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Automatic Core Removal System for a Mars Drill

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Engineering Design and Analysis VIII

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Abstract

NASA has discovered the existence of water under the surface of Mars. To access this water, an automated drilling solution has been proposed. It has been the focus of the Trinity Tigernauts T.N.G. to automate the core removal system, one aspect of the overall automation. A mock drill was constructed based on the Johnson Space Center and Baker Hughes Inc Mark II drill. The Tigernauts designed a robotic arm structure to remove the core sample from the drill bit of the mock drill. The automation process is controlled by a programmable logic controller (PLC) interfacing with motors, encoders, and limit switches. The PLC automation code is complete and has been tested through simulation. In addition, the circuitry has been integrated with the PLC. The current prototype also performs several of the mechanical operations manually; however, full integration of the mechanical and electrical components has not be accomplished.

Executive Summary

NASA believes there may be water under the Martian soil. The discovery and extraction of this water could verify extraterrestrial life as well as allow for future manned colonies on Mars. The most effective way to reach the water at this time involves an automated drilling system. Currently Johnson Space Center and Baker Hughes Inc. are collaborating on the design and construction of the drill; however, they have not yet started automating the drilling process. Thus, with the direction of the Texas Space Grant Consortium (TSGC), the Trinity Tigernauts T.N.G. decided to focus on one aspect of this automated drilling process, the core removal system.

The goal for the project was to build a functional prototype of the core removal process for the Johnson Space Center and Baker Hughes Mars drill. To be considered a success, the prototype would autonomously remove the core sample from the drill and place it on the base of the prototype, which represents the Lander. This process must also run in reverse in order to replace the drill bit into the drill after the core sample is removed. Several additional design constraints included only using current mechanical and electrical component, using only the power supply currently needed for the drilling operation, and making the prototype light and compact.

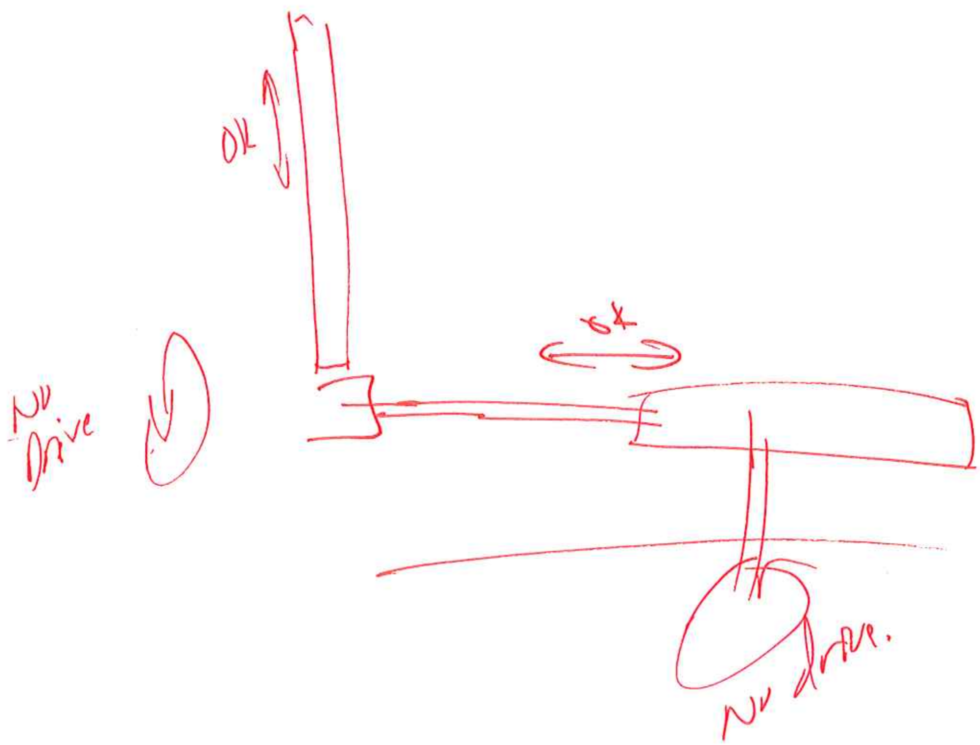
The core removal system is comprised of three main parts: a mechanical, electrical, and electro-mechanical sub-system. The mechanical system consists of two structures: the spud tube/drill and robotic arm assemblies. The spud tube assembly is based off of the Mark II drill that is currently under development by Baker Hughes Inc. This assembly is a representation of the Mark II drill anchored into its support casing, the spud tube. The robotic arm assembly was designed by the Tigernauts to perform the actual core removal from the drill structure. Since this project focuses on the system design as opposed to the actual drilling process, the prototype is constructed out of standard grade aluminum. The electrical system is driven by a programmable logic controller (PLC), which controls the movements of the mechanical structure. The electro-mechanical system, which includes the motors, encoders, and limit switches, interfaces the electrical and mechanical sub-systems.

The first step in the design process involved modeling the prototype in ProEngineer. Once it was determined that the final design was stable and feasible, the mechanical structure was built to these specifications. Throughout the construction process, each piece of the prototype was individually tested and modified to ensure stability and functionality. The electro-mechanical system was also analyzed to verify the functionality of each component. It was determined that the motors, encoders, and limit switches all perform as expected.

The electrical system has also been tested extensively. The PLC has been programmed to perform several simple tasks important to the core removal process, and it has succeeded in executing these tasks. The entire core removal program has been written, and a simulation of this process has been executed. The electrical and mechanical sub-systems have not yet been integrated, therefore, the prototype can not be considered complete.

Currently there are several problems preventing the integration of the sub-systems. One problem involves mounting the motor which controls the rotation of the robotic arm. Also, the group has not determined a way to rotate the robotic gripper. In light of these difficulties,

there are several parts of the prototype that are working. The spud tube/drill assembly can be raised and lowered to its proper positions and the robotic arm can move linearly in and out of its casing, giving it the range of motion required for the core removal process. Also, the gripper is able to exert the necessary force to be considered operational for the process. With additional time, the group expects that the prototype would be able to perform the task it was designated to complete.



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1 Introduction

NASA believes that water lies below the Martian surface, most likely in the form of permafrost. Since water is a fundamental requirement for life, examining this permafrost could be a crucial step in determining whether life has ever existed on Mars. Having access to water on Mars may also allow for long-term, manned Mars missions to take place. Thus, finding a way to reach the water beneath the Martian surface is crucial to NASA. It has been proposed that drilling would be the most effective method of obtaining this water. Currently, interstellar drilling operations are only possible with the aid of humans. Since a manned mission to the Mars is still far in the future, a manual drilling solution is not feasible. Also, due to the large time delay between Earth and Mars, it is not feasible to operate the drill from Earth. Therefore, NASA is interested in developing an automated drilling process that can successfully extract water from beneath the Martian surface.

Johnson Space Center and Baker Hughes, Inc. are currently collaborating on the Mars drill design and construction process. As the drill design has not yet been finalized, the automation process has not yet begun. Therefore, the Trinity Tigernauts T.N.G. spent the year developing an automation process for the core removal system for NASA and Baker Hughes, Inc. The current Baker Hughes design consists of the drill enclosed inside a spud tube, which stands vertically on the Martian surface and is attached to the Lander. The drill has a pressure mechanism that locks the drill into the spud tube, giving the drill bit proper down force to penetrate the Martian surface. Figure 1 displays these inter-workings. As the drill advances further into the ground the pressure system unlocks, which allows the drill to move further into the hole. The drill then locks into place further down in the spud tube so that the drilling process can continue. Once hole is deep enough that the entire drill fits into the ground, it becomes entirely independent of the spud tube. At this point, the locking mechanism functions inside the hole as it did inside the spud tube. This process

continues until a six inch core sample has been collected. At this time, the drill must return to the surface so that the core sample can be removed from inside the drill bit. After the core sample has been removed, the drilling process must continue from the point where it last stopped.

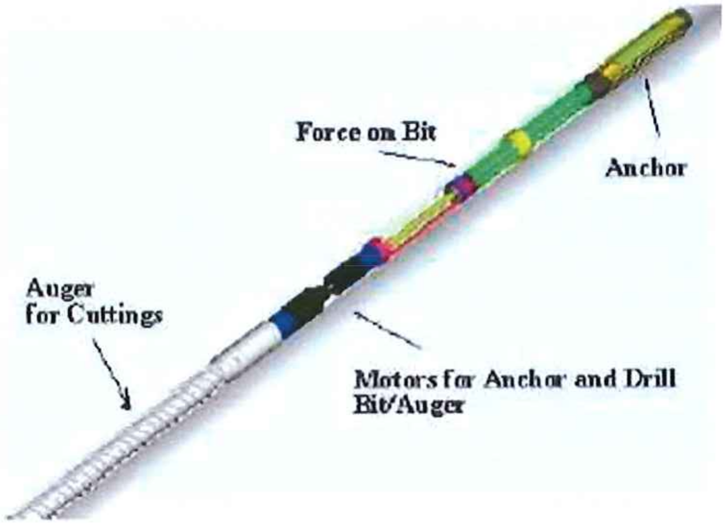

Figure 1: NASA Marl II Drill Schematic

Unclear what parts automated.

While this entire drilling process has not yet been automated, the Trinity Tigernauts T.N.G. have focused on automating the core removal system. A successful prototype will remove the intact core sample from the drill and deliver the sample to the rear of the Lander. On an actual Mars mission, scientific equipment will be waiting at the back of the Lander to analyze the sample. The system must then restore the drill to operational status without damaging any equipment. The prototype must also be constructed out of current mechanical and electrical components, include no additional power supplies, and be a light and compact solution.

The Tigernauts first constructed a mock drill system based on the current Baker Hughes, Inc. Mark II drill. While the mock drill assembly was built as close to the Mark II drill as possible, several modifications were made to non-integral parts. These modifications include

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the addition of extra support structures, simplifying the drill bit locking mechanism, and altering sizes of components so that standard parts could be utilized. Also, the mock drill was constructed out of standard grade aluminum since this project is not concerned with the drilling process. The group constructed the mock drill to be permanently fixed in the spud tube, simulating the pressure mechanism on the Mark II drill. The removable drill bit containing the core sample is attached to the bottom of the mock drill structure. A robotic arm, which is also constructed out of aluminum, removes the drill bit and rotates it to the rear of the prototype.

As for the electrical system, a Programmable Logic Controller (PLC) serves as the director of the automation. A circuit has been constructed to interface the PLC with the various motors, encoders, and limit switches needed to automate the drilling process. Tests were performed to ensure proper electrical contacts between the circuit components as well as to ensure that the correct signal is being delivered to the proper motors at the appropriate times. Finally, a program was loaded into the PLC and the process was simulated.

2 System Design

The three main portions that comprise the Mars drill core removal system are the mechanical, electrical, and electro-mechanical systems. Each of these systems is comprised of several smaller subsystems. The mechanical portion is made up of a spud tube/drill assembly and a robotic arm assembly. The spud tube/drill sub-assembly represents the drill when it is anchored into the spud tube. In order to expose the core sample for extraction, a robotic gripper must hold the drill bit while the spud tube assembly raises seven inches. The robotic arm sub-section involves a linear robotic arm and a robotic gripper. The arm must be able to extend and retract to reach the drill bit as well as rotate to deposit the core sample at the rear of the Lander. A more detailed description of the mechanical subsystem is discussed in

Section 2.1.

The electrical system is comprised of two major subsections. The first subsection involves a Koyo DirectLogic D0-05DR PLC. The PLC controls the automation process of the core removal system via a program written in ladder format. The core removal process involves several steps: the gripper grips the drill bit, the spud tube raises seven inches to expose the core sample, the linear arm retracts from the drill, the robotic arm rotates the drill bit and core sample to the back of the prototype base, and the gripper rotates to deposit the core sample. The process will then run in reverse to prepare the drill for further drilling operations. The second sub-section involves the circuit that connects the PLC to the electrical components such as the motors, encoders, and limit switches. This circuit is constructed using standard electrical components such as multiplexers, resisters, H-bridges, and buffers. A detailed account of this circuitry along with PLC specifics will be discussed Section 2.2.

The electro-mechanical system is the integration of the mechanical and electrical sections of the prototype. The components that comprise the electro-mechanical system include the motors, encoders, and limit switches. The limit switches are used to control the upper and lower limits of the spud tube motion as well as the limits of the horizontal linear motion of the robotic arm. The encoders are used to control the rotation of the robotic arm about the base of the prototype and also to control the wrist rotation of the robotic hand. These components are all driven by 12 V DC motors. A detailed account of the electro-mechanical subsection is discussed in Section 2.3.

2.1 Mechanical

The mechanical system has been divided into two subsystems, both of which are connected to a base platform representing the Lander. These two subsystems are the spud tube/drill assembly and the robotic arm core removal assembly. The mechanical system is constructed

out of aluminum, and the drill itself is not operational. These stipulations fit the focus of the project since the group is concentrating on the core removal system as opposed to the actual drilling process. Aluminum was chosen as the mechanical material because it is relatively cheap and easy to work with. The current prototype design is shown in Figure 2. The vertical red and green structure represents the spud tube/drill assembly, while the horizontal red and black structure in the middle of the picture represents the robotic arm. Also, the Lander is represented by the yellow base structure.

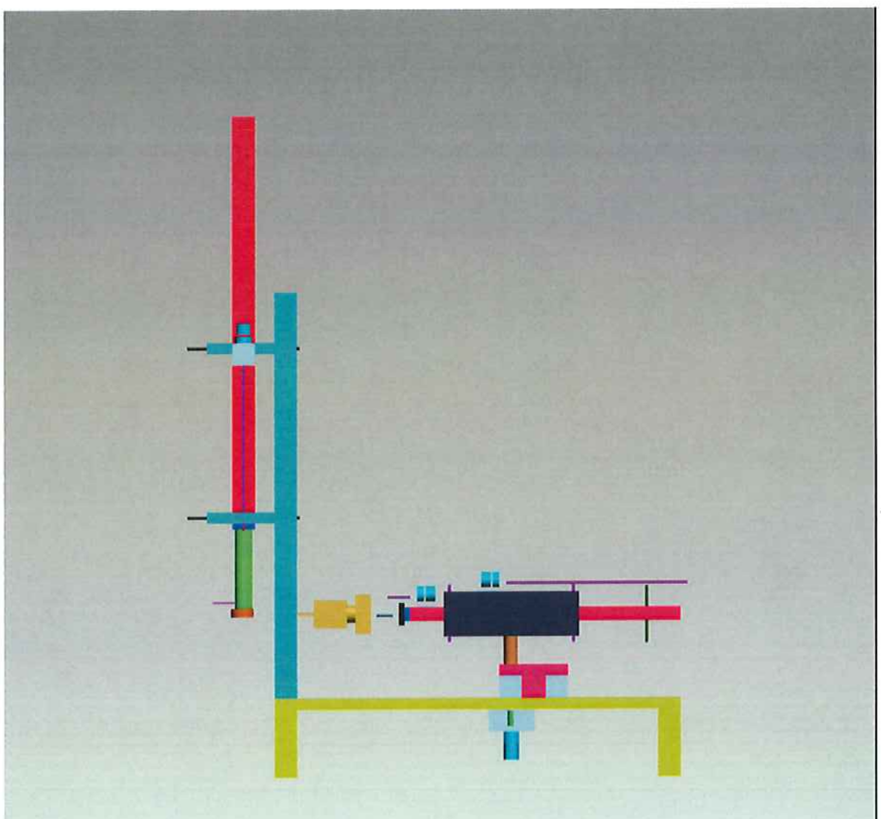


Figure 2: The Full System Assembly.

2.1.1 Spud Tube

The spud tube consists of a 3 foot long rectangular tube with a cap on the bottom end. A 1.5 in. diameter cylindrical aluminum rod, representing the drill, protrudes from the bottom

of the cap. The drill extends 1 ft. from the bottom of the spud tube and is hollow so that a core sample can be stored inside of it. The inside diameter of the drill is 1 in. along the entire length of the mock drill. The core sample is made out of concrete and is approximately 5 in. long. The mock drill bit is attached at the bottom of the drill by a removable pin. The drill bit holds the concrete sample inside the drill and must be removed in order to access the core sample. The entire spud tube/drill assembly is designed to simulate the point in the actual drilling process where the drilling is complete and the drill has been raised to the top of the spud tube. A detailed view of this assembly is shown in Figure 3.

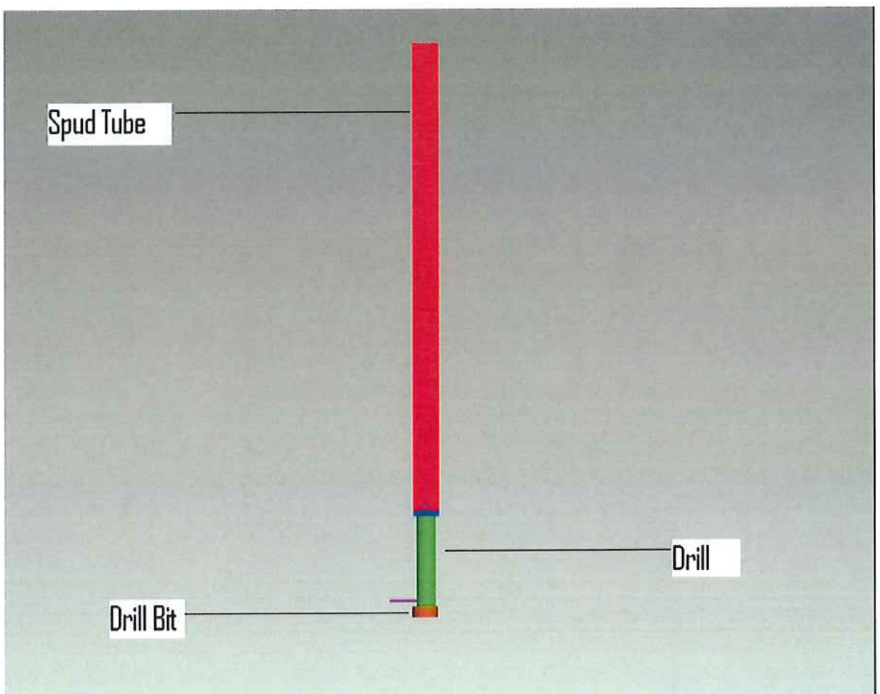


Figure 3: Mock Spud Tube/Drill Assembly.

2.1.2 Spud Tube Support Frame

To ensure that the spud tube remains vertical, a three foot welded aluminum frame surrounds and supports the spud tube. This frame is represented by the teal structure in Figure 4, and is attached to the base of the prototype via L-brackets. In order to raise the spud tube/drill

assembly, power is supplied to a motor attached to the top of the frame. Once powered, the motor rotates a threaded rod. Lead screw connection devices were made by welding nuts, which fit the size of the lead screw, to the tops of screws. The nuts on top of the screws were rotated into position along the threaded rod, and the screws were permanently connected to the frame at these positions. Thus, the spud tube can be lowered and raised by supplying power to the motor.

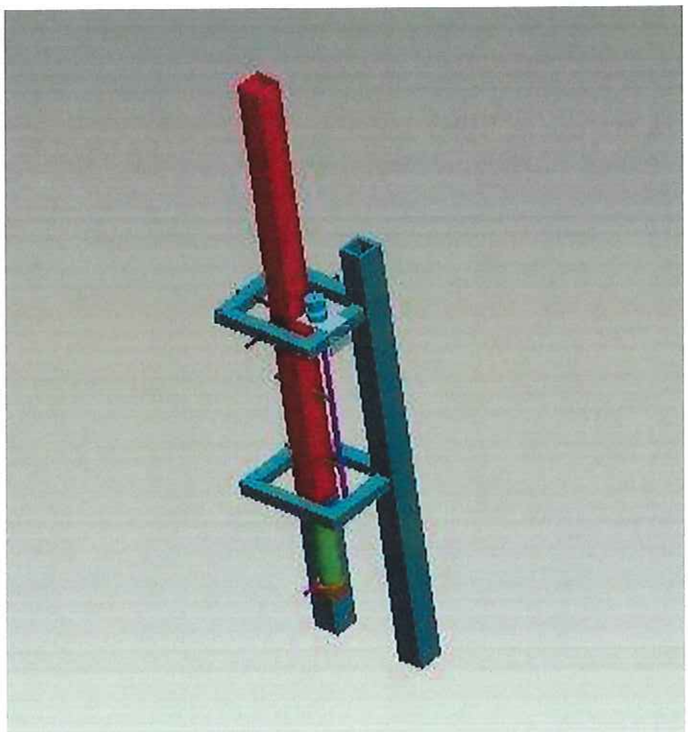


Figure 4: Spud Tube Support Frame

2.1.3 Wheels in Frame

In order to keep the spud tube/drill assembly vertical within the frame as well as keeping the friction low during the spud tube movement, 1.25 in. wheels were added to the inside of the frame. The wheels were positioned on the three sides where the threaded rod is not present. In order to ensure that all the wheels are in constant contact with the spud tube,

washers were placed between the wheels and the frame. Figure 5 shows the frame with the wheels attached to it.

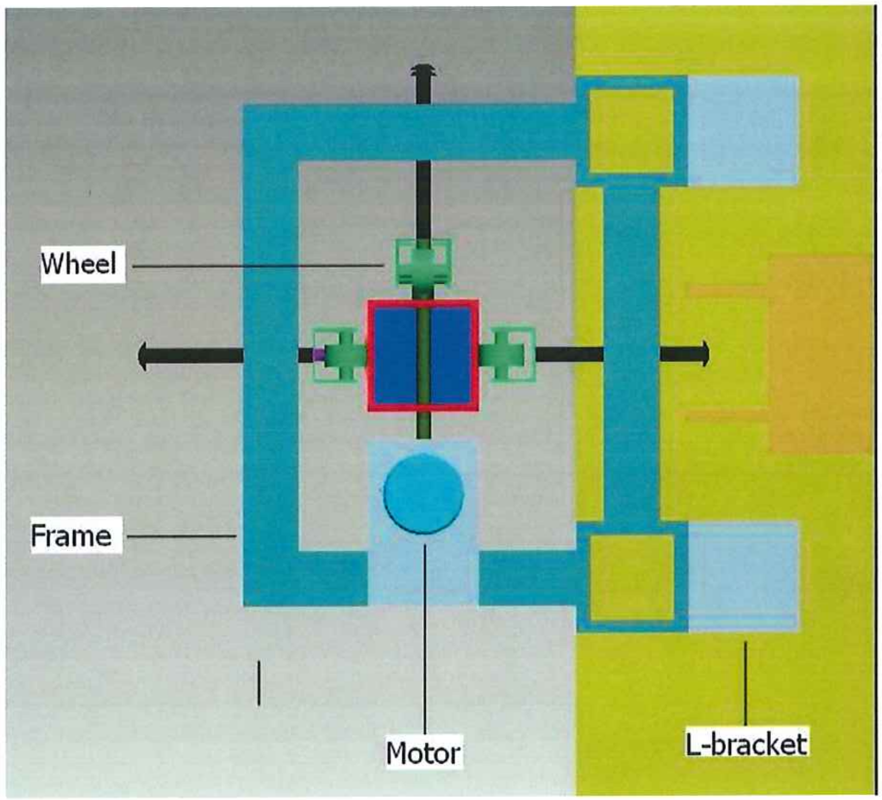


Figure 5: Wheels supporting Spud Tube.

2.1.4 Rotating Arm Base

The robotic arm assembly has several functions: linear extension and retraction, rotation about the prototype base, gripping of the drill bit, and rotation of the robotic gripper about the axis of the arm. Figure 6 represents the entire robotic arm assembly. The robotic arm, indicated by the red component in Figure 6, moves horizontally to and from the spud tube/drill assembly. The robotic arm is supported by Jack, which is represented by the purple component. There are eight felt covered pads positioned inside Jack, which constrain the motion of the arm horizontally. The threaded rod that controls the horizontal motion of

the robotic arm is connected to the motor attached to the top of Jack. The same lead screw connection device that was used on the spud tube assembly connects the robotic arm to the motor via the threaded rod. The lead screw connection device is represented by the green component attached to the threaded rod in Figure 6.

The gripper is attached to the end of the robotic arm so that when the arm is fully extended the gripper is aligned with the drill bit. Both the motor, which controls the rotation of the gripper, and the encoder, which measures the rotation angle, are attached to the end of the robotic arm as shown in figure 6. In order to rotate the robotic arm about the prototype base, Jack is supported by a rotational shaft. This shaft is represented by the orange component in Figure 6, and is attached to a motor positioned beneath the prototype base. An aluminum box which is attached to the prototype base by L-brackets connects the rotational shaft to the motor on the underside of the base. This support box contains ball bearings at both the top and bottom shaft contact points to reduce friction during rotation. The encoder that measures the rotation about the prototype base is positioned with the motor beneath the structure.

2.2 Electrical

There are two subsections of the electrical system: the Programmable Logic Controller (PLC) and the circuitry. The PLC is programmed to control the whole electrical system. The PLC directly controls the drive electronics that power the motors and reads the signals from the encoders and limit switches. The second subsection of the electrical system is the circuitry. The circuitry provides integration between the mechanical structure and the PLC. The user interacts with the electronics via Start, Stop, Reset, and Calibration buttons and toggle switches.

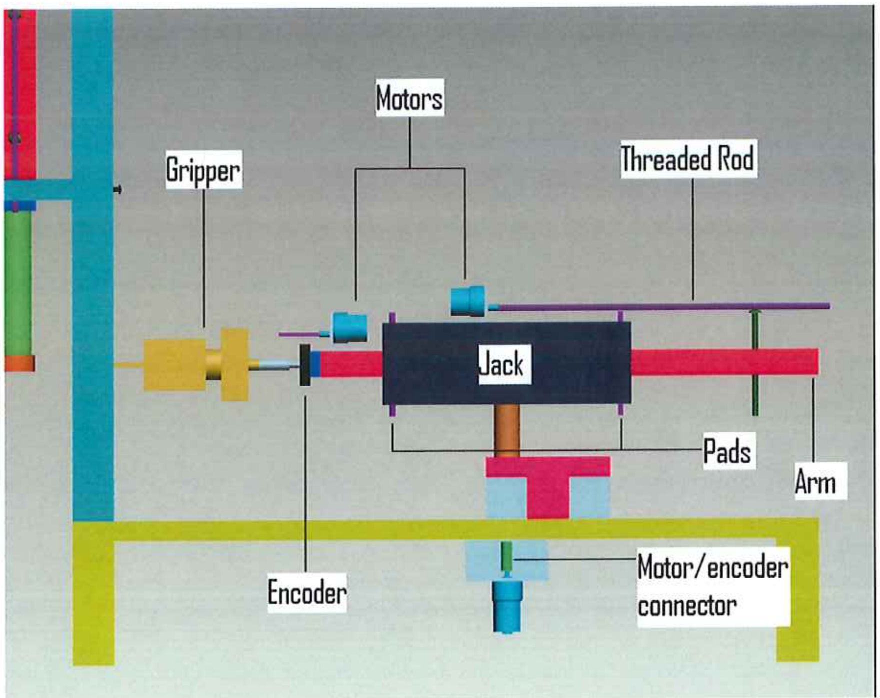


Figure 6: The gripper arm with its supporting base.

2.2.1 PLC

The PLC is a DirectLogic D0-05DR a controller designed for industrial automation. The logic circuits are opto-isolated to minimize the damage resulting from power surges. This PLC has 8 digital inputs where a signal between 10 and 26 V DC is defined to be a logic high signal, while a logical low signal is defined to be less than 2 V DC. When an input is high, an indicator LED near the input port on the PLC is lit. These signals are then taken as inputs to the ladder program, stored and run on the PLC. The program then controls which output relays are energized, allowing the current from the common output terminal to pass to the components. The energized relays then pass current to the appropriate peripheral. Again, an LED is lit when the relay is energized. The PLC is programmed using RLL$^{PLUS!}$ using a GUI programming environment. This programming method makes for a nearly direct translation from a state transition diagram to so-called stages of the PLC program,

expediting programming. The program flowcharts and program code are shown in Appendix C.

The automation routine is split into three distinct states: calibration routine, reset routine, and process routine. Each state is entered into from an IDLE state. The calibration routine rotates the wrist and the arm separately until the index channel of the encoder signal goes high. This position is then set to the 'zero-point' of the rotational motion. In the program this point is not zero but 5000 to give a positive bias to the PLC encoder counter. Rotational motion is then gauged relative to this point, allowing clockwise and counterclockwise rotation while maintaining a positive count-value. This was necessary for use of the high-speed input/output (HSIO) hardware on the PLC. The calibration routine then ends in the IDLE state which requires an execution of the reset routine before the system can enter the process routine. The reset routine positions the system appropriately to begin the process routine. The process routine executes the core removal, controlling the necessary raising, lowering, extending, retracting, rotating, and gripping functions. At any point, a process may be paused. The process may only be reset from the IDLE and PAUSED states to prevent sudden and possibly damaging movements.

2.2.2 Circuitry

The circuit connects the PLC to all of the electrical components and is comprised of three main parts. The first part involves connecting the encoders to the PLC. The PLC only has one high speed input/output module, which has hardware automatically programmed to count for the encoder. To connect both encoders to the high speed input/output module on the PLC, a multiplexer is used to select either the gripper rotation motor or the arm rotation motor to run independently. The encoders run at 5 V DC while the PLC runs at 12 V DC. In order to integrate these parts, a hex buffer with high voltage open-collector output is utilized. The hex buffer has a maximum output voltage of 30 V. The hex buffer outputs

are connected to a 12 V source through pull up resisters. The pull up resister values were estimate to be 4.7KΩ based on manufacturer specified current requirements to the PLC. However implementation determined that 4.7KΩ was too high and testing resulted in an appropriate value of 1KΩ.

In order to control the four motors, four H-bridges are utilized. These allow for simple digital control of the motors (both on/off and direction) while incorporating the necessary power electronics. The H-bridges run at 12 V DC and, therefore, are connected directly to each motor and to the PLC. Finally, limit switches are used to control the upper and lower limits of the motion of the spud tube/drill assembly as well as the limits of the linear motion of the robotic arm. The limit switches are connected to 12 V DC, ground, and then directly to the PLC. The complete wiring diagram can be found in Figure 9 and the parts list can be viewed in Appendix B.

2.3 Electro-Mechanical

In order to control the various movements of our prototype (i.e. vertical, horizontal and rotational motion) motors, encoders, and limit switches are utilized. Each of these components is discussed in detail in the following sub-sections.

2.3.1 Motors

Four small motors are used to control the various motions of the prototype. Each motor is geared appropriately for its expected load. Motors attached to screw-drives are used to raise and lower the spud tube and also to extend and retract the arm. A third motor is attached directly to the rotational shaft on the robotic arm assembly, and a final motor is used with a belt drive to rotate the gripper. All four motors operate at 12 V DC. Also, each of the motors was chosen so that it was capable of supplying a torque exceeding the estimated

value by 2-4 times in order to ensure acceptable motion.

Screw-Drive Motors To determine the torque required for the two screw drive motors, an appropriate lead screw was first selected. The selection of the lead screw determines the torque that the motor must supply in order to move the components as desired. A standard 1/4"-20 threaded rod was chosen as the drive screw for the motors controlling the linear movements. This choice was made because the rod is inexpensive and provides adequate efficiency and accuracy.

The spud tube was first weighed (80 oz.) to determine the force applied to the lead screw. Using the torque equation, which is detailed in Appendix A.3, and the friction estimates taken from [1], the torque needed to rotate the lead screw was found. It was determined 11 oz-in of torque was needed to rotate an un-lubricated screw while 1.8 oz-in of torque was necessary for a lubricated screw. Once the thread length was specified, the desired rotational speed of the motor could be determined. It was decided that a time of thirty seconds to raise the spud tube six inches was acceptable. Ultimately, the spud tube motor was chosen to be a 12 V DC gear-motor running at 60 RPM. This motor delivers 44 oz-in. of torque, which ensured a large safety factor.

The linear arm motor supports a much smaller load than the spud tube motor. Since the extension and retraction motion is completely horizontal, the only forces to be overcome are the friction forces of the arm supports. The friction between the aluminum arm and the felt pads that support the arm is negligible; therefore, a drive screw with a 12 V DC gear-motor provides adequate torque for the arm movement. The chosen motor provides 5 oz-in. of torque at 600 RPM.

Arm Rotation Motor The motor used to rotate the arm assembly must supply a large torque due to the fact that the assembly weighs 14 lbs. Given the rotational inertia of

the assembly and the friction created at the contact point of the rotational shaft and the base, the required torque was calculated to be 102 oz-in of torque. Adding a bearing to the design reduced the friction to an estimated 23.76 oz-in. Since the arm only rotates about 180° during the process, a 2 RPM motor was chosen, so that the rotation motion could be completed in about 15 seconds. The motor chosen was a 12 VDC motor, supplying 83 oz-in of torque at 2 RPM. The torque calculations for the arm rotation motor were done in the same way as the calculations for the wrist rotation.

Wrist Rotation Motor The wrist motor needs to overcome the inertia of the gripper as well as the friction it encounters as it rotates. Due to the support method of the gripper, the moment was expected to cause excessive friction on the axis of rotation. As such, a bearing was added to the wrist. This minimized the friction the wrist motor had to overcome. After this modification, the motor does not require significant torque to rotate the wrist. The motor is connected to the wrist via a belt drive with a gear ratio of approximately 2:1. The selected motor is a 12 V DC motor, with 44 oz-in of torque at 60 RPM. The torque for the motor was calculated by making slight modifications to the equation in Appendix A.3. These modifications adjusted the equation for simple rotation.

2.3.2 Encoders & Limit Switches

The design uses two types of feedback sensors: optical encoders and limit switches. These sensors allow for adequate control over the four major components. The spud tube and robotic arm are fitted with limit switches at their extremes, while the rotational shaft and gripper are fitted with encoders on their axes of rotation. Each encoder was selected to ensure appropriate accuracy for the gripping process.

Encoders The arm rotation encoder ensures that the gripper will be aligned perpendicular to the drill bit. The removing of the drill bit from the spud tube/drill assembly requires a smaller degree of accuracy than the reinsertion of the drill bit. Therefore, encoder selection is based on the reinsertion of the drill bit. From the calculations detailed in Appendix A.2, it was determined that 500 counts per revolution provided the acceptable accuracy of 2^o to grip the drill bit.

The wrist encoder was chosen based on the calculations in Appendix A.2. Since the drill bit has 1/16" clearance with the drill, an encoder of at least 300 counts per revolution was necessary. To ensure a proper safety factor, an encoder of 500 counts per revolution was chosen. This ensures that the gripper fingers close perpendicularly to the drill bit, and that the drill bit is vertical for reinsertion.

Limit Switches Limit switches are used to provide information as to when the linear movements reach their extreme positions. Simple limit switches can be utilized in the prototype due to the size and the speed of the linear moving parts. These limit switches provide for a cheap solution that also supplies adequate information on the position of the linear components.

2.3.3 Gripper

The gripper used for the project was taken from a previously constructed robotic arm which is no longer being used. This gripper was chosen because it was easily available at no cost to the group. Additionally, the gripper is easy to work with and modify. The piston that powers the opening and closing actions of the gripper fingers is pneumatically activated and has 4 inlets, or ports. Two of the ports are responsible for opening the fingers and the other two are responsible for closing them. Each of these inlets has a small air tube, which is connected to the wall air supply through a small metal connector. The gripper will either

open or close depending on which inlets the air is forced through.

New fingers were constructed for the gripper because the original fingers did not have a large enough stroke. The new fingers were longer and were set further apart, which allowed for a wider range of accuracy when removing and replacing the drill bit. In order to make sure the fingers could grasp and hold onto the drill bit, pieces of surgical tubing were placed on the fingers. The surgical tubing adds friction to the contact points between the drill bit and the gripper.

3 Testing

Testing was a very important part of the development of the system. Testing took two forms: development unit testing and in-system testing. The first form involved testing components to ensure correct operation of the component before it was implemented at the system level. The second form involved the testing of the system once each of its components was combined to form the system. This testing focused on component interaction and system performance. Ultimately, each of the major systems were tested independently.

3.1 Electrical

3.1.1 Electric Circuitry

The circuitry was primarily tested for continuity at the appropriate points in the circuit. Once continuity was confirmed, the multiplexing operation of the circuit was verified to select the desired encoder based on the signals received from the prototype motors. Finally, the buffer portion of the circuit was tested by implementing the buffers into the circuit and measuring the output voltage and current.

3.1.2 PLC/Component Interaction

Programs were written for the PLC to test the control of input and output. First, a simple program was written to pass the input through to the output. This test was accomplished by following the first tutorial in the PLC instruction manual [2]. A ladder structure programming style was utilized in this, and all, of the PLC tests. Next, a stage-based program was implemented to demonstrate the use of stages in RLL programming. This test involved implementing one input-output relationship in the first state and a different input-output relationship in another state. The state was changed on the rising edge of an input signal. These programs tested and demonstrated the functions of the PLC and familiarized the programmer with the PLC and the RLL language.

The PLC was then interfaced to peripheral devices, specifically encoders and H-bridge drivers. To test PLC-encoder interaction, an encoder was powered and wired to the PLC High-Speed Input/Output hardware (inputs X0-X2). The PLC was programmed to count a quadrature signal and retain the value. A program was also written to activate an output when the encoder turned beyond a certain count value, and activated another output when it turned below a different count value. This test replicates the demands that are made on the counter during the system process.

Since the motors use only binary control, the PLC-motor interaction was easily tested. The motor was connected to a standard H-bridge, and the PLC outputs were connected to the PWM and direction pins of the H-bridge. The common terminal output relays of the PLC were connected to ground and $1K\Omega$ pull up resistors were connected to a +5V power supply at the H-bridge pins. Then a PLC program was written and loaded to the PLC. One output of the PLC controlled the motor direction while the other output determined whether the motor was on or off. The program was then executed and the rotational direction of the motor was observed.

3.1.3 Extended Programs

After developing the stand-alone programs and ensuring their functionality, the full system process program was developed. The program was broken down into routines, sub-routines, and ultimately to individual stages. The program was debugged on a test bench made to replicate the circuitry and sensors of the system. It was then integrated into the full system.

3.2 Electro-mechanical

3.2.1 Gripper

The first test of the gripper involved blowing pressurized air through each of the four tubes individually in order to determine which hoses control the various gripping functions. The pressurized air utilized for this experiment came from the wall in the shop in Moody Engineering Building. A large hose was attached to the wall air nozzle, and each tube from the gripper was inserted into this hose individually. The gripper tubes are substantially smaller than the hoses that integrate with the wall outlet, therefore the gripper tubes had to be pinched into the hose manually. As air was blown into the gripper tubes, the gripping functions of the gripper were observed.

Once it was determined that the gripper could perform the gripping function, the mock drill bit containing a four inch core sample was placed into the gripping fingers. Pressurized air was again forced into the gripper tubes, and the group observed the force exerted on the drill bit. The gripper was then manually rotated in 90? clockwise to determine if the gripper could maintain proper control of the drill bit throughout the core removal process. The final gripper test involved testing the air pressure entering the gripper. The air pressure was tested by connecting the gripper to the wall supply at an air pressure above 80 psi and the effects of pressure build up were observed.

3.2.2 Spud Tube Motor

The spud tube motor is a 12 V DC motor capable of drawing up to 1 A of current. The first test run on the motor involved applying a 12 V DC supply to the unloaded motor to ensure it was operational. The connections on the motor were then reversed to ensure the motor would operate in the opposite direction. The motor was then mounted and attached to the spud tube structure via the lead screw. The first test was an observational test to ensure that the motor could support the weight of the spud tube structure. A 9 V DC, 1 A wall supply was then attached to the motor and the results were observed. The connections to the motor were then reversed to ensure that the spud tube assembly could move down the lead screw as well.

To test the operating point of the motor under loading conditions, a voltage and current regulated power supply was obtained. The power supply was set to its maximum load of 12 V and 5 A and was attached to the spud tube motor. While the motor was running, the operating conditions were displayed on the front panel of the voltage and current regulated power supply.

3.2.3 Arm Extension Motor

The test procedure for the linear robotic arm motor was similar to the test procedure for the spud tube motor. First, a 12 V 1 A power supply was attached to an unloaded motor to ensure that the motor was functional. The motor was then mounted to the structure and attached to the robotic arm via a lead screw. The voltage and current regulated power supply was then set to a maximum of 12 V and 5 A and attached to the motor. The motion of the robotic arm was then observed for motor functionality.

3.2.4 Wrist and Arm Rotation Motor

The wrist and arm rotation motors were first attached to a 12 V 1 A power supply with no load applied. After verifying the operation of the motor, the wrist rotation motor was attached to the end of the robotic arm as seen in Figure 6. The purple shaft extending from the motor in this figure was connected to the grey wrist connector via a rubber band. The 12 V power supply was then attached to the motor, and the functionality of the gripper rotation was observed.

3.2.5 Wrist and Arm Encoders

Both encoders were individually attached to a Digital Mixed Signal Oscilloscope to ensure the proper counting procedure. The clear encoder discs contain evenly spaced black tick marks around the outer edge of the disc. As the disc rotates with the prototype component, a photo-sensitive sensor registers each tick mark. When the appropriate number of tick marks have registered, the encoder sends a signal to the PLC indicating that the rotational process is complete. This counting process was tested by rotating the encoder discs and observing the clock output on the oscilloscope.

4 Results

4.1 Electrical

4.1.1 Electric Circuitry

The continuity test demonstrated that the circuit connections are all functional. Also, the multiplexing test was validated when the wrist and arm rotation encoders were selected based on the signal sent to the PLC. The buffer portion of the circuit resulted in a voltage increase of about 8 V, which is lower than the desired value for the PLC. However, this

voltage triggered the PLC inputs and resulted in a current smaller than the upper limit of 5 mA entering the PLC. The 8 V increase is due to the 1K?Ω pull up resister, which is smaller than the estimated value of 4.7KΩ. The 4.7KΩ resister would not trigger the PLC inputs, however. Thus, it was determined that the 1KΩ pull up resisters are more appropriate values for the success of the project.

Unclear

4.1.2 PLC and Component Interaction

When the simple program passing the input of the PLC to the output was tested, the input value appeared at the output for all tests. This result indicates that the PLC is functioning correctly. It also allowed the user to become familiar with the PLC programming structure. The second test involving the interfacing of the encoders and H-bridges demonstrated the functionality of the encoders with the PLC. When the encoder was turned clockwise, the PLC counter counted up. Similarly, when the encoder was turned counterclockwise, the encoder counted down. This was the expected result based on the encoder and PLC data sheets. In order to test the PLC and motor interaction, the motor was attached to the circuit and the motor control program was executed. The motor started, stopped, and changed directions when the appropriate signals were read by the PLC. These results indicated that the PLC properly interfaces with the necessary components.

4.2 Electro-mechanical

4.2.1 Gripper

From the first gripper test described in Section 3.2.1, it was determined that the two outer gripper tubes control the opening of the gripper fingers while the two inner tubes control the closing of the gripper. This test also verified that the gripper was functioning properly. The grip strength test indicates that the surgical tubing around the fingers provide adequate

friction to maintain control of the drill bit. When the drill bit was rotated, the gripper continued to provide enough grip strength to maintain a firm hold on the drill bit. When the gripper was connected to the wall air supply at a pressure greater than 80 psi, the surgical tubing was projected off of the wall nozzle approximately five seconds after the air valve was opened. Slits were then added into the surgical tubing to help alleviate the pressure build up. After the slits were added, the test was run again. The slits proved to provide the necessary pressure relief to keep the tubing attached to the wall nozzle.

4.2.2 Spud Tube Motor

When the 12 V supply was added to the unloaded motor, the motor shaft rotated clockwise. When the power supply leads were reversed, the motor rotated in the counterclockwise direction. These results indicate that the spud tube motor is functioning. When the spud tube assembly was attached to the motor, it was verified that the motor was able to support the weight of the structure. With this test confirmed, the 9 V power supply was connected to the motor. The motor was able to raise and lower the spud tube, but the process was much slower than the group had anticipated. After one week of operation the 9 V power supply burned out, indicating that the motor was drawing more current than the maximum allotted current of 1 A. Therefore, a 12 V 1 A DC power supply was obtained and attached to the motor. On the first run this power supply also burned out. The group then decided to determine the voltage and current the motor was drawing. To accomplish this task, the group obtained a voltage and current regulated power supply. The power supply was set to give a maximum of 12 V and 5 A and was connected to the motor. When the motor was in operation, the power supply indicated that the motor was using 12 V and drawing 140 mA, which is well below the operating point of the motor. Thus, the group decided the power supplies were failing for a reason unrelated to the prototype.

4.2.3 Arm Extension Motor

When the unloaded motor was attached to a 12 V power supply, the motor shaft rotated in the counterclockwise direction. When the leads were reversed, the motor shaft rotated in the opposite direction as expected. These results indicate that the arm extension motor functions. The motor was then attached to the threaded rod and connected to the robotic arm. In this loaded condition, the motor was able to move the robotic arm linearly through Jack for approximately five seconds before binding occurred. During these periods of binding the motor would draw 12 V and 360 mA, and the motor would cease functioning. These results indicated that the lead screw was not perfectly straight. The group removed the lead screw and straightened it in a vice. The screw was then re-attached to the assembly and the above experiment was repeated. During this run, the motor operated at 12 V and 200 mA. The arm moved linearly for approximately thirty seconds before binding occurred again. Upon further inspection, it was determined that the motor mount was not in line with the robotic arm. This discovery led the group to drill out the motor mount holes so that the motor could be better aligned with the robotic arm. After this change, the above test was once again run and the same results were observed. At that point, the lead screw connection device became the focus of attention. It was determined that the nut was welded at a slight angle to the top of the screw. To fix this problem, the lead screw connection device was raised approximately 1/4" vertically. This modification allows the threaded rod to sit at an angle which allows the nut to pass freely along the rod. With this change in place, the linear arm functions correctly approximately 75% of the time. The other 25% of the time, binding occurs as it did before the modifications were made.

4.2.4 Wrist and Arm Rotation Motor

When the 12 V power supply was applied to each of the unloaded rotational motors, both shafts rotated in the counterclockwise direction. When the leads were reversed, the motor shafts rotated clockwise, which indicates that the rotational motors function correctly. Then a rubber band was placed between the motor shaft extension and the wrist connector, and the motor was powered by a 12 V, 5 A power supply. During operation the rubber band slipped along the motor shaft extension, indicating this design solution would not work.

4.2.5 Wrist and Arm Encoders

When the encoder counting process was tested and observed on the Digital Mixed Signal Oscilloscope, the encoders produced a clean clock signal at the desired frequency in both cases. These results indicate that the encoders are functioning properly. A readout of the encoder signal received from the wrist encoder during a counterclockwise rotation is shown in Figure 7.

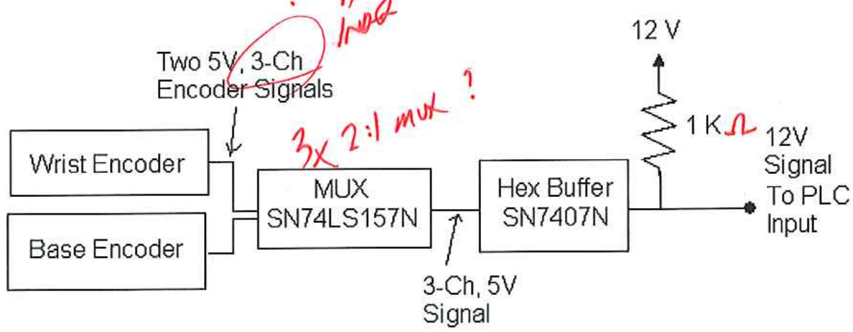


Figure 7: Encoder Count Cycle

As one can see from Figure 7, channel A is leading channel B during the counterclockwise rotation. The test was reproduced in the clockwise direction, and in this case channel B led channel A. This result indicates the proper functionality of the encoder according to the encoder data sheet. Similar tests were performed on the arm rotational motor, and the same

results were observed.

5 Conclusion

While not all design requirements have been met, several aspects of the prototype are functioning correctly. The mechanical structures that are functioning properly include: the raising and lowering the spud tube/drill assembly to the specified heights, the linear robotic arm movement, and the gripping and removing of the drill bit containing the core sample. These three mechanical functions are working very well without any major glitches; however, the bit removal and gripping motion must be actuated manually since the mechanical and electrical systems have not been integrated. The gripper wrist rotation and the robotic arm rotation about the base of the prototype are not functional. The robotic arm rotation motor has lost one of its leads, and therefore, this rotational process could not be tested. As discussed in Section 4.2.5, an effective method for the wrist rotation was not formulated. The group attempted to locate gears or a drive belt system that could perform this rotational function, however, the distance between the shaft extension on the wrist rotation motor and the wrist connector was too small for standardized parts. Time constraints did not allow for the ordering of these custom pieces.

The individual electrical sub-systems have been completed; however, the system integration has not been tested. The circuitry is complete and has been connected to the prototype and the PLC inputs. The program for the PLC has been written and has been simulated successfully with the appropriate software. While the integration testing may expose several small glitches, the group expects that most aspects would integrate well.

The prototype as a whole has does not meet all of the design goals set out at the beginning of the project. The goals that the group has met include: manual control of the majority of the prototype functions, using only current mechanical and electrical devices, not introducing

power supplies in addition to those that run the drilling procedure, and keeping the prototype fairly light and compact. The main design goal that the group has not met is the complete automation of the core removal process.

6 Recommendations

There are several changes that could be made to the prototype to improve its performance and make it more capable of being placed on a spacecraft. The first of these improvements involve implementing an electronically actuated gripper. The current design of a pneumatic gripper would not be efficient in the Martian environment because if damage was incurred to either the air supply or the tubes connecting the gripper to the air supply the success of the mission could be jeopardized. Also, if the air supply to the gripper were to exhaust itself there would be no way to operate the gripping functions. Thus, the most efficient way to avoid these problems would be to implement an electronic gripper. If one did decide to operate the gripper pneumatically it would be prudent to have electronic control over the pneumatic pump and to implement a pressure regulator.

The second improvement that could be made to the prototype involves purchasing a PLC with more high speed input/output pins. The current design requires additional circuitry in the form of multiplexers to perform all of the functions of the core removal system. If the PLC had more high speed inputs this circuitry would not be needed. While it is true that a PLC with more of these inputs may be more expensive, the reduction of circuitry would provide fewer locations for the electrical components to fail. Thus, a PLC with more high speed inputs and outputs would be a major improvement.

Another electrical improvement to the design would involve having internal wiring in the prototype. The current design has the wires exposed to the environment, which poses two very serious problems. The first of these problems is the fact that exposed wires are in

danger of being damaged or severed, which could render the prototype completely useless. The second issue that arises from having the wires exposed is the fact that there is the potential for the prototype to become entangled in the wires during operation. If the wires did in fact catch on a part of the prototype during the core removal process, there is a chance that the prototype would damage itself or become inoperable.

An improvement could also be made to make the gripper and arm rotations easier. If custom gears were implemented in these processes, it would be much easier to accomplish the necessary rotation. The current design of a drive belt is simply too unreliable to be trusted on Mars. Therefore, further designs should include gears to assist in the rotation process.

Lastly, a printed circuit board could be implemented in place of the current circuit board. This improvement would greatly simplify the circuitry, leading to fewer possibilities for failure. With the current circuit board, there is a much greater chance of shorting or damaging the wires. Also, when problems occur, it is much more difficult to find the source of the problem in the current circuit design.

References

[1] Beardmore, Roy. "Coefficient of Friction" *RoyMech.* `http://users.breathe.com/roybeardmore/Useful_Tables/Tribology/co_of_frict.htm`. Last Updated: 28 FEB 2005. Accessed 6 MAR 2005

[2] *DirectSOFT32 Programming Software User Manual.* Automationdirect.com Incorporated: 2002.

[3] Spotts, M.F. *Design of Machine Elements 6th ed.* Prentice-Hall, Inc., New Jersey: 1985.

Only 3 refs?

A Calculations

A.1 Rotational Encoder Calculations

The rotational encoder needed to position the gripper so that, when the arm was extended, the bit would fit between the gripper fingers. The bit is 2 in. in diameter and the gripper fingers are slightly more than 3.5 in. apart in the open position. This leaves 0.75 in. of clearance (See Fig. 8. At an arm length of about 20 in., the angle of allowable error (shown in black) was about 2.11^o, as shown in Eq. 1.

$$\arctan \frac{0.75in.}{20.36in.} = 2.11^o \tag{1}$$

To obtain this amount of accuracy, an encoder needs at least 180 counts per revolution (cpr), which corresponds to about 2^o of accuracy, slightly better than necessary. However, the costs of the encoder wheels was the same for a 180 counts wheel (actually, a 200 count wheel was the closest standard size available) and a 500 cpr wheel were equal so the team opted for the added accuracy of the 500 wheel for the wrist. This resulted in an accuracy of about 0.72^o or, at a 20 in. radius, about 0.25 in., a safety factor of 3.

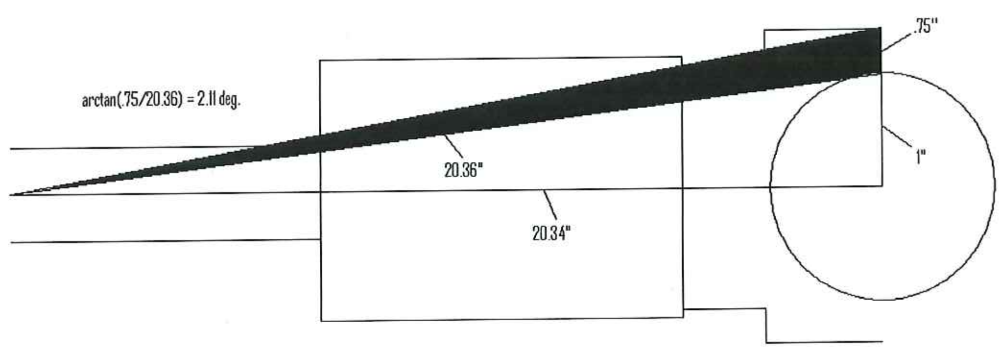


Figure 8: Diagram of the arm encoders uncertainty calculations

A.2 Wrist Encoder Calculations

The accuracy of the wrist encoder was dictated by the tolerance of the bit fitting into the spud tube. The components were designed so that the bit had 1/16 in. clearance in the spud tube hole. There is a distance of 3 in. from the plane on which the grippers grasps the bit and the spud tube at the point shortly before the bit is inserted into the spud tube. At this length, with 1/16 in. tolerance, an accuracy of about 1.19° is necessary or, an encoder cpr of at least 300 is necessary. Once again, the team opted with extra accuracy and used a 500 cpr encoder. The accuracy calculation is shown in Eqn. 2.

$$\arctan \frac{0.0625in.}{3in.} = 1.19^o \tag{2}$$

A.3 Screw-Thread Calculations

To determine the torque necessary to drive the spud tube and arm extension, Eqn. 3 was taken from [3].

$$Torque = W_{rt} \left(\frac{\cos \theta_n \tan \alpha + \mu_1}{\cos \theta_n - \mu_1 \tan \alpha} \right) \tag{3}$$

where $Torque$ is the torque required to turn the screw, W_{rt} is the weight applied at r_t, the pitch radius, and θ_n is the 3-D angle normal to the thread calculated by Eqn. 4, α is the helix angle calculated by Eqn. 5, and μ_1 is the coefficient of friction between the screw thread and the nut. The friction value used was for steel-steel contact found in [1]. The unlubricated value used was 0.8.

$$\tan \theta_n = \tan \theta \cos \alpha \tag{4}$$

$$\alpha = \arctan \frac{P}{C} \tag{5}$$

where P is the pitch of the screw and C is the circumference of the screw at r_t.

Using a 1/4"-20 threads per inch threaded rod, the torque estimate was about 9.5 oz-in. to lift the spud tube. For a safety factor, a 30 oz-in. motor was used. Also, the threaded rod could be lubricated to reduce the amount of friction and thus the required torque.

Similar calculations were performed for the arm extension power screw. However, the W_{rt} was significantly reduced since the motion was strictly horizontal, resulting in a significantly lower torque requirement. A 1/4"-20 threaded rod was also used.

B Circuit Board Layout

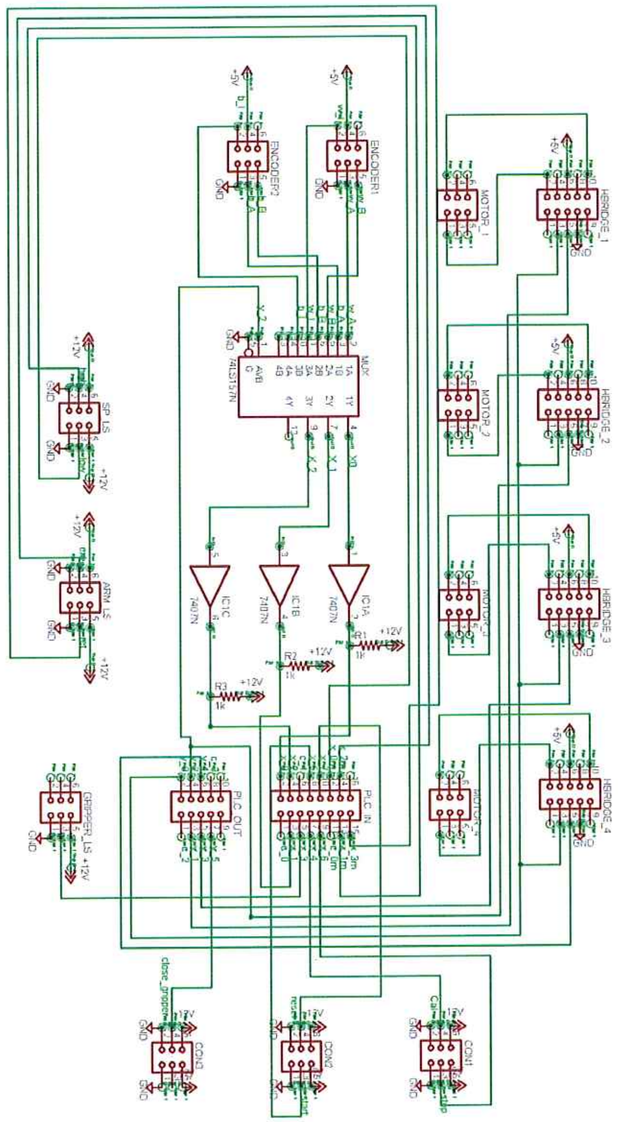
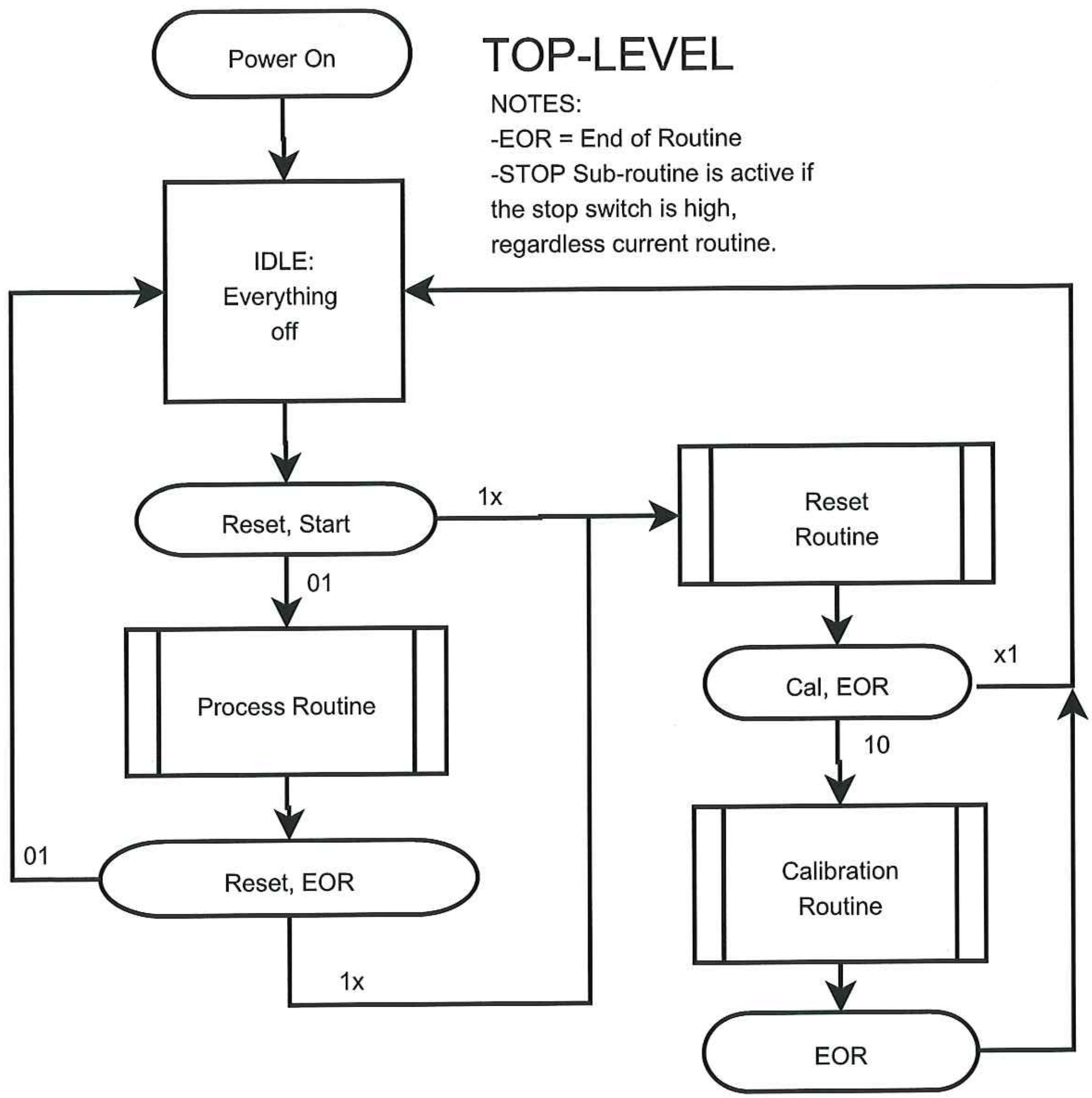


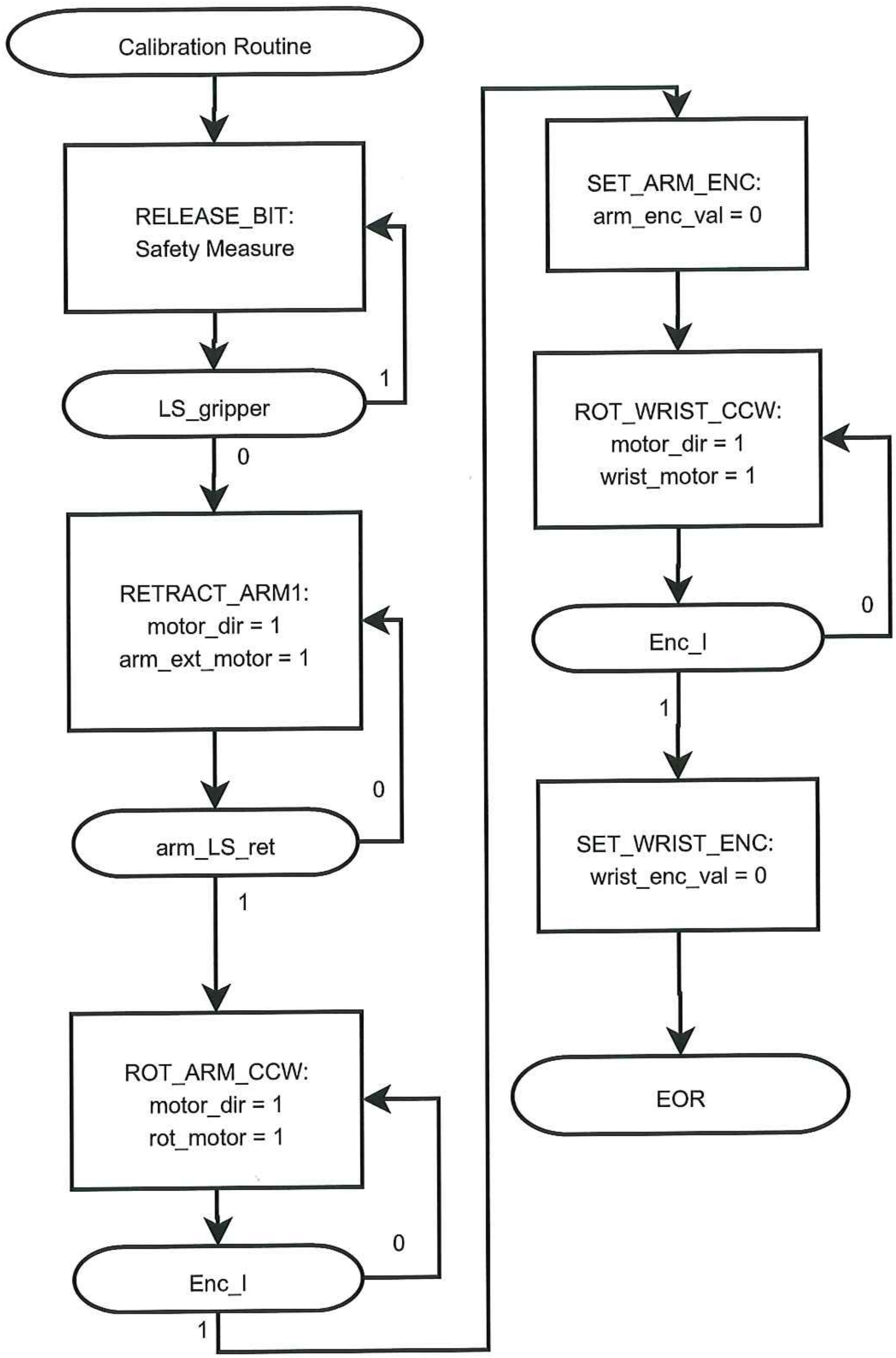
Figure 9: The circuit board was layed out as shown here. This circuit processed the PLC input/output signals to interface with sensors and motors and served as a collection point for the power and signal lines for the system.

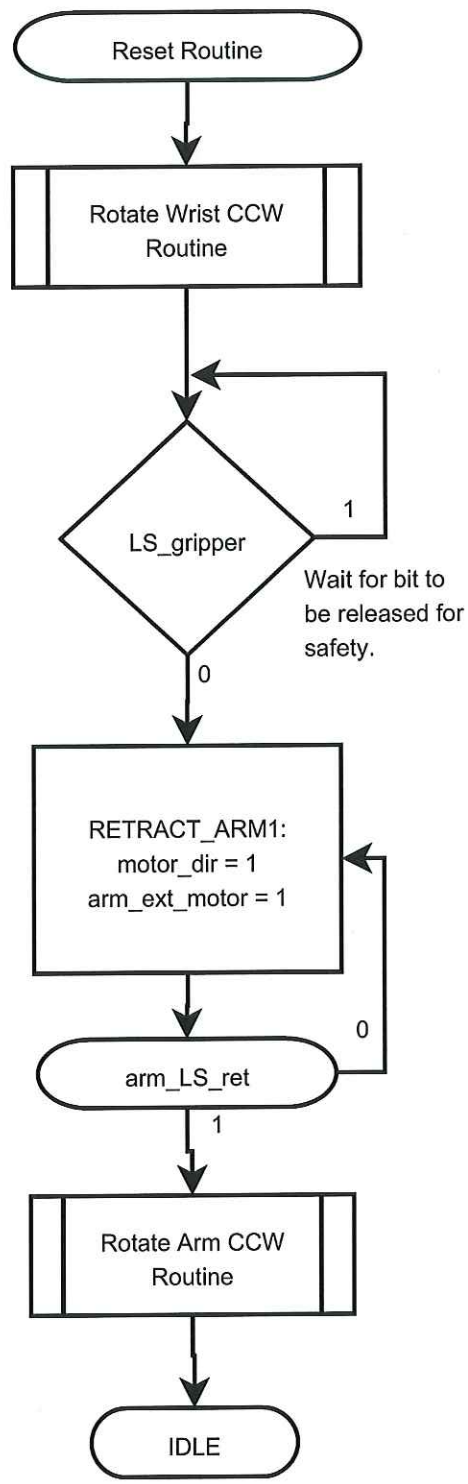
C Programming

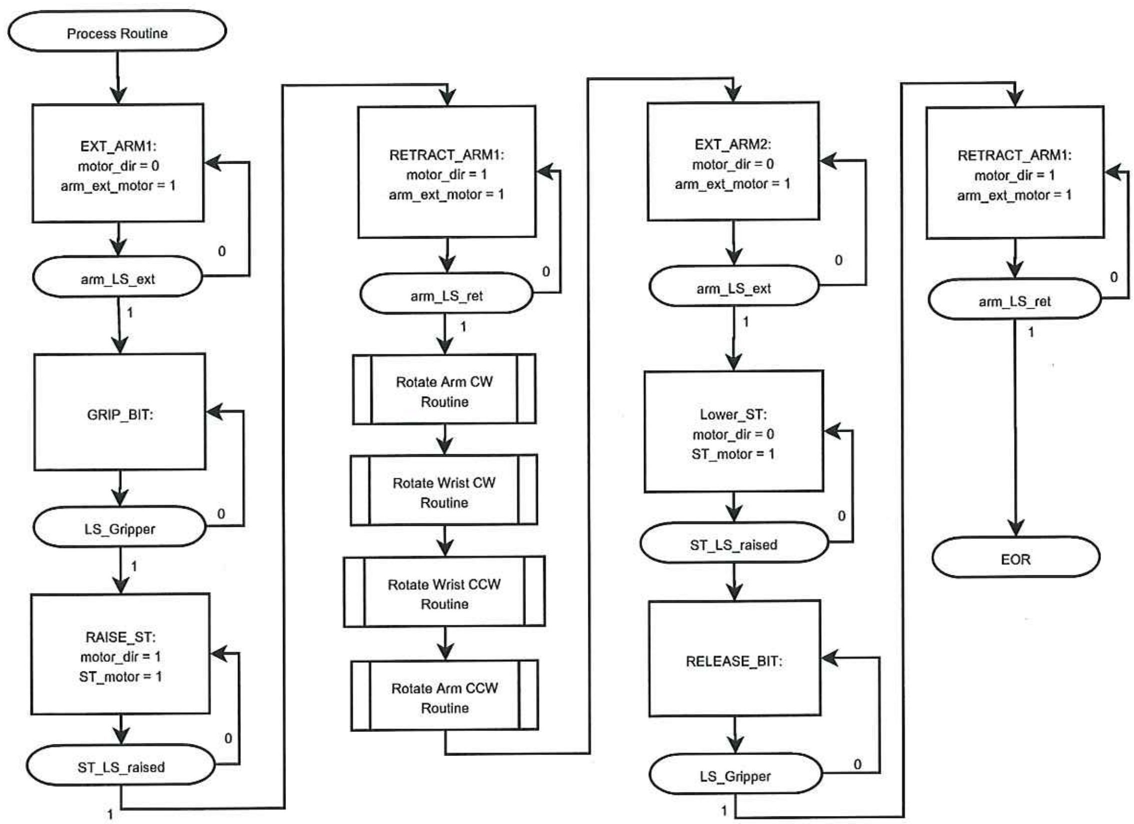
C.1 Program Flowchart

The Flow charts for the PLC Process Program follow. While some of the stage names have been changed from the flow chart, the program flow is the same.



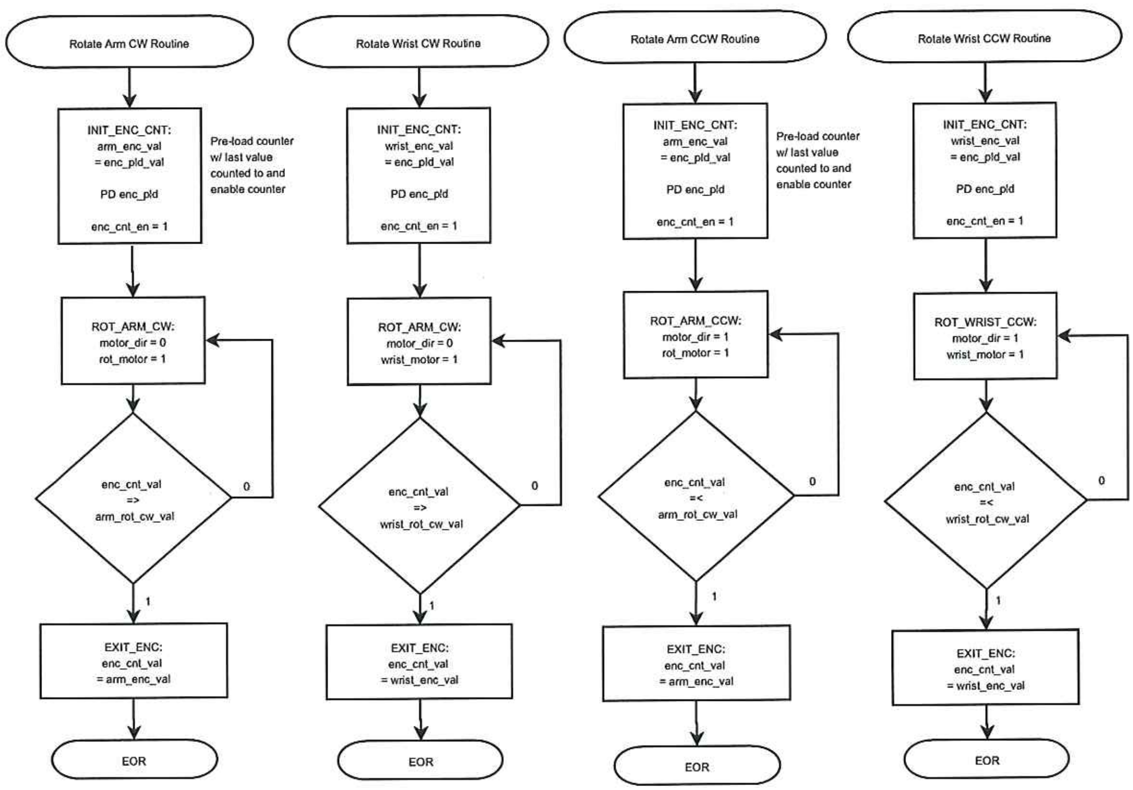

Calibration Routine
RELEASE_BIT:
Safety Measure
LS_gripper
1
0
RETRACT_ARM1:
motor_dir = 1
arm_ext_motor = 1
arm_LS_ret
0
1
ROT_ARM_CCW:
motor_dir = 1
rot_motor = 1
Enc_I
0
1
SET_ARM_ENC:
arm_enc_val = 0
ROT_WRIST_CCW:
motor_dir = 1
wrist_motor = 1
Enc_I
0
1
SET_WRIST_ENC:
wrist_enc_val = 0
EOR


Reset Routine
Rotate Wrist CCW Routine
LS_gripper
1
Wait for bit to be released for safety.
0
RETRACT_ARM1:
motor_dir = 1
arm_ext_motor = 1
0
arm_LS_ret
1
Rotate Arm CCW Routine
IDLE



NOTES:

-STOP sub-routine valid throughout this routine
-Reset only functions from within the stop routine.
-Rotate Routines complete before execution
in the parent rountine continues.


Rotate Arm CW Routine
INIT_ENC_CNT:
arm_enc_val
= enc_pld_val
PD enc_pld
enc_cnt_en = 1
Pre-load counter
w/ last value
counted to and
enable counter
ROT_ARM_CW:
motor_dir = 0
rot_motor = 1
enc_cnt_val
=>
arm_rot_cw_val
0
1
EXIT_ENC:
enc_cnt_val
= arm_enc_val
EOR
Rotate Wrist CW Routine
INIT_ENC_CNT:
wrist_enc_val
= enc_pld_val
PD enc_pld
enc_cnt_en = 1
ROT_ARM_CW:
motor_dir = 0
wrist_motor = 1
enc_cnt_val
=>
wrist_rot_cw_val
0
1
EXIT_ENC:
enc_cnt_val
= wrist_enc_val
EOR
Rotate Arm CCW Routine
INIT_ENC_CNT:
arm_enc_val
= enc_pld_val
PD enc_pld
enc_cnt_en = 1
Pre-load counter
w/ last value
counted to and
enable counter
ROT_ARM_CCW:
motor_dir = 1
rot_motor = 1
enc_cnt_val
=<
arm_rot_cw_val
0
1
EXIT_ENC:
enc_cnt_val
= arm_enc_val
EOR
Rotate Wrist CCW Routine
INIT_ENC_CNT:
wrist_enc_val
= enc_pld_val
PD enc_pld
enc_cnt_en = 1
ROT_WRIST_CCW:
motor_dir = 1
wrist_motor = 1
enc_cnt_val
=<
wrist_rot_cw_val
0
1
EXIT_ENC:
enc_cnt_val
= wrist_enc_val
EOR

D Budget

Table 1: Income and Material Expenses.

	Budgeted	Actual
Earnings		
Senior Design Budget	$1000	$1000
TSGC Earnings	925	925
Expenditures		
TSGC Field Trips		960
PLC	300	300
Electro-Mechanical	200	220
Plywood	30	35
Aluminum	220	233
Miscellaneous	165	82
Net Balance		$132

Table 2: Team Labor Expenses. Team Leader earns $30/hr, members earn $20/hr.

Team Member	Hours	Expense
Jeffrey Bennett	295	$6220
Konrad Izbinski	275	5920
Eric Mullen	226	4960
Michael Pickford	205	4320
Lindsay Wetzel	270	5870
Total	1271	$27,290

295 hrs / 16 wks = 18 hrs/wk 1 sem = 9 hrs/wk 2 sem

205 / 16 = 12.8 hrs/wk 1 sem = 6.4 hrs/wk 2 sem

E Schedule

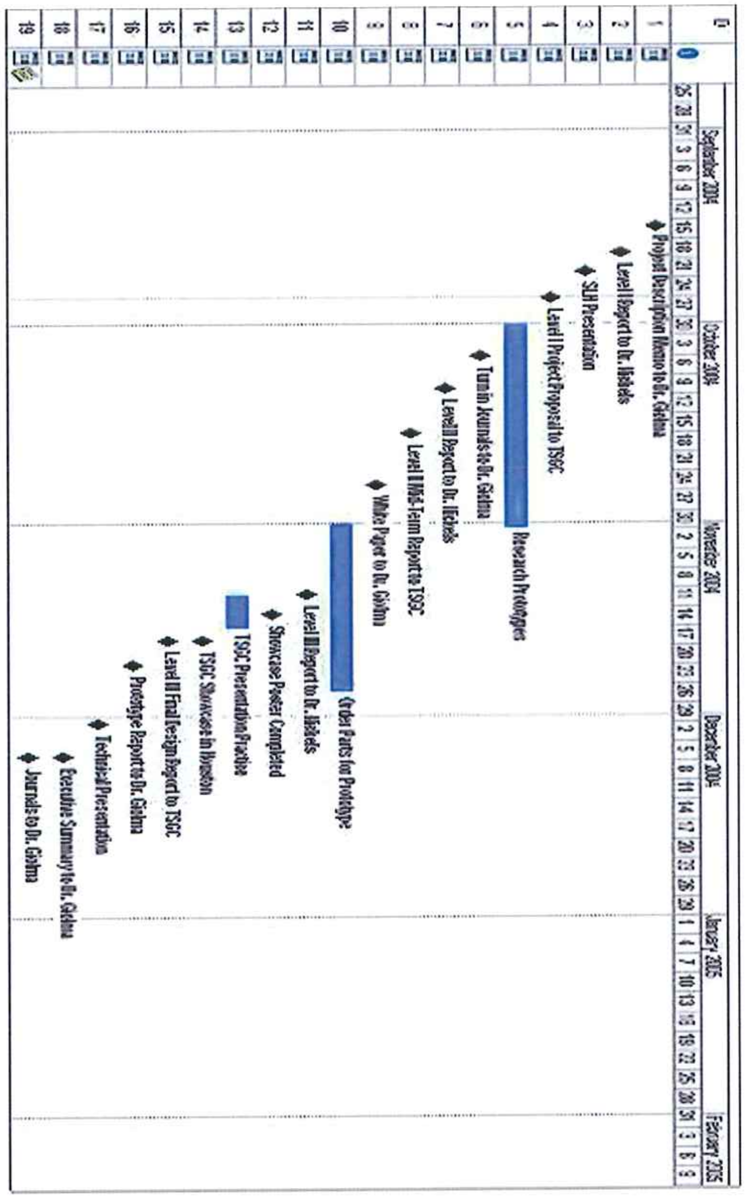


Figure 10: The team's schedule for 1st semester.

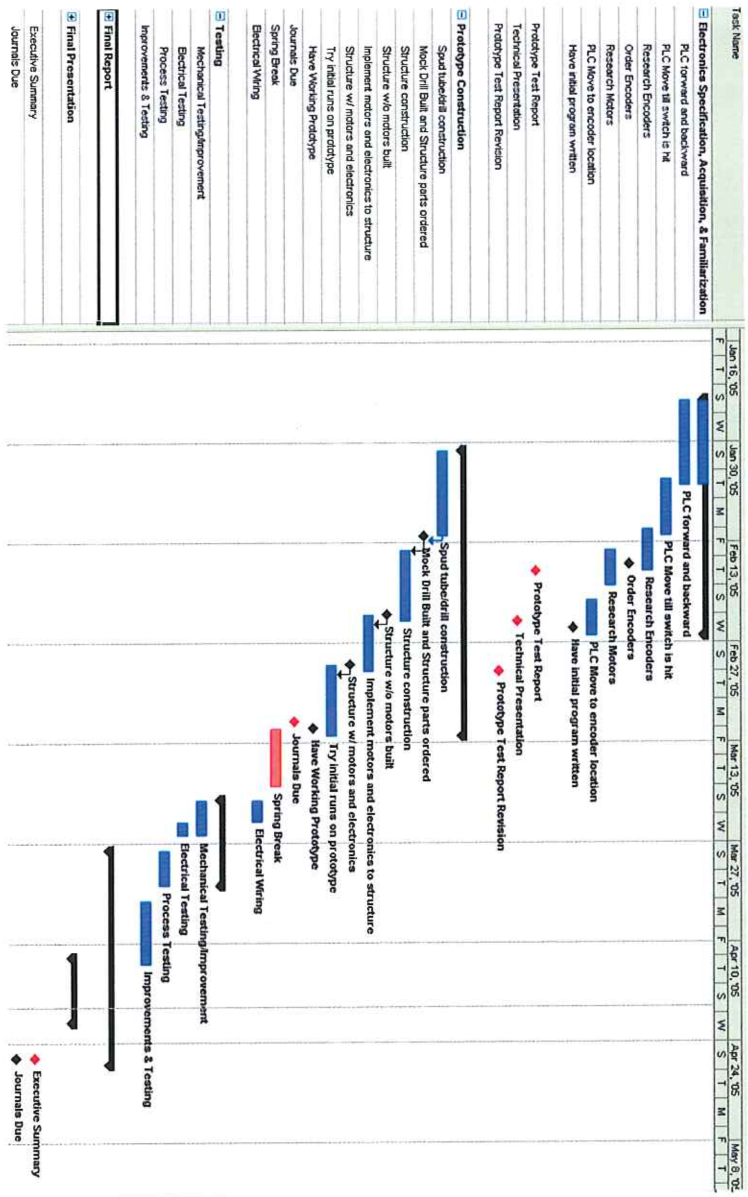


Figure 11: The team's schedule for 2nd semester.

F Division of Labor

Jeffrey Bennett My contributions to the project included motor and encoder selection, PLC selection and programming, prototype construction, and system integration. For the motors I found equations for and calculated the torque required for the various motions. From this information I researched and selected motors appropriate for the torques required. For the encoders, I helped Pickford determine the accuracy necessary for each encoder and after the accuracy was determined I researched and selected the encoders for the prototype. After meeting with Michael Yockey, I researched and selected the PLC for the project. Once the PLC was here, I began developing the flow chart and program for the PLC process. After I did initial PLC testing to ensure PLC operation and PLC interfacing with the components, I began writing and debugging the program. During prototype construction, I developed the design for the wrist and for the arm rotation mechanisms. I helped develop the mounting methods for the motors and the encoders and mounted the wrist and its encoder. I developed and then assisted Wetzel in designing the circuit.

On the report, I translated the various sections into LaTeX for final submission. I wrote the sections discussing the PLC at the design level and at the Testing level. I wrote the Design sections covering the motor, encoders, and limit switches. I wrote the Calculations appendix (the graphic was drawn by Pickford). I finalized the Schedule in the appendix. For the presentation I was in charge of developing the PLC implementation, programming, and testing sections.

As team leader, I oversaw most of the construction of the prototype, the PLC programming and debugging, and the writing of the final report and presentation. I started March 7th and continued through the end of the semester. Ultimately the project almost came to completion, leaving only the arm rotation motor mounting and operation.

Konrad Izbinski The two main aspects of the senior design project I have had to focus on are the Pro ENGINEER modeling and the construction of the prototype. The Pro ENGINEER task was assigned to me, which gave me the responsibility of not only modeling our structure, but also designing the structure from scratch. Once I had a feasible design created, I had to test it to see if it would bend or whether there would be too much torque. For this analysis, I had to use COSMOSWorks because I was having trouble using Pro ENGINEER. The last work I did with Pro ENGINEER, besides updating little changes we made while in the shop, was to animate the model for our final presentation.

The other work I did in the group was construction. I did not focus on any specific part of the construction, but rather helped with all of the components. The most work I have put into the prototype has definitely been in the arm which holds the gripper. There was a lot of slack which creates significant uncertainty, so I spent a lot of time in this area trying to minimize undesired movements.

Eric Mullen My major contribution to the project involved a lot of the construction on the prototype. I researched and purchased several of the parts of our drill, and I helped build every sub-system on our prototype, including the spud tube/drill assembly and the robotic arm. Specific parts of the prototype I spent a lot of time on included the mounting all of the motors and making the spud tube operational. This task took up a lot of my time as the spud tube/drill assembly was initially unstable during operation and the spud tube brace is very hard to work around once all of the supportive wheels had been added. Additionally, I also added L-bracket braces in the robotic arm to make that piece more stable. I performed all of the testing on the motors and spent a good deal of time with Konrad optimizing the linear movement of the robotic arm.

My contributions to the final report included writing and editing the introduction, conclusion, electro-mechanical testing, and the executive summary sections. I also helped Lindsay

work on the system process section a little. Additionally, I am the person in charge of making the slides dealing with the spud tube assembly and testing for our final presentation.

Michael Pickford For our Senior Design project, I focused on the mechanical aspects of the project. I was responsible for testing the gripper to make sure it worked, as well as designing new fingers for the gripper for greater accuracy. I also made the calculations concerning the accuracy of the encoders before we ordered them. Once we had the gripper working, I designed and built air lines that connect to the gripper and control the opening and closing of the gripper fingers. I have also worked on both the spud tube assembly and the robotic arm assembly. I made the drill bit and the piece that connects the gripper to the arm, mounted motors and assisted other group members if I did not have a specific task to complete during a week. This seemed to happen a lot of the year because the tasks I was given working with the gripper did not take up as much time as some of the other tasks other members were responsible for.

Lindsay Wetzel This year I have worked on a wide variety of tasks for our prototype. Most of the time I spent on the mechanical structure was dedicated to the spud tube/drill assembly and the drill support structure. I helped to design, construct, and make stability improvements to these sections. I also helped with several smaller tasks such as adding legs to the base structure, making the connectors for the air valves to connect to the gripper, researching and purchasing bearings, as well as helping out in the shop when needed. In addition, I designed and am in the process of constructing the circuitry necessary to integrate the PLC with the mechanical prototype. Once this is complete, we will integrate the two systems and then I will be helping with the testing and improvements needed.

G Analysis of Design Concepts

G.1 Establishment of Design Specifications and Criteria

Establishing design specifications and goals for the year helped us to plan out each of the necessary steps to complete the project. We were able to break the large project into several smaller aspects, which added structure to the year. By setting out all of the project criteria in the beginning, we have also been able to keep track of our progress throughout the year.

G.2 Analysis

The first semester of our design project was almost completely dedicated to design and analysis. We came up with an original idea of how to successfully complete our project goal. Throughout the year, we consistently analyzed our prototype design with ProEngineer and made necessary adjustments. Even beyond the final prototype design, we have continued to analyze each part of the structure as it is built. We've learned that the analysis design concept is one of the most important aspects because it is a continual process for a successful project.

G.3 Synthesis

Our project has dealt with a variety of concepts that we have learned from the engineering program over the last four years. A large part of our project involves integrating mechanical and electronic components. We had to consider aspects such as torque, moments, buckling, and stability which we learned from our mechanical engineering classes. We also had to implement encoders and limit switches through circuitry we have studied in electronics. Our wide range of knowledge allowed us to integrate the mechanical and electrical systems successfully.

G.4 Health and Safety

Throughout the year, we have been very careful in looking out for our own safety as engineers as well as the safety of the public. For our own safety, we only attempted to construct the parts of our prototype which were within the bounds of our abilities, leaving the more dangerous machining to Manuel. We also were very careful to follow the rules of the machine shop at all times. For the safety of the public, we carefully analyzed all aspects of the prototype design before construction to ensure that all parts would not fail under appropriate use.

G.5 Construction

We delegated sections of the project for each group member to complete. We first split the group into mechanical and electrical specialists. We then subdivided each of these sections into specific jobs for each member. This expedited the construction process because each group member had specific goals to complete on their own.

G.6 Testing

Throughout the year, we have learned that the most efficient method of testing is to test each part as it's constructed as opposed to completing the project before starting the testing process. Testing throughout the construction process has allowed us to catch many small potential problems before being implemented into the final prototype. If these problems are not caught early enough, they might affect other aspects of the system, making correction extremely difficult.

G.7 Evaluation

The group has looked over the design and has noticed aspects of the prototype in which we exceeded as well as areas we could improve on. We spent a lot of time on the ProE models which allowed us to improve our design without spending any money. However at times we would spend more than the allotted amount of time on a particular section and ended up getting behind in our schedule.

G.8 Communication

Communication is one of the most important jobs of a group member. In order to encourage group member communication, our group always has at least two meetings together each week. The ability to express both concerns and ideas to a group is very important for an engineer. Without good communications skills between group members, a great idea could go unsaid while a problem could go unnoticed. Our group strived to keep the lines of communication always open, making significant use of e-mail, discussion board-based weekly progress reports, formal reports, and formal presentations.

G.9 Mathematical Modeling

In the design process, we used ProEngineer as well as several other calculations to ensure the various parts of the prototype could work together. Structural analysis was performed in ProEngineer to ensure that all parts could withstand their necessary loads. Also, several calculations were performed to make sure that appropriate encoders and motors were purchased.

G.10 Chemical, Electrical, and Mechanical Engineering Analogs

We did not use any chemical, electrical, or mechanical analogs in our design process.

G.11 Optimization

In order to optimize our PLC inputs, we used a multiplexer along with a hex inverter with open collector outputs for our encoder inputs.

G.12 Ethics

Each group leader throughout the year made sure to delegate specific tasks to the member or members that could complete the task the best. Those studying electrical engineering focused on the electrical components of the project and those studying mechanical engineering focused on the mechanical aspects of the project.

G.13 Aesthetics

The group focused getting the prototype to function properly before we went out of our way to improve the aesthetics of the prototype. We still however believe that the structure of the prototype is solid and the appearance is very professional.

G.14 Robust Design

The prototype is constructed of aluminum which provides more than enough strength to withstand the functions of the prototype. Some of the parts of the spud tube tower have been welded together to ensure a stable structure. All other connections are either held in place using bolts or epoxy.

G.15 Economics and Life Cycle Analysis

In relation to construction, throughout the year the group stayed within the predetermined budget of $1000. As far as maintenance is concerned, the prototype should require very little

work after it is constructed. All the parts are reliable and tested to ensure a prototype that functions properly for a long time.

G.16 Manufacturability, Reliability, and Sustainability

Manufacturability was not really taken into consideration for our project. After all, this project is for NASA and there will only be one constructed for the journey to Mars. Reliability and sustainability however were considered in every aspect of our prototype. Our design is required to function on Mars for an extended period of time as well as survive the trip there. If our prototype is unreliable or can not stay intact during the mission, it will be a total failure.

Presentation 90/100
Report 85/100
Final HW/SW 75/100
Final Testing [illegible]/100
87
All +/- based on individual