melt rate of the tool needs to be tested. Finally, the maximum operating temperature has yet to be determined, but we expect it to be between 200C and 300C depending on future test results.

F. *Pump/Filtration System*

Simple testing is required for the filtration system to ensure continual flow despite partial filter blockage. Both filters will be integrated in series to ensure nothing larger than 5 microns passes through the system. The test will also tell us if a finer primary filter is required to avoid unnecessary clogging of the secondary filter. Both the inlet and outlet of the pump will be fitted with pressure transducers that will allow us to determine which filter is fouled first. Calibration and testing of the pressure sensors is expected to take place before April. Endurance testing for the whole system will be the last major hurdle.

G. *Telemetry System*

Although preliminary results look good, further testing will confirm the accuracy and precision of the Z-axis load cells. The current programming of the load cell utilizes a rough calibration constant determined in preliminary testing not accounting for uncertainty propagation. The other major test for the telemetry system will be the resolution and connectivity of the wireless camera probe and its ability to identify layer changes. The probe design now utilizes a 45 degree mirror to peer through a line of windowed holes in a driven sheath.

VI. Tactical plan for contingencies and redundancies

The STYX team's tactical plan for contingencies consists of purchasing and acquiring backups equipment in the case of failure. Failure would be defined as broken or faulty hardware or parts. The STYX budget will allow for the purchase of backup electronics, drilling tools, and pump/filtration systems. A 3d printer will be brought along to aid in any other unforeseen issues. The load cells are already redundant and most subsystems have been designed to be serviced on-site.

VII. Safety Plan

During the design and build phase of the project a set of hazards specific to STYX operations were compiled into a safety plan. The list and relative severity of hazards were assessed using several methods including an FMEA included as Appendix 1 and risk assessment software. The resulting safety plan table is included below. PPE requirements include safety glasses, face shields, dust masks, and hearing protection.

Table 1. Safety Plan with Corrective Actions

Description of Hazard	Planned Corrective Action
Revolving drill bit	- Competition rules prohibit touching the device while it is in operation - Stay >3 feet away from rotating components - Remove any clothing/items that may get caught in machinery before operating
Falling Weight Hazard	- The use of lead screws will keep heavy moving components in place in the event of a power failure.
Sharp edges	- Drill bits will be contained in sheathes during transportation - Drill bit tips will be fully encased while in the tool changer.
High voltage electrocution risk	- All high-voltage circuitry will be approved by faculty before use. - All devices will be properly grounded and insulated
Loud noise during drilling operation	- Use earplugs during hammer drilling procedure.
Burn risk from heaters and drill bits	- All component temperatures will be checked with IR thermometer to verify <40°C before handling
System is used in an unsafe manner	- System will only be operated by designers. Designated group members will be specially trained.
Pinch points	- All motion components will be de-energized before handling the system.
Tipping hazard	- Connect the frame to the mounting rails provided at the competition before installing heavy subassemblies
Required emergency stop	- A physical kill switch will be accessible on the control station and the robot, in case an immediate shutdown is required.

VIII. Updated Timeline for Deliverables

A condensed timeline including all major project deliverables and registration dates has been tabulated below. An extended timeline including STYX testing and building dates has been included in Appendix 2.

Table 2. Deliverables Required by the NASA RASC-AL Challenge

Date	Description
3/15/2020	Mid-Point Review deadline
3/20/2020	Teams are notified of MPR pass/fail status and stipends are sent to universities (as appropriate)
4/20/2020	Anticipated date for completed full integration. Begin all-up testing and endurance tests.
5/1/2020	Deadline for Hotel Reservations and registration/payment for the forum
5/14/ 2020	Technical Paper and Integration Document submission deadline
6/1-6/4/2020	Onsite Competition at NASA Langley Research Center

Appendix 1. Risk Assessment

												Action Results				
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**RPN**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Criticality**	**RPN**
Heating Element	Power Cable Break	No heat	10	Over extension of probe	-Ample Cable -Play at hinge -Rounded edges	3	Temp Sensor	7	210	Ample Cable	Alex / Others		10	1	7	70
	Overheat (burn out)	No heat	10	Lack of temp control resulting in overheating	-Monitor Temp -Variable Power Control	4	Temp Sensor	6	240	Sensitive Temp Control	Alex / Others		10	3	6	180
	Temp Sensor Failure	Improper Temp Control	6	Improper Calibration, Seneor Burn out	-Monitor Temp -Variable Power Control	4	Temp Sensor	3	72							0
Heating Actuation	Actuation Motor Failure	No Actuation	6	Motor over exertion	-Speced Motors	2	Resistance on Motor Disapears	3	36							0
	Actuation Cable Break	No Actuation	8	Wear and tear with friction, over actuation	-Ample Cable -Play at hinge -Rounded edges	5	Resistance on Motor Disapears	7	280	Ample Cable	Alex / Others		8	3	7	168
	Faulty Hinge	No accuation	8	Poor hinge selection, introduction of dust	-Nice Hinge -Dust Prevention -Lubricant	3	Resistance on Motor Increases	6	144							0
	Surface Contact Failure	Killing Motor / Overheat Element	6	Improper motor control / Improper heat control	-Motor Control and Feedback	4	Resistance on Motor Increases / Temp Sensor	8	192							0
Filtration	Clogging	lowered flow rate	4	Insufficient Back flushing	-Back flow ability	5	Pressure Sensor	4	80							0
	Not Sufficient Flow rate	lowered flow rate	4	Cloging, improper pump selection	-Properly Speced Pump and Filter	5	Pressure Sensor	5	100							0
	Leaking	loss of valuable water	4	Waer and tear of tubing	-Proper Tubing -NP Standards	3	Pressure Sensor / Visual Inspection	5	60							0
Pumping	Clogging	lowered flow rate	4	Insufficient Back flushing and filtration	-Back flow ability	5	Pressure Sensor	4	80							0
	Tube wear and tear	loss of suction	6	Kinking / material wear and tear	-Proper Tubing -Norprene Tubing	5	Pressure Sensor	8	240	Abrasion Resistant Tubing	Ryan / Westin		6	3	8	144
	Gear Box Failure	Pump Failure	8	Poor chinese manufacturing / over torqued		2	STOPS	8	128							0
Piping	Leaking	loss of valuable water	4	Improper piping connections	-Proper Tubing -NP Standards	2	Visual Inspection	5	40							0
	Piping Kinking	lowered flow rate	4	Sharp bends turns	-Proper Tubing -NP Standards	4	Pressure Sensor / Visual Inspection	4	64							0
	Clogging	lowered flow rate	4	Insufficient Back flushing and filtration	-Back flow ability	5	Pressure Sensor	4	80							0
Drilling Control	System Failure	Cannot Properly Control	10	Bug in the code	-Solid Programing	3	Visual Inspection	2	60							0
Drilling Servo Control	Directional Failure	Inability to disconnect from sheath	8	Bug in the code	-Rigid -Over Speced	2	Visual Inspection	2	32							0

Drilling Mode Selection	Mode Selection Failure	switch no longer actuates	6	Bug in the code		3	Visual Inspection	2	36							0
Drilling Rotary	Mode Failure	Doesn't rotate	8	Bug in the code / Faulty Drill		3	Visual Inspection	2	48							0
Drilling Hammering	Mode Failure	Doesn't hammer	8	Bug in the code / Faulty Drill		3	Visual Inspection	2	48							0
Auger Drill Chip Clearance	Clogging	Cannot Clear	6	Not sufficiently pulverized	-Suficiently Pulverize	6	Visual Inspection	2	72							0
	Auger Stuck	Auger Stuck	6	Not sufficiently pulverized	-Suficiently Pulverize	6	Visual Inspection / Force Data	2	72							0
Pile Drive Sheath	Exced Force Req.	WE LOSE POINTS	2		-Feedback	8	Force Data	4	64							0
	Sheath Failure	Sheath Collapse	6	Buckling	-Properly Speced	4	Force Data	4	96							0
Tool Changer Rotation	Inproper rotation control	spinny thing spins out of controll	6	Bug in code / stepper motor slips downs the stairs	-Feedback	4	Visual Inspection	2	48							0
Quick Change Servo	Not releasing tool	Inability to use variable tools	4	Improper diengagment	Test Chuck Release	3	Visual Inspection	2	24							0
	Not Grabbing Tool	Not using tools at all	6	Missalignment	Change Plunge Depth	3	Visual Inspection	2	36							0
Frame	break	WE LOSE	10	FEA did not function / Trucker Failure	Over Spec Frame / Design For Proper Loads	2	Visual Inspection	2	40							0
	exceeds desired weight	WE LOSE POINTS	2		Redesign	7	Weigh Before	1	14							0
Linear Motion x axis	motor underpowered	Load Changes / Lose Travel Ability	8	rails go out of parallel	Overspec Motor	2	Power Pull / Torque Output	6	96							0
	rails go out of parallel	Load Changes / Lose Travel Ability	8	Improper Assembly	Assemble with precision / Shim it	7	Visual Inspection / Stepper Motor Data	6	336	PRECISION ASSEMBLY!!	Aaron / Others		8	4	6	192
	screws fill with debris	Binding / Motion stop	8	Not sufficiently clearing material	Seal Open Operating Areas	5	Visual Inspection / Stepper Motor Data	4	160							0
Linear Motion z axis	motor underpowered	Inability to pull sheaths	8	Motor sizing incorrect / not sufficient power	Overspec Mototr	2	Power Pull / Torque Output	6	96							0
	rails go out of parallel	Load Changes / Lose Travel Ability	8	Improper Assembly	Assemble with precision / Shim it	7	Visual Inspection / Stepper Motor Data	6	336	PRECISION ASSEMBLY!!	Aaron / Others		8	4	6	192
	screws fill with debris	Binding / Motion stop	8	Not sufficiently clearing material	Seal Open Operating Areas	5	Visual Inspection / Stepper Motor Data	4	160							0
Camera Connection	does not connect	No video	6	Interference with wifi / Distance feom camera	Test Connection / Define Distance of Operation	4	No Video	2	48							0
	poor frame rate	Inability to resolve layers	4			3	Loss of Resolution	3	36							0
Camera Resoltion	Faulty Mirror	Inability to resolve layers	4	Scratches Mirror	Replace Current Mirror / Protect From Abrasion	5	Loss of Resolution	2	40							0

Lack of resolution through sheath	Scratched Tubing	Inability to resolve layers	4	Material scratches tubing while pile driven	Protect From Abrasion / Don't Use Windows	4	Loss of Resolution	3	48							0
Load Cell Calibation	Improper Calibration	Inacurrate force data	6	Improper Calibration	Calibrate Properly	4	Innacurate Data	7	168							0
Load Cell Failure	Exceed Max Force	Load Cell no longer resolves	4	Exceed Max Force	Monitor Force and Do not Exceed	4	Innacurate Data	7	112							0
	Do not meet 10% error	LOSE POINTS	2	Improper Calibration	Calibrate Properly	4	Innacurate Data	7	56							0

Appendix 2. Extended Timeline