FLORIDA A&M UNIVERSITY - FLORIDA STATE UNIVERSITY
COLLEGE OF ENGINEERING

Team 11 – NASA/RASC-AL Robo-Ops

FAMU/FSU College of Engineering

Deliverable #6 – Final Report

Concept Generation

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Project Overview (Competition Proposal)

1.0 Abstract

This document describes the FAMU/FSU College of Engineering's proposed rover design for the 2013 RASC-AL Robo-Ops competition. The team consists of five undergraduate engineering students each with an interest in space exploration and experience in fields pertinent to remote robotic systems. Professional guidance and working facilities have been provided to the team by their main advisor, Dr. Jonathan Clark, and the STRIDe Lab, which operates under his direction.

The goal of this year's team is to build upon the successes of last year's competition team while developing cutting-edge designs to overcome the shortcomings of the previous year's rover. The proposed design features hexapedal locomotion which naturally provides the rover with key features to be rover successful. The rover then features a four degree of freedom robotic arm which is designed to complement a unique compliant gripper. Finally, the design features a new control interface will allow for real time control and improved communication throughput paired with iterations of redundancies.

2.0 Team Leads and Facilities

Jason Brown, Mechanical Systems Lead – Jason Brown is a senior at Florida State University pursuing his BS in Mechanical Engineering. He spent this past summer working in the Center for Intelligent Systems, Controls and Robotics on the development of an autonomous quadrotor. The work focused on the integration of an autonomous quadrotor with an autonomous ATV.

Linus Nandati, Electrical Lead – Linus Nandati is a Senior at The Florida State University and is pursuing a BS in Electrical Engineering. Currently, he is employed by Tallahassee Board of Realtors as a Networker and IT intern. His area of expertise is communication systems and security.

STRIDe Lab, Working Facilities – Scansorial and Terrestrial Robotics and Integrated Design Lab was founded in 2007 by its director, team advisor Dr. Jonathan Clark, with the aim of developing robotic platforms which can challenge the agility and versatility of animals and insects. STRIDe Lab has worked extensively on the design and control of legged platforms and is well equipped for the task of developing a legged rover. The lab boasts several tools to aid in the manufacture of a rover including a laser cutter, composite material construction tools, extensive analysis and testing devices, and a capable machine shop located adjacent to the FAMU/FSU College of Engineering.

3.0 Lessons Learned

Last year the FAMU-FSU team competed with a legged rover with a low degree of freedom robotic arm, utilized a 3G/4G Verizon Wireless Dongle inserted into a type G router which communicated commands sent from the home base GUI system via LAN connections to 2 Raspberry Pi's. The Raspberry Pi's connected sent commands to an Xula2-LX25 FPGA via SPI communication, which sent commands to each of the six individually actuated legs.

The rover consisted of 6 independently actuated C shaped passively compliant legs utilizing Buehler's Algorithm to command the position of each leg. The legged motion provided a unique and capable means of handling the various obstacles at the NASA rock yard. Experience from both last year's team in the competition and experiences in the Lunabotics Competition in 2012 has shown a hexapedal legged the platform is capable of handling sandy terrain (including fine Regolith sand), steep inclines, and obstacles larger than the ground clearance. This further supported the ability of legged locomotion and thus we plan to implement the hexapedal locomotion as will be discussed later.

While the locomotion platform performed well against any terrain in a straight line, the control algorithms struggled with navigating around obstacles and handling minor adjustments. The legged locomotion has a fixed minimum distance for forward motion with standard stepping motion. Additionally, turning motions are more challenging to accomplish compared to wheeled platforms. The rover last year had 3 different gaits: moving forward/reverse, turning in place, and a hill climbing gait. The team experienced challenges in moving to a rock once it was identified. Some of the limitations of the control are inherent to the locomotion system, which include the standard step size which influences the minimum in place turn which can be achieved. This made clear the need for more control schemes to effectively maneuver the course. Some of the limitations can be overcome with new gaits and control schemes.

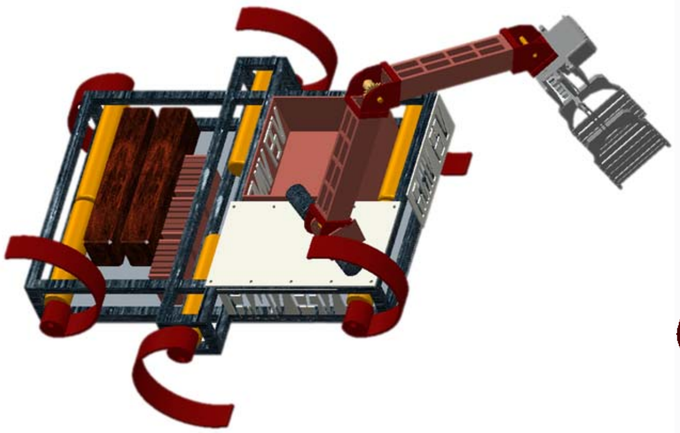
The Sample Extraction Module from last year was designed to take advantage of the unique locomotion platform, having only 2 linear degrees of freedom in the x and y directions, with the rover itself providing the third degree of freedom. The mechanism was relatively slow from the point of identifying a sample to acquiring the sample. The system's stored configuration was far away from the extraction area. Next, the system required the operator to make many minor adjustments once the system was deployed. Limited visibility and perspective from the main camera then amplified the difficulty in making the small adjustment. The limited workspace hindered the modules collection speed which was then amplified by the limited refined movement of the rover. The design did used a simple string to help the user see the ground location of the gripper, and some simple creative solutions will also be implemented into this years design. The team also planned to implement a click to grab system incorporated into their GUI which would have reduced the load on the operator. (Refine and describe further)

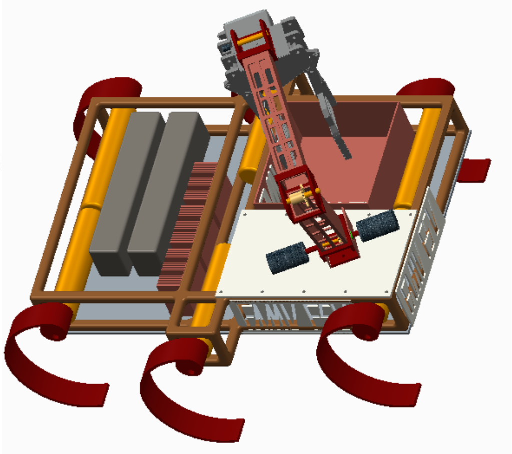
The user control from last year was a GUI system which used command inputs to control the rover. The command inputs were constructed through the GUI in the form of arrows which designated direction and a window where the user entered the desired number of steps. The system would then execute the command and a new command could not be entered until the previous command had been completed. This method of user input slowed the team in handling the rover, for it required several seconds to enter each command. Since hundreds of commands were entered during competition, the seconds added up and the added lag in communications hindered user command speed. This made clear a new interface need to be developed which was more intuitive and allowed for the rover to respond in real time.

The communications system utilized Verizon Wirelesses 4G network to send command to the rover and send the video feed to the mission control. The Verizon network was slower than expected on the day of competition, which resulted in the connection being dropped multiple time during competition. This made clear a more advanced communication system would be necessary to maintain connection and transmit the necessary video feed.

	Performance During Competition	Lessons Learned
Locomotion	Straight Line handled all obstacles Navigation was challenging	Showed legged motion's ability to handle obstacles Showed need for additional gate types
User Interface	Required multiple commands to execute step based control	System slowed teams ability to control the rover and real time interface would be desirable for competition
Communication	Connection dropped multiple times and lagged continuously during competition	Communication dependent on single network is vulnerable to network fluctuations.
Sample Extraction Module	Able to pick up single rock, but struggled for several minutes and failed to acquire an relatively easy sample	Slow mechanism Poor vision Limited reach/workspace Poor terrain adaptation

4.0 Rover Dimensions and Performance

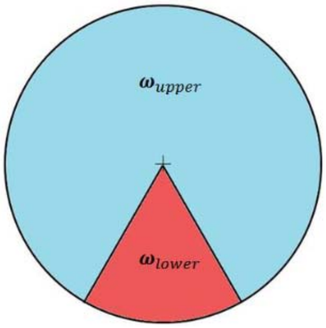


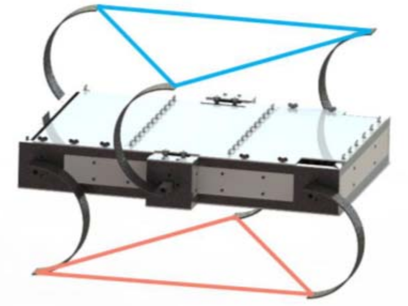


5.0 Systems Components

Locomotion

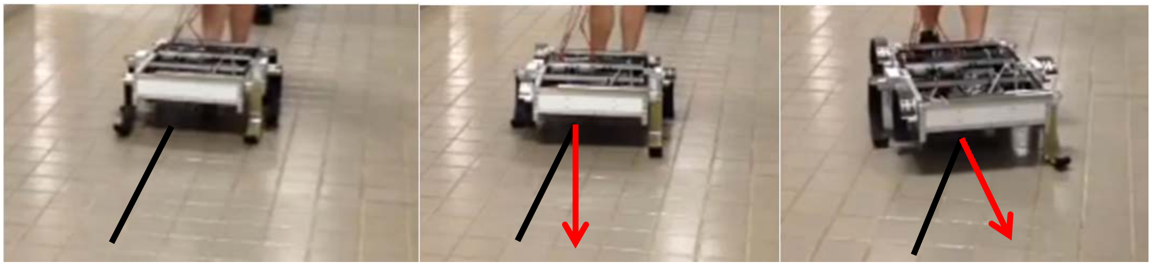
The biggest benefit to the legs over wheels is the legs ability to move freely across certain terrains. The legs are able to step over obstacles and quickly maneuver over steep inclines, large rocks, and sand.





The hexapedal design will be sturdy enough to handle tough collusions with rocks but also agile and light. A carbon fiber material was effective last year in this regard and will thus be re-used. The diameter will stay at 25 cm, since at this height the robot was effective at traversing the rocks in the JSC Rock Yard. The legs will still be operated according to the Buehler Clock algorithm. As with almost all RHex platforms, the Buehler clock controls the speeds at which the legs rotate, and thus ensure that the rover will never fall. The legs which are in the air must move faster in order to cover the ground necessary to reach the ground by the time the other set of legs finishes its respective ground phase. This aspect of the rover was completed last semester, and was effective in handing multiple terrains, thus it will be used again.

Last year's rover had the capability of turning in place and traversing directly forward or backward. However, there were no control algorithms which allowed the rover to quickly dodge obstacles without stopping and turning. Therefore, this fall, a "turn while walking" function was created in order to allow for more precise and fluid control. The turn while walking function maintains the same sets of legs, but rather than keeping the legs completely in phase to each other, the phases are adjusted depending on the turn angle desired. For example, to make a left turn of mild intensity, the right legs in each set are moved ten degrees ahead of their left leg counterparts. This separation in phase allows the right legs to hit the ground early (while the left legs are about to finish their ground phase) and nudge the rover in the left direction slightly before the other legs join and even out the motion to a normal walk. Thus, for every step taken, a slight left turn is made. The phase difference can be amplified in order to get a more drastic turn and more rapidly avoid looming objects. The turn while walking can create turns ranging from 1 degree per step to about 10 degrees per step, which compares to the turn in place turn which turns at a rate of approximately 30 degrees per step.



A problem was discovered when testing the rover's ability to walk on a hill. It was discovered last semester that a sloped surface caused the rover to turn slightly in either direction. To combat this, a hill gait function was written and proven to work. The rover will lie down, and rotate its outer four legs in a full circle to create one forward step. While this was nice, this year's rover will be much more maneuverable on hills. A turn while climbing function will also be written and implemented. Mars hill may contain obstacles, or quicker routes to traverse, in which case, a turn while climbing will be extremely handy in gathering more samples in a shorter amount of time.

Minor adjustments are often needed once a sample is identified, so the team will be developing a locomotion gate which can be used when the rover is laying down to nudge the rover into place. The method this will be accomplished is using the legs to pick up the rover a small amount off the ground which will move the rover forward at the same time. When a set amount forward has been achieved, the legs will release and let the rover fall. With more control, the rover would be able to turn in place using the nudge functions

Control and Programming

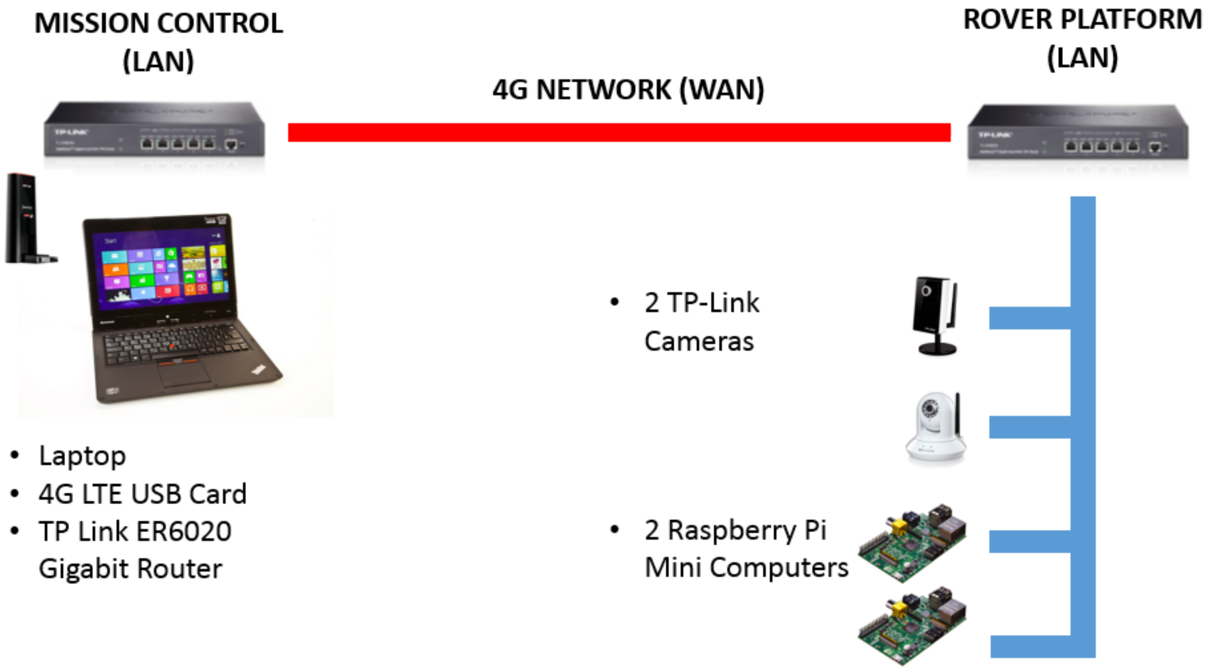
The GUI which was used in the previous competition was very non-user friendly and it required tedious command inputs in order to operate the robot. Each command executed a routine and disabled user inputs until the function was fully terminated. This year, the controls will be completely overhauled. A video game controller (XBOX 360 device) will be used to control the rover instead of a GUI. A joystick allows for easy locomotion control and the buttons will be utilized for commands such as lie down and stand up. A software program called XPadder allows for the mapping of an XBOX controller's buttons and joysticks to buttons on the keyboard. This program has been used and implemented. Though only a prototype version of the XBOX controller is functioning, it is already much quicker to input commands and it will definitely prove effective at making a more fluid walking rover.

Once this mapping is finalized, there is a library written in C called the SDL library. The SDL library is a pre written library which will allow for the XBOX to affect the program dynamically. What this means is that by simply holding forward a joystick, the rover will continue to walk until the joystick is released. This ability to stop the rover once it has reached its destination as opposed to predicting how many steps are necessary will create a real time interface which will allow for more precise positioning over the samples to be extracted. In addition, the rover will be much simpler to control and the time between commands will be nonexistent, allowing for quicker traversal of the competition field.

The arm mechanism controlled mechanism will be controlled using end effector mapping from desired workspace to angular positions. This will then be feed into our GUI system and a point to click system will be used to minimize the amount of information which must be transmitted across the wireless network and to take advantage of the processing power onboard the system. The video feed with be processed at the home base and the user will click the point which the gripper needs to reach.

Communication

The figure below is a schematic illustrating the overall communications system. Mission Control, consisting of a computer linked to a 4G-enabled router, communicates with the rover. Mission Control makes up the first Local Area Network (LAN). The rover has a router that communicates with the mini computers that activate the robots legs and arm, and two IP (Internet Protocol) cameras that send a video feed, making the rover a second LAN. The Mission Control rover communicates with the on board router by bridging the two routers. They communicate via a VPN (Virtual Private Network) tunnel over a Wide Area Network (WAN).



ROVER COMUNICATION DESIGN OVERVIEW

On board the rover, a router with a Verizon 4G LTE USB Card installed will link the rover's components to mission control. This router will be linked with the mission control rover over a commercial WAN. Last year's design relied solely on the Verizon 4G Network, however this lead to interruptions in communication as the network faced problems on the day of the competition. This year, the communications design will integrate the Verizon and AT&T 4G networks. The purpose of utilizing both networks is for one to share the data transmission load, and serve as a back-up in case the other fails. Additionally, integrated into the design will be the ability to dynamically switch between networks if necessary, thus ensuring communication across the WAN is not interrupted.

The vision system will include an IP camera that sits atop the camera mast must be able to pan and tilt. A second IP camera will mount to the Sample Extraction Module to ensure an optimal viewing angle for the user controlling the arm. The cameras are ideal for the design as they have specific IP addresses, enabling direct communication. Hypertext Transfer Protocol (HTTP) will be used to feed the videos to the on-rover router.

Secure Shell (SSH) protocol will be used to communicate with the Raspberry Pi mini-computers. The Raspberry Pis are programmed with the C programming language and have a Linux-based Operating System installed. The SSH server and client are readily available on many Linux distributions making SSH protocol a viable solution. Last year's team discovered most wireless broadband carriers prevent incoming SSH connections, but do permit outgoing SSH connections. Thus, a script was written that, upon booting the system, connects the

Raspberry Pi to a Mission Control port, allowing the server to reverse-SSH back into the Raspberry Pi allowing the user to communicate with the mini-computer.

To communicate between different devices on the rover (i.e. between the leg motors and the mini computers) Serial Peripheral Interface (SPI) wires were integrated into the design. The SPI protocol transmits information in full Duplex, meaning it can transfer a byte and read another byte being sent all simultaneously. This property greatly improves the speed of the design.

ROUTER UPGRADES

In last year's design, we used two TP-Link MR3220 routers. One aspect of the routers that needed to be addressed was the port speed. The TP-LinkMR3220 router had 10/100 Mbps Ethernet ports. Routers are now enabled with 10/100/1000 Mbps ports. Port speed is crucial to the efficiency of a communications design. The quicker the data can be updated from the LAN to the WAN, the more efficient the design will be – and there will be a discernable difference in speed.

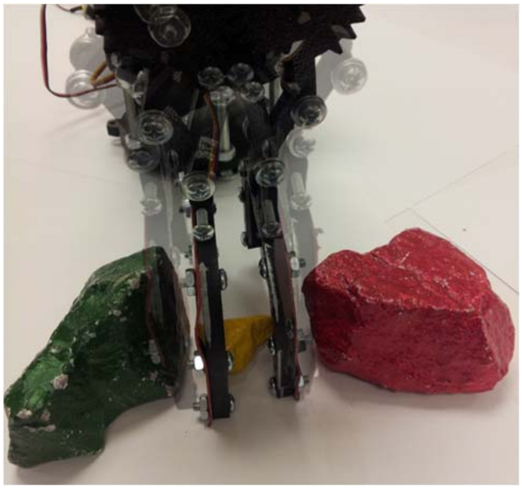
Another area that was addressed was the lack of a VPN-client mode for either of the MR3220 routers. A lack of this client does not make communication between routers impossible, but it does cause delays. There is free software to install in routers to create a pseudo-client mode in routers, but a router already enabled with a client mode is more ideal. A router that meets the needs listed above is the TP-Link ER6020. The router is VPN-enabled and has Gigabit ports. The router was chosen since last year's team was sponsored in kind by TP-Link and this year's team wishes to continue the partnership.

Sample Extraction Module

Sample Extraction

The proposed sample extraction design consists of a three degree of freedom arm manipulator complete with a one degree of freedom revolute wrist joint and a compliant end effector. Lightweight and agility were the primary consideration of the sample extraction module as it was shown in the past competition participation that rover weight and precision turning still have rooms to improve upon.

The proposed arm design utilizes a traditional three degree of freedom with three revolute joints with 270 degree range of motion around the base joint, combined with 2 feet of reach length resulting in a 9.5 ft^2 operating area for the end effector. The frame of the arm made out of hollow Aluminum 6063 beams with cutouts will provide sufficient structural integrity to minimize beam deflection yet minimize the load on the linkage motors. The two base motors responsible for majority of the weight on the arm will be mounted on the rover platform combined with a chain driving mechanism to actuate the arm linkages.



The end effector design is a hybrid design aimed to capture the usefulness of several common end effector designs. The fundamental mechanism composed of a two pronged pincher aimed to execute precise grasping motions, coupled with a wide attachment to increase surface area between the sample and the end effector. The attachment "finger" is lined with elastic materials designed to conform to the orientation and shape of the sample to provide maximum traction with minimum motor torque needed.

The anticipated end effector design should be able to provide superior sample retention ability, all the while only requiring a low torque motor thus achieved the goal of lightweight.

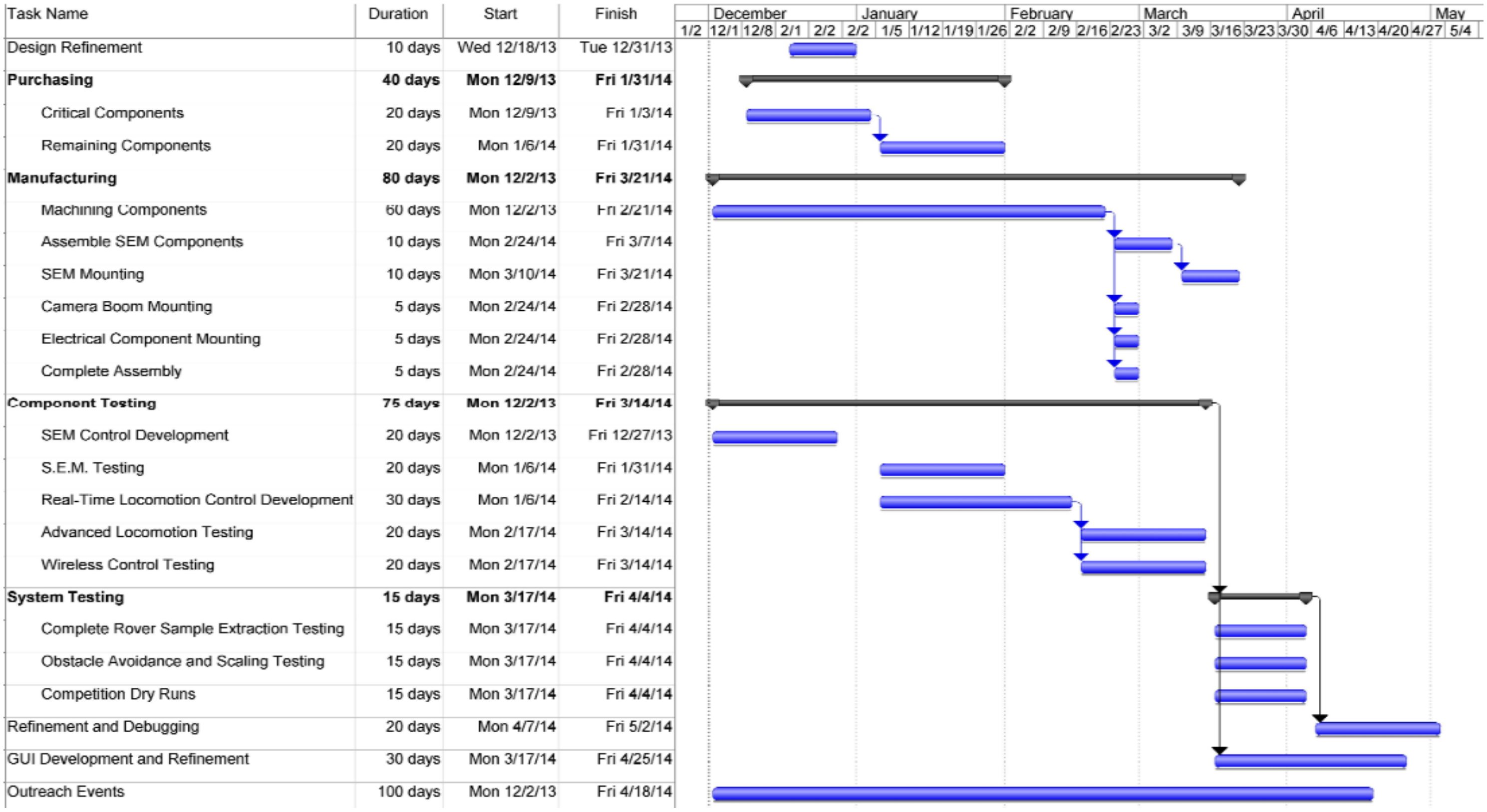
Compliant material for the end effector attachments have been carefully considered due to the potentially extreme cold climate of outer planets such as Mars. The proposed material polydimethylsiloxane, commonly known as silicone rubber, is known for its elasticity and ability to withstand large temperature variation ranging from -120C to 300C while maintaining the essential elastic properties. It is also important to note that the manufacturing process in which the silicone rubber polymer is synthesized and shaped determines the various temperature ranges the material can endure. The team will be using low grade silicone rubber sheet for the low cost and availability but the design could be suitable for extreme cold climate with higher grade material.

6.0 Education and Public Outreach

The team currently maintains a Facebook page, a website, a YouTube channel, and an Instagram account to fulfill the electronic portion of the educational and public outreach (E/PO) requirements. The website is a primary hub for project documents and reports. It also contains information about all team members, sponsors, and an overview of the project itself. Most photos and videos of progress made will be posted on the team's Facebook page. Important photos and videos will also be featured on the team's website. The YouTube channel is used to feature all videos of progress and to chronicle important project milestones and events. The Instagram account is used to provide impromptu picture-updates on team activity.

The team has future plans to participate in public outreach events at the Challenger Learning Center, the K-12 outreach facility of the Florida A&M University - Florida State University College of Engineering. The Challenger Learning Center has a theme of space exploration, and hosts family-friendly space-oriented events year-round. The team also plans to engage in an outreach event at a local middle school to engage students with the theme of robotic planetary exploration, using the team's rover as a set piece. Finally, the team plans to utilize on campus events at Florida State University and Florida A&M University's main campuses.

7.0 Proposed Timeline



Task Name	Duration	Start	Finish
Design Refinement	10 days	Wed 12/18/13	Tue 12/31/13
Purchasing	**40 days**	**Mon 12/9/13**	**Fri 1/31/14**
Critical Components	20 days	Mon 12/9/13	Fri 1/3/14
Remaining Components	20 days	Mon 1/6/14	Fri 1/31/14
Manufacturing	**80 days**	**Mon 12/2/13**	**Fri 3/21/14**
Machining Components	60 days	Mon 12/2/13	Fri 2/21/14
Assemble SEM Components	10 days	Mon 2/24/14	Fri 3/7/14
SEM Mounting	10 days	Mon 3/10/14	Fri 3/21/14
Camera Boom Mounting	5 days	Mon 2/24/14	Fri 2/28/14
Electrical Component Mounting	5 days	Mon 2/24/14	Fri 2/28/14
Complete Assembly	5 days	Mon 2/24/14	Fri 2/28/14
Component Testing	**75 days**	**Mon 12/2/13**	**Fri 3/14/14**
SEM Control Development	20 days	Mon 12/2/13	Fri 12/27/13
S.E.M. Testing	20 days	Mon 1/6/14	Fri 1/31/14
Real-Time Locomotion Control Development	30 days	Mon 1/6/14	Fri 2/14/14
Advanced Locomotion Testing	20 days	Mon 2/17/14	Fri 3/14/14
Wireless Control Testing	20 days	Mon 2/17/14	Fri 3/14/14
System Testing	**15 days**	**Mon 3/17/14**	**Fri 4/4/14**
Complete Rover Sample Extraction Testing	15 days	Mon 3/17/14	Fri 4/4/14
Obstacle Avoidance and Scaling Testing	15 days	Mon 3/17/14	Fri 4/4/14
Competition Dry Runs	15 days	Mon 3/17/14	Fri 4/4/14
Refinement and Debugging	20 days	Mon 4/7/14	Fri 5/2/14
GUI Development and Refinement	30 days	Mon 3/17/14	Fri 4/25/14
Outreach Events	100 days	Mon 12/2/13	Fri 4/18/14

The rover's hardware and framework will be maintained from last year's design, which means the S.E.M. system is the only system that requires construction. The S.E.M system is fully design and hardware will be ordered with the first installment of the competition grant. The real time programming is nearly complete, and initial tests with the Xbox controller have been promising. The wireless communications design is complete and initial testing will begin once the components have been received.

Appendix A – Competition Overview

A. Competition Rules and Requirements

Competition Summary

The NASA Rascal Robo-Ops competition's goal is to create new and innovative solutions toward the development of rover's capable of traversing mars which is simulated at the NASA Space Center. The rover must be controlled remotely over a commercially available wireless network, be able to navigate obstacles, and be able to identify and acquire brightly colored rock samples. Teams also must engage in public outreach to foster interest in space exploration and robotic development, utilizing social media and community events.

Requirements for 2013

The process to become a participant is as follows. First, a notice of intent form is submitted to the competition stewards. Next, an proposal documents is submitted (due December 8, 2013) which must be no more than 8 pages. From the proposals submitted, 8 teams will be selected (notified December 20, 2013), which nets the team a $5,000 grant to construct the proposed rover.

Rover specs for competition trim

In the rover's "Stowed configuration", meaning with all peripherals retracted, the rover must not exceed dimensions 1m x 1m x0.5m. The maximum mass (without payload) must not exceed 45kg, or else points will be deducted. No internal combustion engines are allowed, and the rover must be water-proof.

Rover performance and capability required

The rover must be capable of traversing obstacles at least 10cm tall, negotiate +/- 33% grades, and traverse level sand surfaces for at least 20 feet of distance. The areas of the JSC Rock Yard to be included in the competition are the Rock Field, Lunar craters, Sand Dunes, and the Mars Hill. The rover must selectively acquire at least five irregularly shaped rocks while traversing the JSC Rock Yard. The rocks are outlined as having diameters from 2 - 8 cm, masses from 20 - 150 gm, and be of different colors each corresponding to a point value. The rover must store and carry these rocks throughout the course. The JSC Rock Yard and the rocks of interest can be seen in Figure 8, below.

Controls and Communications Requirement

As stated before, the rover must be remotely controlled from the team's home campus over a commercial cellular data network (ie. via wireless broadband card). Rover data must be sent from the rover itself to operators and spectators online. This data is required to consist of live video feed and some rover telemetry. The video feed must be capable of distinguishing color (rock samples), and must be recorded and posted on the team's website.

Requirements for 2014

After being selected to compete in the 2014 RASC-AL Robo-Ops competition, the team will be required to continuously document and broadcast rover development progress. These reports are required to outline how the team has met the aforementioned "milestones" of the competition. Next, each report will be introduced along with the milestones the team is expected to cover in that report.

Mid-Project Review Report + Video – due March 15, 2014

The purpose of this report is to display to the competition stewards that a team is on schedule to completing a rover capable of satisfying all design and performance requirements. This report consists of a five-page written portion and a YouTube video. The whole report must demonstrate the rover's present functionality and chronicle what is yet to come. Team must outline where they are with the project and how confident they are that their rover will be completed. If the stewards feel that a team's report does not show this, they will be required to do a live follow-up web chat with the stewards to redeem themselves. Only after the stewards are satisfied with a team's progress will be awarded an additional $5,000 grant money be awarded to a team.

Appendix B – Design Concepts

B1.0 -- Proposed Designs

B1.1 – Arm Concepts

B1.1.1 – 2 DOF Arm

The first arm concept is to improve upon last year's design, a planar two degree of freedom arm. The design would need to be reduced and a more advanced wrist would be developed with the arm. The rover can have very precise control over it Z position making this arm simple and easy.

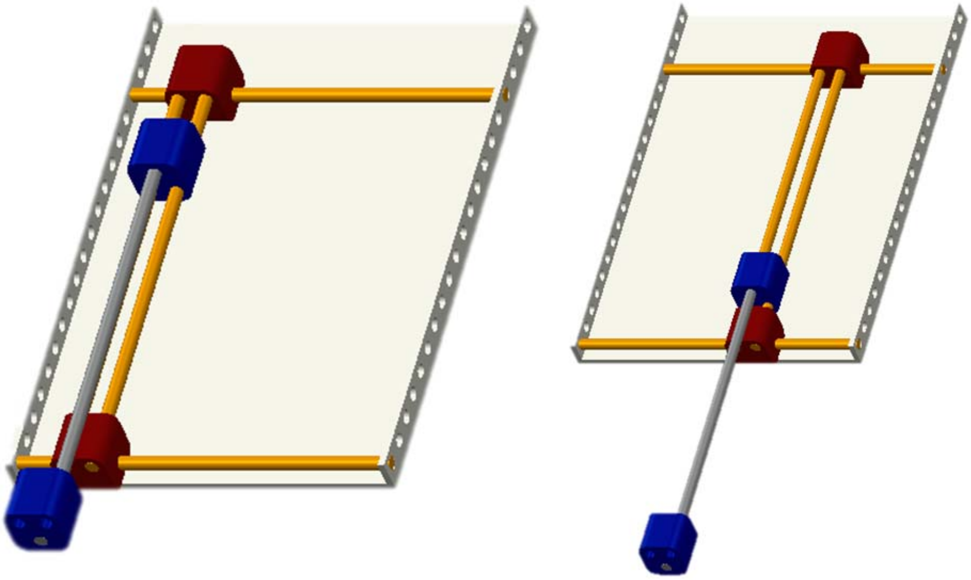


Figure 1 -- 2 DOF Arm Design

The advantages of this design were described by last year's team, but will be explored again for comparison. The system requires the control of only 2 motors, and the control over the rover itself. The thought was also that by having fewer motors and systems, the overall weight would be reduced, and would impact the cost and reliability of the system. The final thought was that the arm remaining close to the body would keep the platform more stable.

The desired advantages turned out to be some of the arms shortcomings. The control did turn out to be significantly easier, and allowed the team to develop a click to grab routine where the user could click on the GUI and the robot would move the arm into position to pick up the sample. This routine was not tested in competition because an encoder failed the night before competition.

The from the hardware desire, the arm could not fit into the competition dimensions with the arm remaining planar. A innovative rail follower was devised, but forced the arm into the air, which then hurt the center of gravity and the deployment speed. Finally, to achieve the reach desired, a large linear actuator was needed and then forced the rest of the system to be bigger and heavier than originally thought.

B.1.2 – 3 DOF Arm with 1 Planar Joint

Three degree of freedom arm concepts were then explored. The first of these was this arm design which has 2 revolute joints and a planar joint to extend the arm. This design would be similar to WPI's design with the addition of a linear actuator instead of a rigid arm.

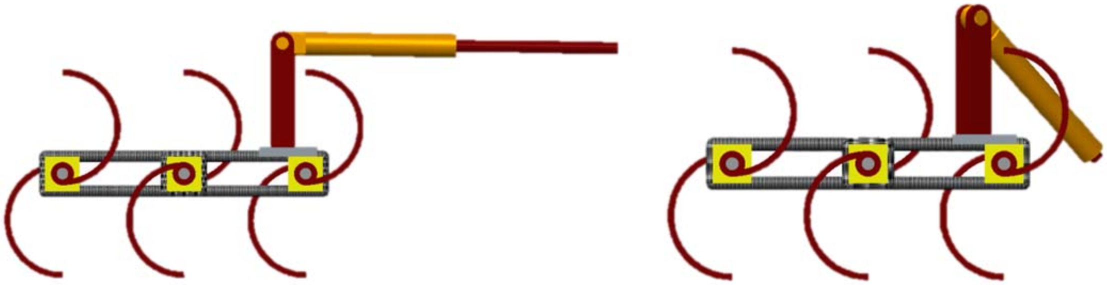


Figure 2 -- 3 Degree of Freedom with 1 Planar Joint

The advantages to this design is it requires less control than an arm like Caltech's or Maryland's, but still give the necessary degrees of freedom to reach most rocks without the rover needing to move. The design could still stay close to the body and keep the center of gravity low.

The disadvantages for this design include the weight of the system which would likely by higher to include an linear actuator. The revolute joint would need to be designed to withstand the weight and the motors controlling the degrees of freedom would need to be stronger.

B.1.3 – 3 DOF Arm with All Revolute Joints

The final design explored is a three degree of freedom arm with all revolute joints. The design would consist of a 2 degree of freedom "shoulder" joint, and a 1 degree of freedom "elbow. The current concept is to include a 1 degree of freedom wrist, but this would depend on the gripper concept chosen.

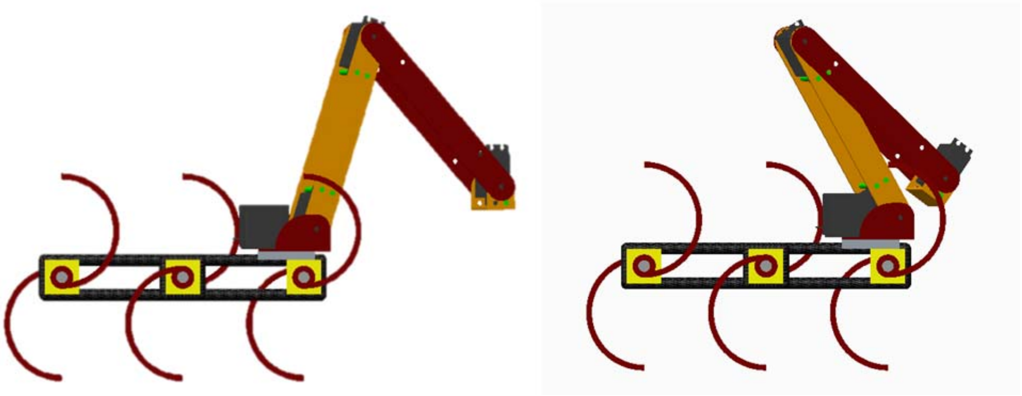


Figure 3 -- 3 Degree of Freedom Arm with all Revolute Joints

The advantages of this concept is the flexibility in it use and in its flexibility in placement on the rover. It could be placed on top of or in front of the rover without any difference in functionality. Additionally, the storage compartment could be placed in any location which is convenient. Finally, it can be very compact and utilize very lightweight materials and still be strong enough and have the desired range.

The disadvantage is the advanced control necessary to utilize such a design. For it to be user friendly to use, the arm would need to have some form of automation, or at least control mapped from the x y z frame to the motor.

B.2 Gripper Concepts

B.2.1 – Scooper Design

The first design discussed was a scooper designed gripper. Scoop is defined by Merriam Webster as “something that is shaped like a bowl or bucket and used to pick up and move things”. Essentially, it uses a distinctive shape and gravity to collect large quantities of material. It does not require as much precision as the pincer design which we will talk through next.

Figure 4 -- Scooper Design in Action

B.2.2 – Pincer/ Finger Designs

Pincer/finger grippers use the same technique as the human had to grab and secure small objects. The pincer normally has two fingers which can move in toward an object or release away from the object, and uses a constant force on the object to keep it secured. It is very good at picking up discrete objects, but needs to be placed precisely for the object to be secured.

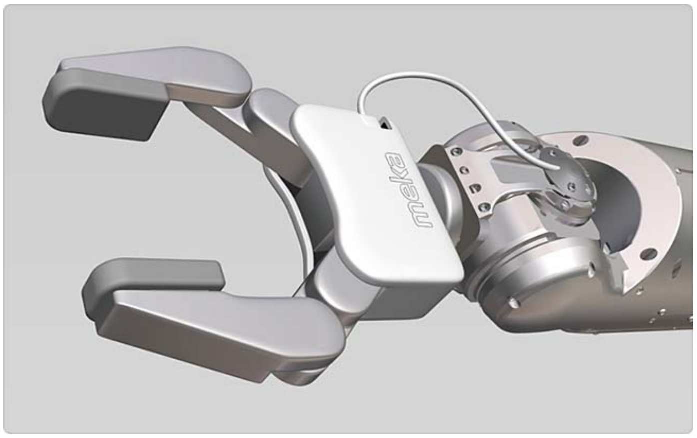


Figure 5 -- CAD Model of a Pincer Design

B.2.3 – Universal Gripper

Some more recent gripper research has gone into attempting to develop a gripper which has the ability to easily grab a discrete object. This has led to the development of universal grippers which utilize a conformable material to grasp an object. The gripper shown below in **Figure #** consists of a balloon filled with ground coffee. The balloon is pressed onto the object desired, and then a vacuum pump evacuates air from the balloon, causing the coffee grounds to jam against each other, forming a 'rigid' gripper.

Figure 6 -- Universal Gripper Design

B.2.4 – Compliant Gripper Mechanism

The combinations of the previous designs lead to very interesting concepts. The first of these is compliant fingers which combines the universal gripper with the pincer gripper. Compliant finger grippers need to be precise in their implementation, but require less precision than rigid fingers. They can reach and grab discrete objects in confined spaces, however the precision required to use them is still very high. There are a few finger ideas on the board, 2 pronged, which is small and can reach most everything but needs to squeeze the rock and get a good grip as it's only touching the rock in two places, or 3 pronged, which would hold the rock very stable but may not be able to get access to 3 different sides of the rock. The FESTO Fin Adaptive Finger (right) has gained our curiosity as its shape conforms to object it is grabbing and is delicate enough to pick up an egg. The second idea for fingers are rake-like, skinny tendrils on the fingers allow the fingers to close around the rocks shape to have greater contact area.

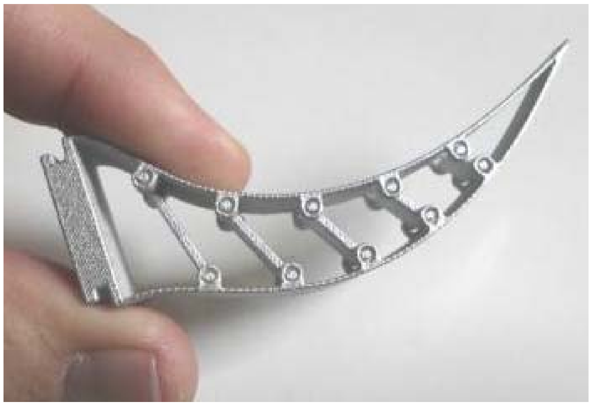


Figure 7 -- FESTO Fin Adaptive Fingers

By combining the universal gripper, with a scoop design, along with some elements of the pincer, you can come up with a mesh gripper. The mesh gripper consists of two clamps that have a mesh screen in their center, then became an elastic mesh grip which will be more versatile and have a higher friction coefficient. With the bottom support was removed to create an upside-down U structure so we can get the mesh as close to the ground as possible. This mesh gripper clamps onto the rock and it conforms to the unique shape of the rock.

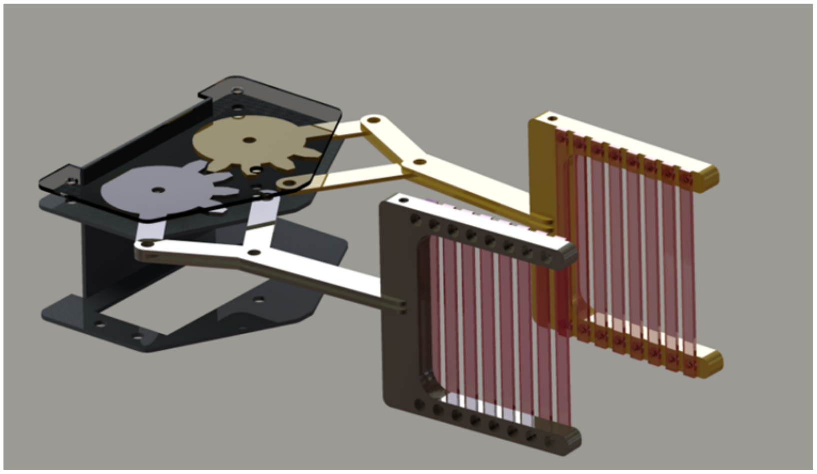


Figure 8 -- Cad of Mesh Gripper Design

B.3 Communications Concepts

Last year's design utilized Verizon 3G coverage to communicate with the platform. This was advantageous considering the fact that a tower is very near to the competition site. A "mission control" center was established in Tallahassee where the users controlled the rover. The design was simple. Mission control consisted of a user working with the GUI to operate the robot. The GUI would be on a laptop. Using a 3G USB Card, the laptop would communicate with a router on board the rover. The router has a USB port, which is helpful in communications. Last year's operators plugged in a Verizon 3G card in the router as well. The on-rover router would communicate with the Raspberry Pi computers, thus linking the user to the rover.

B.3.1 – Graphical User Interface

The Graphical User Interface (GUI) is a custom computer application which aims to greatly simplify the operation of the rover through integration of information display, in the form of video feeds and sensor data, and rover control. In essence, it gives the user a tool for controlling the rover.

In last year's design, the GUI was written in the C# program language. Below is an image of the objective of the design:

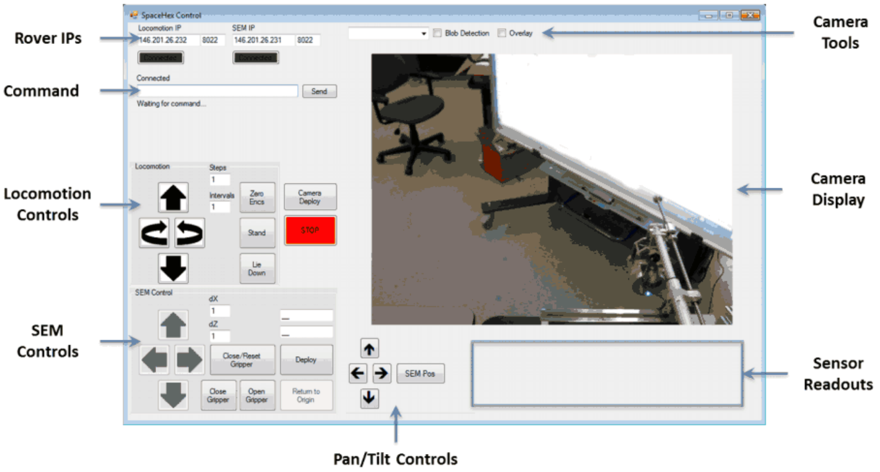


Figure 9 -- Previous Year's GUI

The GUI was operational, but many aspects will be changed in order to make the GUI more user friendly. For one thing, the user would have to input the number of steps and the direction that the rover should proceed. The process was very cumbersome, especially if the user needed the rover to move to a specific spot. As the rover will be competing with other rovers to pick up the most rocks, creating a GUI that allows the user to interact more freely with the rover would be much more efficient. There were also locomotion concerns, as was discussed earlier, as the rover could not turn while walking. So the GUI only has the controls Forward, Reverse, turn-Left, and turn-Right. Our goal is to implement an Xbox or PlayStation controller allowing the user 360 degrees of control, with the ability to change direction while moving. We wish to eliminate the need to enter the number of steps prior to moving. A simple push of the joystick will command the rover to move.

B.3.2 – Communications and Networking

To establish communication between the cameras and computing systems on the rover and the Mission Control server located at the college detailed networking protocol is desired. The figure below displays the design of the network. The blocks on the right represent (top to bottom) the rover arm, locomotion and cameras.

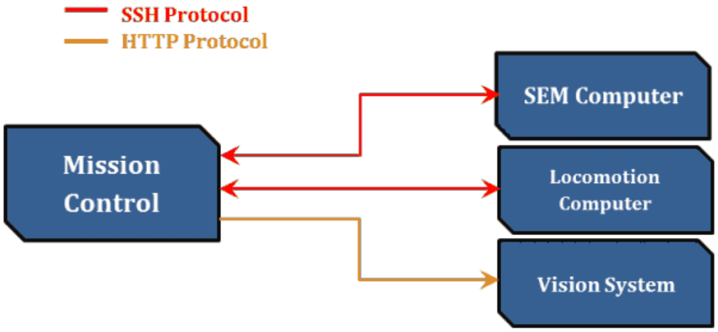


Figure 10 -- Communication Block Diagram

As the above figure shows, communications via SSH (Secure Shell) were established between the on-rover computers and the mission control computer; communication via HTTP (Hypertext Transfer Protocol) was used to link the cameras to mission control. In last year's case, both the mission control computer and networked hardware on the rover are behind NAT (Network Address Translation) firewalls. The NAT firewall prevents all incoming connections to all the devices.

B.3.3 – SEM and Locomotion Computers

In last year's design, the communications system was put together in more haste than what would have been ideal. For one, the mission control operated from a student's apartment. Also, the on-rover router used was a G-type router leading to limited bandwidth. Looking at last year's issues, a lack of bandwidth may have contributed to the issues of last year's team, such as lagging and dropped communications. Additionally, the video feed would be impaired by a low-resolution, which normally would be used in cases where the bandwidth was limited. To counteract these issues, a higher grade router will be used. Last year's router, the TP-Link TL-MR3430 (pictured below) was a fine router for home usage, but a higher grade router would do the project well.

Figure 11 -- Communication Between User and Raspberry Pi

Figure 12 -- Left: Type G Router Right: Type N Router

The router's function was so that the user could communicate with the Raspberry Pi computers. Raspberry Pi's are now 3G compatible, but using a router makes the connection between the user and the Pi computers more secure. As will be discussed below, we plan on using a 4G network for this year's design. The TP-LINK SafeStream TL-ER6020 Gigabit Dual-WAN VPN Router (pictured below) is an ideal router to use with a 4G card. It is a next generation, the N-type. It creates a VPN (Virtual Private Network) thus adding more security by securing an IP address, and preventing interference from other addresses. Additionally, the router is much more powerful, with enough bandwidth to spare.

B.3.4 – Networks

In order to further improve the design, some other minor modifications are necessary. This year's team will make the mission control router the DNS-enabled router. Last year, the team did not take care to make sure only one router was DNS-enabled. Also, some issues arose that were out of the control of the team. The team relied on Verizon's 3G network as there was a tower near the site. Ironically, the 3G network had issues on the day of the competition. This year's team plans to incorporate 4G. While some 3G networks are faster than 4G networks, within a carrier, 4G always trumps 3G. For instance, Verizon 3G is faster than MetroPCS 4G, but Verizon's 4G is faster than its 3G. Verizon's 3G network is actually relatively poor when compared to other network speeds with download and upload speeds 1.05 and 0.75 Megabits per second (Mbps) respectively However, Verizon's 4G network showcases a vast improvement over its predecessor with download and upload speeds of 7.35 and 5.86 Mbps respectively. These speeds are bested only by AT&T's network. Verizon's network is advantageous in part due to the tower nearby the competition site. We plan on using 2 Verizon 4G USB sticks, 1 on the rover, and 1 at mission control.

Figure 13 -- Verizon 4G USB Stick (left) AT&T 4G USB Stick(right)

We are going to strive for as much redundancy with the platform due to some issues that arose last year. The Verizon Network was down that day, much to the team's dismay. Using AT&T's network is an option we are strongly considering in case Verizon's network fails this year. We will use the same communications model as with the 4G, but we will not utilize it unless Verizon's network fails. This practice ensures we are not sending conflicting commands to the rover, which may cause serious ramifications, such as the robot's malfunction. Since Houston is a major city, using AT&T may very well be the way to go.

B.4 Controls Concept Development

Last year's six legged design had the necessary tools for traversing the competition grounds, but there is still work to be done to allow the rover to move more freely and efficiently through the different terrains. The rover was only able to turn while stationary, and walk directly forwards/backwards.

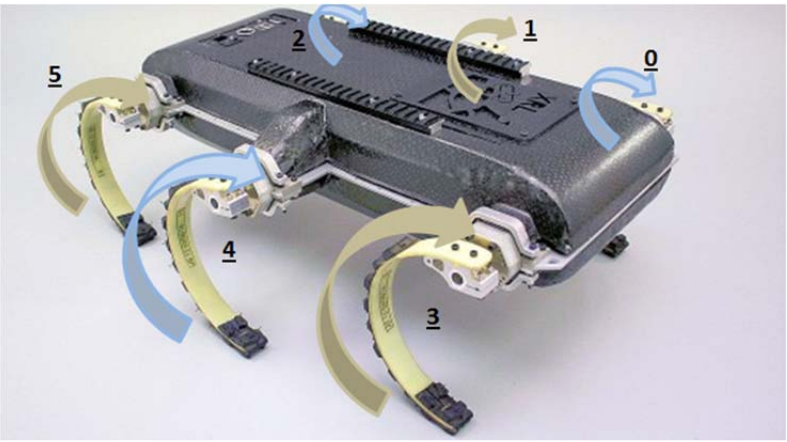


Figure 14 – Proposed six legged device. The legs are labeled (and will be referenced as) 0 through 5.

This year, the team will be attempting to implement a turn while walking function, a turn while climbing function, a more precise turning function, and a "lay-down-nudge" function. These will all be controlled by a wireless controller instead of the GUI interface which was used last year.

B.4.1 – Turn While Walking

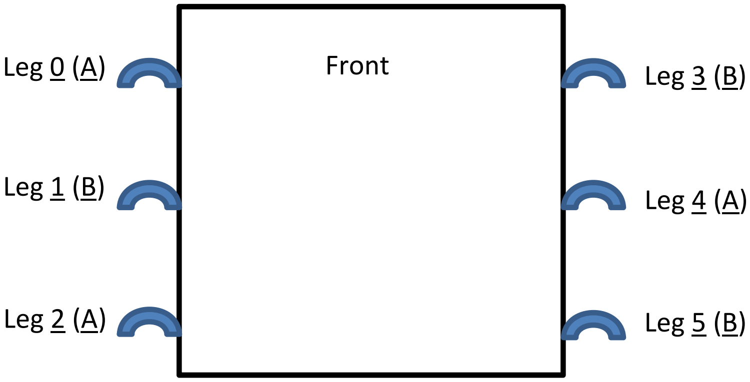


Figure 15 -- Aerial view of the robot to display the leg's labels and their respective groups

When the robot walks in a straight line, the 0, 2, and 4 legs will be coupled together (call them set A), sharing the same movements. The 1, 3, and 5 legs will also be coupled (set B), and they will move at exactly 180° phase difference from set A. To be precise, this means that while one set is pointing directly downward, in its peak contact with the ground, the other set will be directly upright, at its highest point.

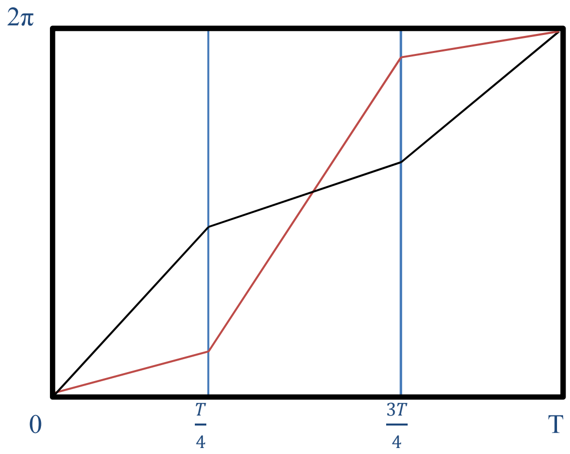


Figure 16 -- Buehler Clock graph for both sets of legs (Red = A, Black = B)

To understand the locomotion further, one must understand the Buehler clock. The Buehler clock describes the relationship between the speed of the leg and its location in its rotation. When any given set of legs are on the ground, they must move slower than when they are in the air, so that the other legs can "catch" the robot right as they are leaving the ground stage. Figure 13 shows this relationship. The slope of the lines describes the speed of the legs rotation, the y axis describes the location in the legs rotation, and the x axis describes time. Notice that the legs change speeds at T/4 and (3T)/4. Notice that in this image, both sets of legs start and end at 0 and 2π respectively.

Now that walk is understood, turn while walking must be implemented. One's immediate response to implementing turn while walking is to increase the speed of one side of the legs and thus create a turn. This design was considered but quickly failed when it was hypothesized and proven that the rover would simply fall over, since the legs would lose their coupling over time. The next idea was to adjust the phase at which the left legs differ from the right legs. For example, put leg 1 20° ahead of legs 3 and 5, while simultaneously putting leg 4 20° behind legs 0 and 2. This will cause the left legs (the ones that are ahead) to hit the ground slightly before the right legs leave the ground. For the second that the legs are together on the floor, there will be a slight turning motion to the right, and then the robot will continue to move forward once the left legs catch up (at which point the other set of legs will have lifted into the air).

B.4.2 – Turn While Climbing

Turning while climbing is very similar to turning while walking, but with an extra hurdle. Walking on flat land is simple, if the legs are in phase, they will move forward with no problem. However, on a small hill, the rover has a tendency to turn with the hill as it climbs. To adjust for this, a separate hill climbing function was created and is currently functioning on the rover.

This function must now be added to. Just as with the turn while walking, the team wants to make the robot more agile when on a hill. It seems likely that adjusting the phase just as was done in the turn while walking will resolve this issue and become extremely helpful in climbing hills quickly.

B.4.3 – Precision Turns

Currently, precision turns are working, but not for slight turns. The reason for this is that the robot is defined to work in “steps”. Every time the precision turn function is called, a number of steps must be input to the rover. The robot then takes this many “steps” to that direction, without moving forwards or backwards.

Currently, it takes the robot six steps to completely turn around an approximate 180°. This means that for each step that the robot is instructed to take; it is currently turning roughly 30°. This is great for a machine which wants to turn quickly, but extremely non-ideal for one which wants to pick up rocks, and precisely position a gripper to easily pick up those rocks. The turn must be worked on so that it can be more precise for angles lower than 30°.

To do this, the robot will have to be programmed to be able to take a “half step”, or maybe even a “quarter step”. Currently, a step is counted every single time a set of legs gets off of the floor, so every time a set of legs makes a full rotation, it is two steps. This means that part of the problem comes from the fact that the legs are long. Downsizing to the smaller machines should serve as a partial solution to the problem, but it might not be enough. On a more core level, however, there are two options to create a precise precision turn. Steps will either be redefined in the current function or a new function will have to be written which can input fractional steps, and thus allow the rover to stop its rotation mid-step.

B.4.4 – “Lay-Down-Nudge” Function

A new idea which is going to be attempted this year is to implement a nudge while laid down function. Last year’s team discovered that the most efficient way for the rover to pick up objects is to lay it down and then operate the arm and gripper. This causes a problem, however, because if the robot lies down and is slightly out of position, a complete repositioning of the machine is required. This means it has to completely stand up and relocate to a hopefully better position.

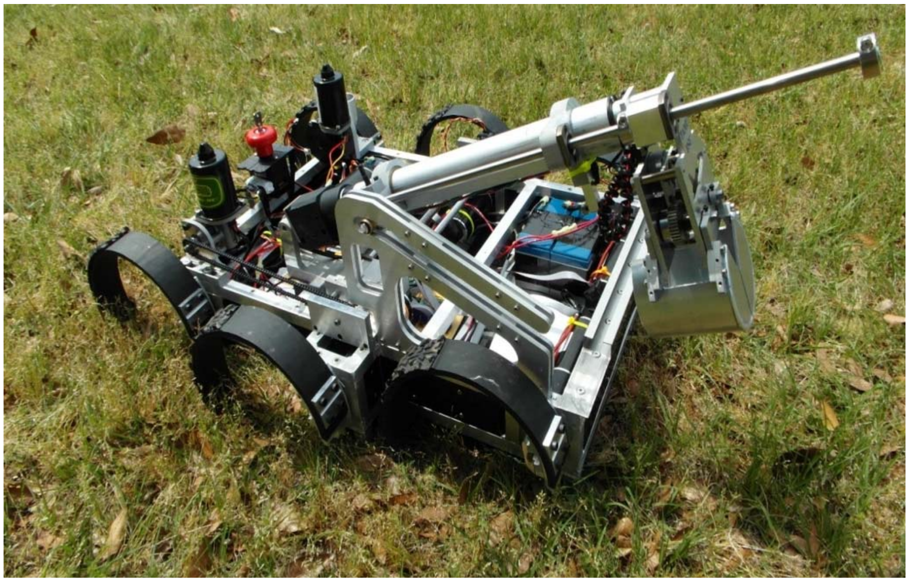


Figure 17 -- SpaceHex laying down

To combat this, a “nudge” function will be implemented. The rover will very quickly push the legs into the ground, creating lift and hopefully pushing the robot backwards. This could also be implemented to just the left or right legs, which will allow the robot to turn slightly even though it is lying down.

The advantages to this could be incredibly evident, since the team which collects the most rocks gets the most points. Last year’s team was only able to collect one rock because of how hard it was to correctly position the rover over a rock.

B.4.5 – Control through Gaming Controller

Using a GUI (graphical user interface) was reasonable for last year’s machine, but this year a more user-friendly interface is going to be implemented. All options are being considered, so long as it is a wireless controller. Some ideas have been discussed, but the most common ones are gaming controllers.

Figure 18 -- Common Gaming Controllers

The advantage to these types of controllers is extremely evident. There are so many ways which these controllers could be of use to the rover. First and foremost, there must be a way to control the locomotion of the machine, while simultaneously controlling the arm of the machine.

The current machine is designed to operate in locomotion until a rock is spotted and gone after. The machine lies down before the arm is activated. This is a good design, and allows for the machine to perform both tasks. On startup, the controller can be in "locomotion mode." In this mode, the left analog sticks will be used to control the robots forward and backward motion, while the right analog stick is going to control the left and right motion. This will allow the controller to control speed, direction, and intensity of every motion the machine makes. When the robot enters "lie down mode" (i.e. after pressing 'X'), the robot can use the joysticks to control the arm. The vast numbers of buttons can allow the robot to perform different tasks such as "drop arm" and "nudge backwards".

The biggest problem with this design is that the current code for the rover isn't dynamic enough for this control mechanism. The robot moves with each command, and does not allow any commands to be input until the command finishes its execution. A controller is constantly changing commands (with a joystick). This can be worked around by making the code more dynamic and allowing commands to change throughout. This is usually easily accomplished by enabling interrupts in the code, which will be attempted.

Appendix C – Decision Matrices

C.0 Decision Matrices

After considering the designs above, the team created the following decision matrices to make our selection.

C.1 Arm Selection

Table 1 -- Arm Design Decision Matrix

Robotic Arm								
	Rank	Weight	2 DOF		3 DOF w/ 1 planar		3 DOF all revolute	
			Value	Score	Value	Score	Value	Score
Weight	1	0.25	7	0.175	8	0.200	9	0.225
Size	8	0.02	5	0.010	7	0.014	8	0.016
Controllability	6	0.06	10	0.060	8	0.048	6	0.036
Speed	4	0.15	7	0.105	7	0.105	8	0.120
Reliability	3	0.17	9	0.153	7	0.119	6	0.102
Autonomous	7	0.04	9	0.036	7	0.028	6	0.024
Reach	2	0.21	5	0.105	7	0.147	8	0.168
Cost	5	0.10	8	0.080	7	0.07	6	0.06
				0.724		0.731		0.751
Total			**0.724**		**0.731**		**0.751**	

Description of Design Factors

Weight – The weight of the overall rover design greatly affects the score teams receive at competition. The weight of the arm mechanism therefore has the most weight in our decision

Reach – Once the rover has gotten close to a rock, the amount of reach it has becomes important. Being able to grab a rock that is far away from the rover will reduce the time needed to collect rock samples.

Reliability – The reliability of the arm is also very important. Several teams, who were selected to compete in the competition, could not do so because some part of their system failed the day before of the day of competition.

Speed – The rate at which the arm goes from stowed position to the position of the sample and is important to improve the overall speed of sample acquisition.

Cost – As a school project, cost is a factor. The more expensive the design, the harder it will be to receive the necessary funds to construct the design.

Controllability – The difficulty to move the arm from one point to a new point. The difficulty of mapping from robots joints frames to the x y z coordinate frame.

The difficulty in making the system autonomous – The difficulty in making the system almost completely autonomous. With autonomous control, less work will be required to command the arm and acquire the rock samples, saving time on collection.

Size – The overall size of the design needs to fit within certain size requirements. The robotic arm cannot exceed these specifications, but as long as the design does, the arm's size is not critical.

C.2 Gripper Selection

Table 2 -- Gripper Design Decision Matrix

Gripper Design										
	Rank	Weight	Scooper		Pincer		Complaint Finger		Complaint Mesh	
			Value	Score	Value	Score	Value	Score	Value	Score
Weight	6	0.05	3	0.015	7	0.035	5	0.025	3	0.015
Size	4	0.10	5	0.050	9	0.090	7	0.070	5	0.050
Speed	7	0.03	7	0.021	3	0.009	4	0.012	5	0.015
Reliability	3	0.20	7	0.140	3	0.060	3	0.060	5	0.100
Tolerance	1	0.30	9	0.270	1	0.030	3	0.090	8	0.240
Precision	2	0.25	1	0.025	9	0.225	9	0.225	7	0.158
Cost	5	0.07	9	0.063	7	0.049	5	0.035	7	0.049
Total			**0.584**		**0.498**		**0.517**		**0.627**	

Description of Design Factors

Tolerance – Tolerance is the grippers ability to pick up the same rock from multiple different positions and orientations

Precision – Precision is the gripper's ability to selectively pick up a single rock without picking up any other material.

Reliability – The Reliability of the gripper is its consistence in working for the same rock and for no component on the gripper to fail.

Size – The size of the gripper affects the size of the arm and the motors needed for the arm. However, the larger the size, the more area the gripper has to use to grab samples.

Cost – Cost is the difference in cost for the components of the grippers

Weight – Weight is similar to size and affects the size and motors needed for the arm mechanism.

Speed – Speed is the amount of time it takes the grippers to close onto a rock and acquire it.

Appendix D – Detailed Design and Design for Manufacturing

D1.0 – SEM Prototyping

One of the key goals of the project was to develop designs quickly and prototype the most viable design concepts. The prototype could then be tested to establish the capabilities and weakness of the initial design, which will allow further prototypes to correct for the weakness encountered in the initial design without significant investment into a sign design.

The initial designs show in Figure 19 uses 4 servos to control the various joints of the arms, and has each servo placed at the joint it controls. This design was created to reduce the difficulty of the control needed to program and control the robotic arm. Servo's are actuated by providing a desired position in the form of a pulse width, then the servo has its own built in control to maintain the position. Placing the motors on the joint it will actuate translates to the position of the motor being the same as the position of the arm.

Our initial prototype, shown in Figure 19 utilized servo controlled joints and was built to a relative ½ scale of our expected design. The prototype was constructed using ABS plastic which was laser cut for rapid manufacturing. The design showed some flaws with the initial concept, which were the servos preprogrammed control could not accurately maintain a position when it was strained toward the limit of its torque capability. It was evident the torque capability of the servos would be insufficient for the full scale robotic arm.

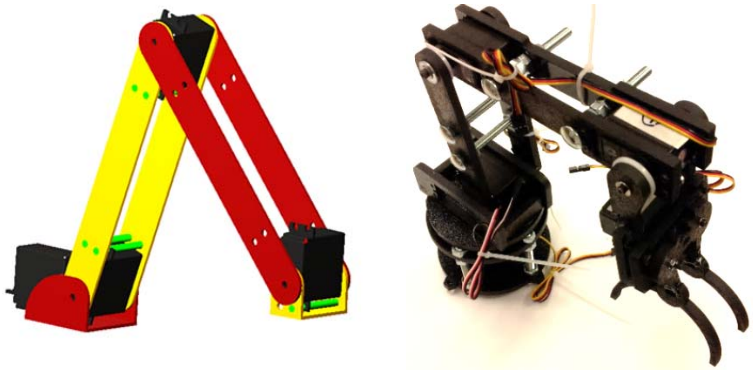


Figure 19 -- Initial Design CAD and Prototype

The arm was then redesigned to rectify the issues of the initial design. The solutions were to use DC motors, which require more complex control algorithms but can produce significantly more torque. By using DC motors, the control algorithm can be tuned so the arm will maintain the exact desired position in situation which are below the torque limit of the motor. Selecting a DC motor for the various joints require analysis to determine the amount of torque necessary for each joint while keeping the weight of the arm light. The motor selection is described in section D.2.2. The second solution was to move the motor on the elbow joint to the base and use some form of linkage or chain drive to actuate the joint. These design changes led to the second generation design.

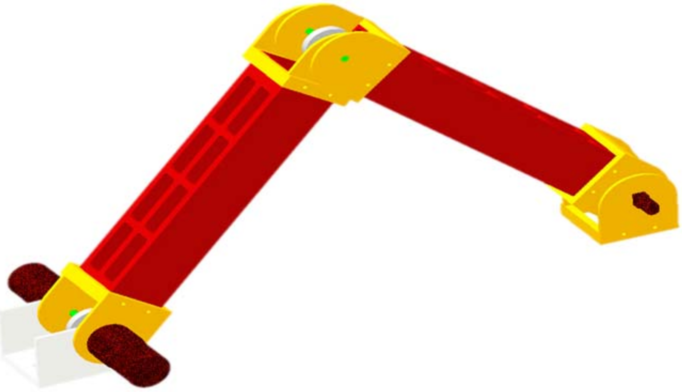


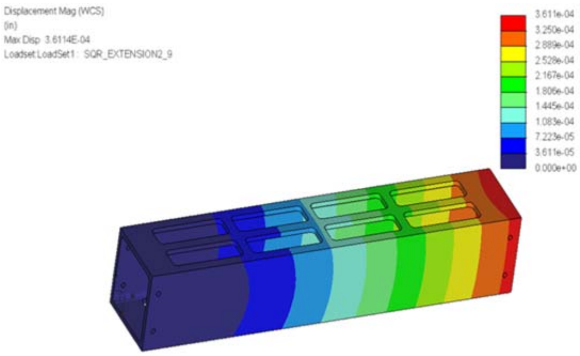
Figure 20 -- Second Generation Design

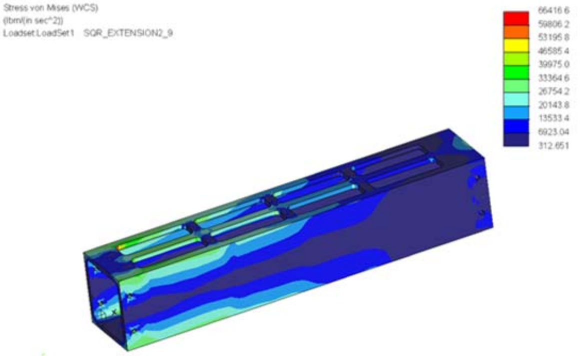
Once DC motors were selected and the motor placement was determined, the second-generation design was created. The scale model showed we needed to reduce the amount of weight the motors need to actuate to allow readily available motors to be utilized. The initial design used a 3 feet reach, which was designed to require minimal precision of the rover to acquire samples, however, the design was shortened to 2 feet to reduce the torque requires at the base joint to support and accelerate the arm through its range of motion.

The design has a chain drive to drive the second joint. A chain drive was selected to provide the closest simulation of direct drive. Only the relative sizes of the sprockets, which are going to be the same, are needed to be added the position of the motor. A chain drive was selected over a belt drive for durability and for the reliability in cold temperatures expected on mars.

D1.1 – FEM Analysis

FEM analysis was used to determine the amount of deflection and the stresses which the beams would experience during the competition. The deflection is important in maintaining a mapping from the base of the arm to the location of the gripper based on just the positions of the motors which will be directly measured using encoders. The FEM analysis is shown below. The deflection measured was 0.0036in which is small enough to not affect the ability of the gripper to move to a set location. The stress analysis showed the max stress was 309.38 psi which is below the modulus of elasticity of Aluminum 6063 which is 10000 ksi.





D1.2 – Motor Analysis

The amount of torque necessary was determined by assuming the arm was in its worst case scenario and determining the forces on the arm. The arms were represented by a distributed mass, the motors were evaluated as point masses at their location. The equations for the torque at any point were then calculated in Matlab and plotted to visualize the torque requirements through the entire range of motion.

The base motors selected were a RE 40 Ø40 mm, Graphite Brushes, 150 Watt with a Planetary Gearhead GP 42 C Ø42 mm, 3–15 Nm. This combination of a 170 mNm motor with a 113:1 planetary gearbox provides allows the motor to provide 15 Nm of torque nominally. The expected load determined in the worst case scenario is 10 Nm. Since these motors are going to be installed at the base, their weight will not affect the torque requirements.

The motors for the wrist and the gripper do not require significant torque, the requirement determined was 3 kg-cm, but the motor weight will affect the torque of the base motors. Therefore, the Pololu 298:1 Micro Metal Gear motor was selected because it was the lightest weight motor that could provide the necessary torque.

D2.0 – Gripper Prototyping

The work done to prototype the gripper has produced several working prototypes. The first generation was a proof of concept which was actuated by hand. It gave us a sense of the amount of effort a motor would need to provide and some of the manufacturing issues we would face with producing a gripper with compliant materials. The material for the elastic gripper was initial chosen to be rubber bands for simplicity.

Figure 21 -- First Generation Gripper Prototype

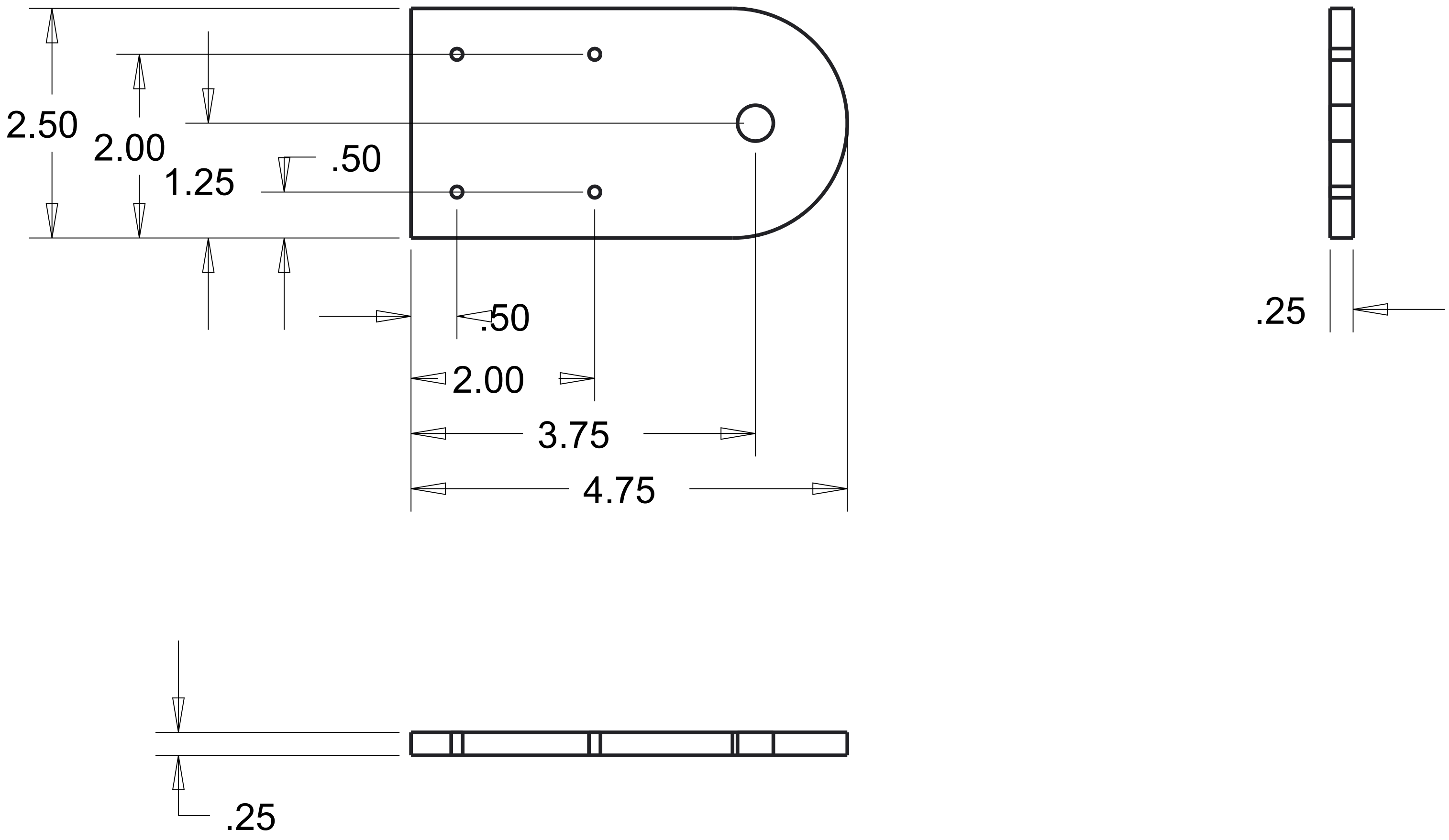
The second generation model was produced using rapid prototyping techniques. Cardboard was used as the construction material, for it is free from the local hardware store and when paired with hot glue can produce a reasonably strong structure. The prototype used a servo mechanism to actuate the gripper and an elastic first aid tape for the elastic material. With this gripper, we were able to test the design and see the design pick up rock samples. While the prototype was able to pick up rocks, the cardboard caused some issues which were resolved in the current prototype.

Figure 22 -- Second Generation Gripper Prototype

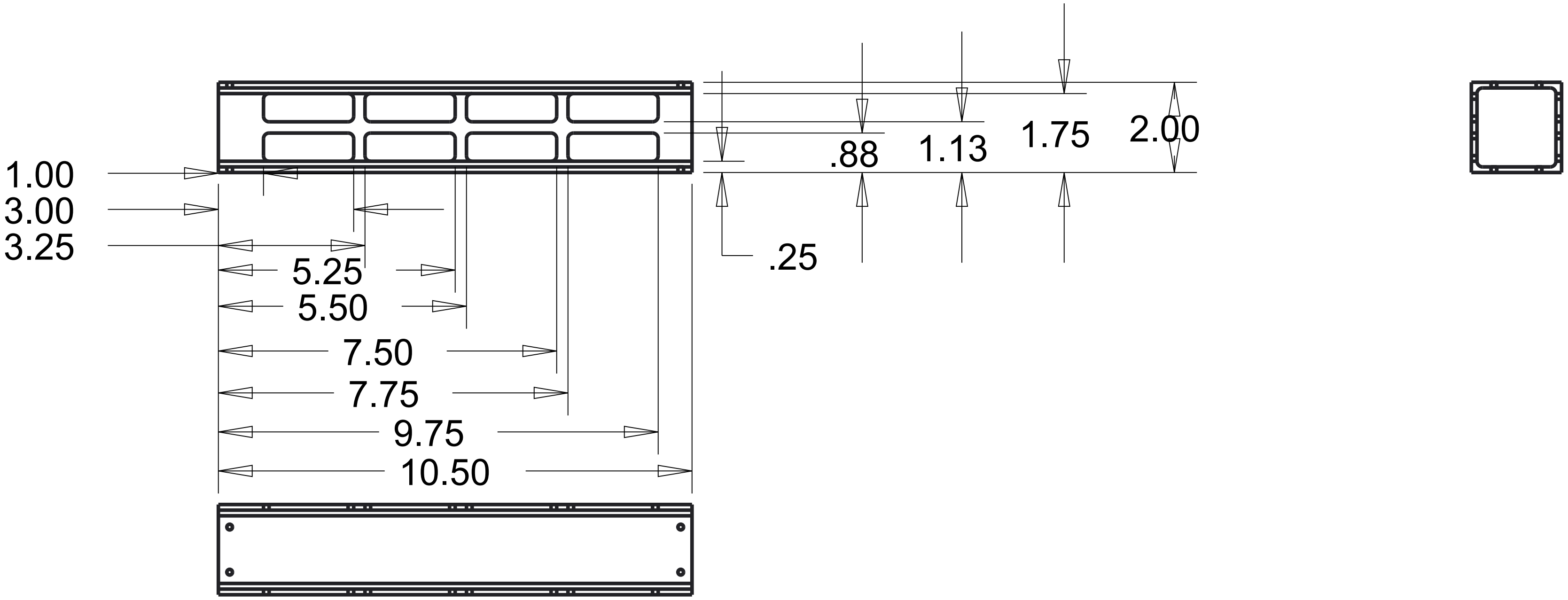
The current gripper prototype, which appears to work as our final version used ABS plastic for the frame and linkages. The ABS was used to make gear which keep the linkages at the same location through the range of motion. The elastic material was changed to silicon rubber, which will remain elastic at the temperatures expected on mars. The design also utilize the pololu motor and was shown to prove powerful enough to pick up rocks larger than expected at the competition.

Figure 23 -- Third Generation Prototype

D3.0 – Engineering Drawings



PROJECT		PART NAME	
Robo-Ops		Elbow	
SIZE	DRAWING NUMBER		REV
A	JMB-SD_001		1
SCALE	SHEET	DATE	DRAWN BY
0.500	1 of 1	05 December, 2013	Jason Brown



PROJECT Robo-Ops	PART NAME Arm	
SIZE A	DRAWING NUMBER JMB-SD-002	REV 1

SCALE 0.250	SHEET 1 of 1	DATE 05 December, 2013	DRAWN BY Jason Brown

Appendix E – Programming and Control Implementation

E1.0 –Xpadder

Once the SDL is imported onto the SD card and implemented, the next step is transferring those commands from the keyboard to the actual XBOX controller. Using a free program called Xpadder, this is not only possible, but it is easy to implement.

Figure 24 -- Example of Xpadder Interface

Xpadder is a software application which allows a controller to emulate a keyboard. The user must upload a picture of the controller to the program, and then map the buttons to whichever keyboard button they wish. The computer will then read the button presses as key presses, and thus the computer will act normally as if that button was pressed on the keyboard.

With the combination of Xpadder and SDL, the rover will be able to take commands directly from the XBOX controller. By simply mapping the joystick to the forward, backward, left and right buttons on the keyboard, the rover will be able to walk continuously until the joystick is released. This will allow for real-time control and a dynamic rover, as intended.

E2.0 – SDL Library

Currently, the rover is being controlled through the command prompt on a laptop. While this is a functioning design, it is not ideal since there are huge delays between inputs and they are not intuitive. To improve the rover’s locomotion and control, an XBOX controller will be implemented in order to reduce delays between commands, essentially controlling the rover in real-time.

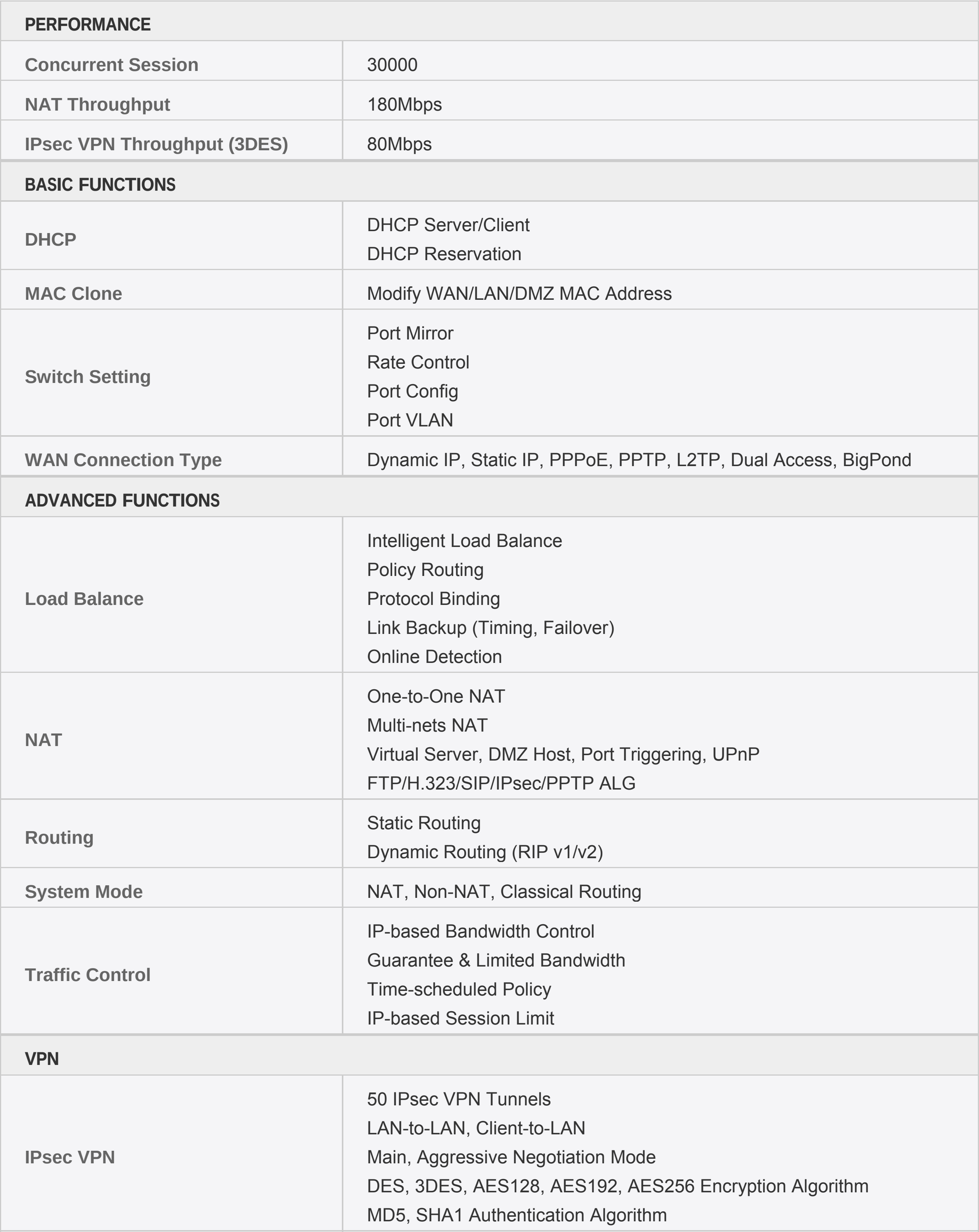
In order to achieve this, low level keyboard access and event handling are necessary. Simple DirectMedia Layer (SDL) is a library written in C which enables both keyboard access and event handing to the user. With this, the user will be able to control the rover by simply pressing buttons on the keyboard (i.e. holding w will move the rover forward) as opposed to typing entire commands to the command prompt. The code will then have to be re-written in order to allow for real-time control, which means the implementation of a dynamic function with either interrupts or continuous looping of the walk function.

Appendix F – Product Specs

Router Specs

TP-LINK SafeStream TL-ER6020 Gigabit Dual-WAN VPN Router

HARDWARE FEATURES	
Standards and Protocols	IEEE 802.3, IEEE802.3u, IEEE802.3ab TCP/IP, DHCP, ICMP, NAT, PPPoE, SNTP, HTTP, DNS, IPsec, PPTP, L2TP
Interface	2 Gigabit WAN ports 2 Gigabit LAN ports 1 Gigabit LAN/DMZ port 1 Console Port (RJ-45 On RS232)
Network Media	10BASE-T: UTP category 3, 4, 5 cable (Max 100m) EIA/TIA-568 100Ω STP (Max 100m) 100BASE-TX: UTP category 5, 5e cable (Max 100m) EIA/TIA-568 100Ω STP (Max 100m) 1000BASE-T: UTP category 5, 5e, 6 cable (Max 100m)
Flash	16MB
DRAM	DDRII 128MB
LED	PWR, SYS, Link/Act, Speed, DMZ
Button	Reset Button
Dimensions (W X D X H)	11.6*7.1*1.7in. (294*180*44mm) 13-inch Standard Rack-Mount Width, 1U Height
Fan Quantity	Fanless
Power Supply	Internal Universal Power Supply AC100-240V~ 50/60Hz Input
PERFORMANCE	



PERFORMANCE	
Concurrent Session	30000
NAT Throughput	180Mbps
IPsec VPN Throughput (3DES)	80Mbps
BASIC FUNCTIONS	
DHCP	DHCP Server/Client DHCP Reservation
MAC Clone	Modify WAN/LAN/DMZ MAC Address
Switch Setting	Port Mirror Rate Control Port Config Port VLAN
WAN Connection Type	Dynamic IP, Static IP, PPPoE, PPTP, L2TP, Dual Access, BigPond
ADVANCED FUNCTIONS	
Load Balance	Intelligent Load Balance Policy Routing Protocol Binding Link Backup (Timing, Failover) Online Detection
NAT	One-to-One NAT Multi-nets NAT Virtual Server, DMZ Host, Port Triggering, UPnP FTP/H.323/SIP/IPsec/PPTP ALG
Routing	Static Routing Dynamic Routing (RIP v1/v2)
System Mode	NAT, Non-NAT, Classical Routing
Traffic Control	IP-based Bandwidth Control Guarantee & Limited Bandwidth Time-scheduled Policy IP-based Session Limit
VPN	
IPsec VPN	50 IPsec VPN Tunnels LAN-to-LAN, Client-to-LAN Main, Aggressive Negotiation Mode DES, 3DES, AES128, AES192, AES256 Encryption Algorithm MD5, SHA1 Authentication Algorithm

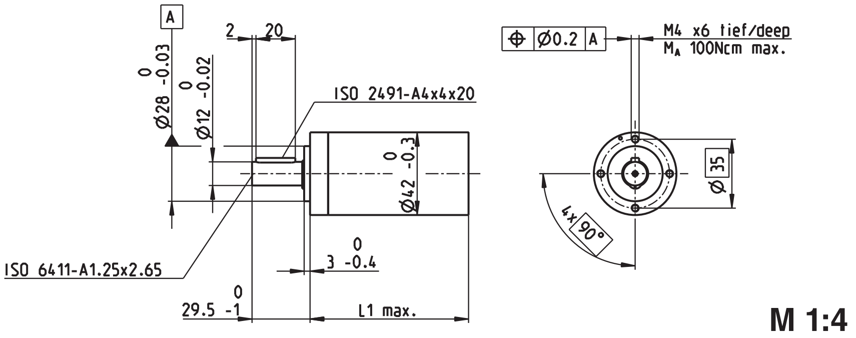
VPN	
	Manual, IKE Key Management Mode IPsec NAT Traversal (NAT-T) Dead Peer Detection (DPD) Perfect Forward Secrecy (PFS)
L2TP VPN	16 L2TP VPN Tunnels L2TP VPN Server/Client L2TP over IPsec
PPTP VPN	16 PPTP VPN Tunnels PPTP VPN Server/Client PPTP with MPPE Encryption
VPN Pass-through	IPsec (ESP), PPTP, L2TP
SECURITY	
ARP Inspection	Sending GARP Packets ARP Scanning by WAN/LAN IP-MAC Binding
Application Control	IM, P2P, Web IM, Web SNS, Web Media, Protocol, Proxy Blocking
Attack Defense	TCP/UDP/ICMP Flood Defense Block TCP Scan (Stealth FIN/Xmas/Null) Block Ping from WAN
DMZ Port	1 Hardware DMZ Port
Filtering	MAC Filtering URL/Keywords Filtering Web Content Filtering (Java, ActiveX, Cookies)
MANAGEMENT	
Maintenance	Web/CLI/Telnet Management Interface Remote Management Export & Import Configuration NTP Synchronize Syslog Support
Service	PPPoE Server E-Bulletin Dynamic DNS (Dyndns, No-IP, Peanuthull, Comexe)
OTHERS	
Certification	CE, FCC, RoHS
Package Contents	TL-ER6020

OTHERS	
	Resource CD Power Cord Ground Cable Rack-mount Kit Installation Guide
System Requirements	Microsoft® Windows® 98SE, NT, 2000, XP, Vista™ or Windows 7, MAC® OS, NetWare®, UNIX® or Linux
Environment	Operating Temperature: 0℃~40℃ (32℉~104℉) Storage Temperature: -40℃~70℃ (-40℉~158℉) Operating Humidity: 10%~90% non-condensing Storage Humidity: 5%~90% non-condensing

Motor Specs

Planetary Gearhead GP 42 C ∅42 mm, 3–15 Nm

Ceramic Version



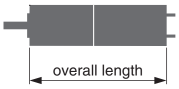
Technical Data

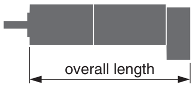
Planetary Gearhead	straight teeth
Output shaft	stainless steel
Bearing at output	preloaded ball bearings
Radial play, 12 mm from flange	max. 0.06 mm
Axial play at axial load < 5 N	0 mm
> 5 N	max. 0.3 mm
Max. permissible axial load	150 N
Max. permissible force for press fits	300 N
Sense of rotation, drive to output	=
Recommended input speed	< 8000 rpm
Recommended temperature range	-40…+100°C
Number of stages	1 2 3 4
Max. radial load, 12 mm from flange	120 N 240 N 360 N 360 N

🟥 Stock program
☐ Standard program
▨ Special program (on request)

	Part Numbers		**203113**	203115	**203119**	**203120**	203124	**203129**	203128	203133	203137	203141
	Gearhead Data											
1	Reduction		3.5 : 1	12 : 1	26 : 1	43 : 1	81 : 1	156 : 1	150 : 1	285 : 1	441 : 1	756 : 1
2	Reduction absolute		$^{7}/_{2}$	$^{49}/_{4}$	26	$^{343}/_{8}$	$^{2197}/_{27}$	156	$^{2401}/_{16}$	$^{15379}/_{54}$	441	756
10	Mass inertia	gcm²	14	15	9.1	15	9.4	9.1	15	15	14	14
3	Max. motor shaft diameter	mm	10	10	8	10	8	8	10	10	10	10
	Part Numbers		**203114**	**203116**	260552*	203121	203125	260553*	203130	203134	203138	203142
1	Reduction		4.3 : 1	15 : 1	36 : 1	53 : 1	91 : 1	216 : 1	186 : 1	319 : 1	488 : 1	936 : 1
2	Reduction absolute		$^{13}/_{3}$	$^{91}/_{6}$	$^{36}/_{1}$	$^{637}/_{12}$	91	$^{216}/_{1}$	$^{4459}/_{24}$	$^{637}/_{2}$	$^{4394}/_{9}$	936
10	Mass inertia	gcm²	9.1	15	5.0	15	15	5.0	15	15	9.4	9.1
3	Max. motor shaft diameter	mm	8	10	4	10	10	4	10	10	8	8
	Part Numbers		260551*	203117		203122	203126		**203131**	203135	**203139**	260554*
1	Reduction		6 : 1	19 : 1		66 : 1	113 : 1		230 : 1	353 :1	546 : 1	1296 : 1
2	Reduction absolute		$^{6}/_{1}$	$^{169}/_{9}$		$^{1183}/_{18}$	$^{338}/_{3}$		$^{8281}/_{36}$	$^{28561}/_{81}$	546	$^{1296}/_{1}$
10	Mass inertia	gcm²	4.9	9.4		15	9.4		15	9.4	14	5.0
3	Max. motor shaft diameter	mm	4	8		10	8		10	8	10	4
	Part Numbers			203118		**203123**	203127		203132	203136	203140	
1	Reduction			21 : 1		74 : 1	126 : 1		257 : 1	394 : 1	676 : 1	
2	Reduction absolute			21		$^{147}/_{2}$	126		$^{1029}/_{4}$	$^{1183}/_{3}$	676	
10	Mass inertia	gcm²		14		15	14		15	15	9.1	
3	Max. motor shaft diameter	mm		10		10	10		10	10	8	
4	Number of stages		1	2	2	3	3	3	4	4	4	4
5	Max. continuous torque	Nm	3.0	7.5	7.5	15.0	15.0	15.0	15.0	15.0	15.0	15.0
6	Intermittently permissible torque at gear output	Nm	4.5	11.3	11.3	22.5	22.5	22.5	22.5	22.5	22.5	22.5
7	Max. efficiency	%	90	81	81	72	72	72	64	64	64	64
8	Weight	g	260	360	360	460	460	460	560	560	560	560
9	Average backlash no load	°	0.6	0.8	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0
11	Gearhead length L1	mm	41.0	55.5	55.5	70.0	70.0	70.0	84.5	84.5	84.5	84.5

*no combination with EC 45 (150 W and 250 W)



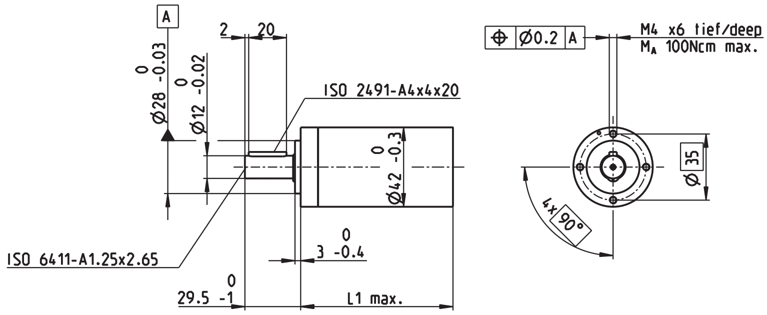


maxon Modular System

+ Motor	Page	**+ Sensor**	Page	**Brake**	Page	**Overall length [mm]** = Motor length + gearhead length + (sensor/brake) + assembly parts									
RE 35, 90 W	104					112.1	126.6	126.6	141.1	141.1	141.1	155.6	155.6	155.6	155.6
RE 35, 90 W	104	MR	303			123.5	138.0	138.0	152.5	152.5	152.5	167.0	167.0	167.0	167.0
RE 35, 90 W	104	HED_ 5540	305/307			132.8	147.3	147.3	161.8	161.8	161.8	176.3	176.3	176.3	176.3
RE 35, 90 W	104	DCT 22	315			130.2	144.7	144.7	159.2	159.2	159.2	173.7	173.7	173.7	173.7
RE 35, 90 W	104			AB 28	348	148.2	162.7	162.7	177.2	177.2	177.2	191.7	191.7	191.7	191.7
RE 35, 90 W	104	HED_ 5540	305/307	AB 28	348	165.4	179.9	179.9	194.4	194.4	194.4	208.9	208.9	208.9	208.9
RE 40, 150 W	105					112.1	126.6	126.6	141.1	141.1	141.1	155.6	155.6	155.6	155.6
RE 40, 150 W	105	MR	303			123.5	138.0	138.0	152.5	152.5	152.5	167.0	167.0	167.0	167.0
RE 40, 150 W	105	HED_ 5540	305/307			132.8	147.3	147.3	161.8	161.8	161.8	176.3	176.3	176.3	176.3
RE 40, 150 W	105	HEDL 9140	310			166.2	180.7	180.7	195.2	195.2	195.2	209.7	209.7	209.7	209.7
RE 40, 150 W	105			AB 28	348	148.2	162.7	162.7	177.2	177.2	177.2	191.7	191.7	191.7	191.7
RE 40, 150 W	105			AB 28	349	156.2	170.7	170.7	185.2	185.2	185.2	199.7	199.7	199.7	199.7
RE 40, 150 W	105	HED_ 5540	305/307	AB 28	348	165.4	179.9	179.9	194.4	194.4	194.4	208.9	208.9	208.9	208.9
RE 40, 150 W	105	HEDL 9140	310	AB 28	349	176.7	191.2	191.2	205.7	205.7	205.7	220.2	220.2	220.2	220.2
EC 40, 170 W	181					121.1	135.6	135.6	150.1	150.1	150.1	164.6	164.6	164.6	164.6
EC 40, 170 W	181	HED_ 5540	306/308			144.5	159.0	159.0	175.5	175.5	175.5	188.0	188.0	188.0	188.0
EC 40, 170 W	181	Res 26	316			148.3	162.8	162.8	177.3	177.3	177.3	191.8	191.8	191.8	191.8
EC 40, 170 W	181			AB 32	350	163.8	178.3	178.3	192.8	192.8	192.8	207.3	207.3	207.3	207.3
EC 40, 170 W	181	HED_ 5540	306/308	AB 32	350	187.2	201.7	201.7	216.2	216.2	216.2	230.7	230.7	230.7	230.7
EC 45, 150 W	182					152.3	166.8	166.8	181.3	181.3	181.3	195.8	195.8	195.8	195.8
EC 45, 150 W	182	HEDL 9140	310			167.9	182.4	182.4	196.9	196.9	196.9	211.4	211.4	211.4	211.4
EC 45, 150 W	182	Res 26	316			152.3	166.8	166.8	181.3	181.3	181.3	195.8	195.8	195.8	195.8
EC 45, 150 W	182			AB 28	349	159.7	174.2	174.2	188.7	188.7	188.7	203.2	203.2	203.2	203.2
EC 45, 150 W	182	HEDL 9140	310	AB 28	349	176.7	191.2	191.2	205.7	205.7	205.7	220.2	220.2	220.2	220.2
EC 45, 250 W	183					185.1	199.6	199.6	214.1	214.1	214.1	228.6	228.6	228.6	228.6
EC 45, 250 W	183	HEDL 9140	310			200.7	215.2	215.2	229.7	229.7	229.7	244.2	244.2	244.2	244.2
EC 45, 250 W	183	Res 26	316			185.1	199.6	199.6	214.1	214.1	214.1	228.6	228.6	228.6	228.6
EC 45, 250 W	183			AB 28	349	192.5	207.0	207.0	221.5	221.5	221.5	236.0	236.0	236.0	236.0
EC 45, 250 W	183	HEDL 9140	310	AB 28	349	209.5	224.0	224.0	238.5	238.5	238.5	253.0	253.0	253.0	253.0

Planetary Gearhead GP 42 C ∅42 mm, 3–15 Nm

Ceramic Version



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Technical Data

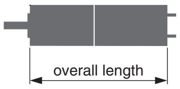
Planetary Gearhead				straight teeth
Output shaft				stainless steel
Bearing at output				preloaded ball bearings
Radial play, 12 mm from flange				max. 0.06 mm
Axial play at axial load < 5 N				0 mm
> 5 N				max. 0.3 mm
Max. permissible axial load				150 N
Max. permissible force for press fits				300 N
Sense of rotation, drive to output				=
Recommended input speed				< 8000 rpm
Recommended temperature range				-40…+100°C
Number of stages	1	2	3	4
Max. radial load, 12 mm from flange	120 N	240 N	360 N	360 N

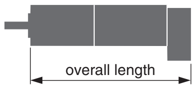
🟥 Stock program
☐ Standard program
▨ Special program (on request)

Part Numbers

			203113	203115	**203119**	**203120**	203124	**203129**	203128	203133	203137	203141
Gearhead Data												
1	Reduction		3.5 : 1	12 : 1	26 : 1	43 : 1	81 : 1	156 : 1	150 : 1	285 : 1	441 : 1	756 : 1
2	Reduction absolute		$7/2$	$49/4$	26	$343/8$	$2197/27$	156	$2401/16$	$15379/54$	441	756
10	Mass inertia	gcm²	14	15	9.1	15	9.4	9.1	15	15	14	14
3	Max. motor shaft diameter	mm	10	10	8	10	8	8	10	10	10	10
	Part Numbers		**203114**	**203116**	260552*	203121	203125	260553*	203130	203134	203138	203142
1	Reduction		4.3 : 1	15 : 1	36 : 1	53 : 1	91 : 1	216 : 1	186 : 1	319 : 1	488 : 1	936 : 1
2	Reduction absolute		$13/3$	$91/6$	$36/1$	$637/12$	91	$216/1$	$4459/24$	$637/2$	$4394/9$	936
10	Mass inertia	gcm²	9.1	15	5.0	15	15	5.0	15	15	9.4	9.1
3	Max. motor shaft diameter	mm	8	10	4	10	10	4	10	10	8	8
	Part Numbers		260551*	203117		203122	203126		**203131**	203135	**203139**	260554*
1	Reduction		6 : 1	19 : 1		66 : 1	113 : 1		230 : 1	353 : 1	546 : 1	1296 : 1
2	Reduction absolute		$6/1$	$169/9$		$1183/18$	$338/3$		$8281/36$	$28561/81$	546	$1296/1$
10	Mass inertia	gcm²	4.9	9.4		15	9.4		15	9.4	14	5.0
3	Max. motor shaft diameter	mm	4	8		10	8		10	8	10	4
	Part Numbers			203118		**203123**	203127		203132	203136	203140	
1	Reduction			21 : 1		74 : 1	126 : 1		257 : 1	394 : 1	676 : 1	
2	Reduction absolute			21		$147/2$	126		$1029/4$	$1183/3$	676	
10	Mass inertia	gcm²		14		15	14		15	15	9.1	
3	Max. motor shaft diameter	mm		10		10	10		10	10	8	
4	Number of stages		1	2	2	3	3	3	4	4	4	4
5	Max. continuous torque	Nm	3.0	7.5	7.5	15.0	15.0	15.0	15.0	15.0	15.0	15.0
6	Intermittently permissible torque at gear output	Nm	4.5	11.3	11.3	22.5	22.5	22.5	22.5	22.5	22.5	22.5
7	Max. efficiency	%	90	81	81	72	72	72	64	64	64	64
8	Weight	g	260	360	360	460	460	460	560	560	560	560
9	Average backlash no load	°	0.6	0.8	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0
11	Gearhead length L1**	mm	41.0	55.5	55.5	70.0	70.0	70.0	84.5	84.5	84.5	84.5

*no combination with EC 45 (150 W and 250 W) **for EC 45 flat L1 is–3.5 mm

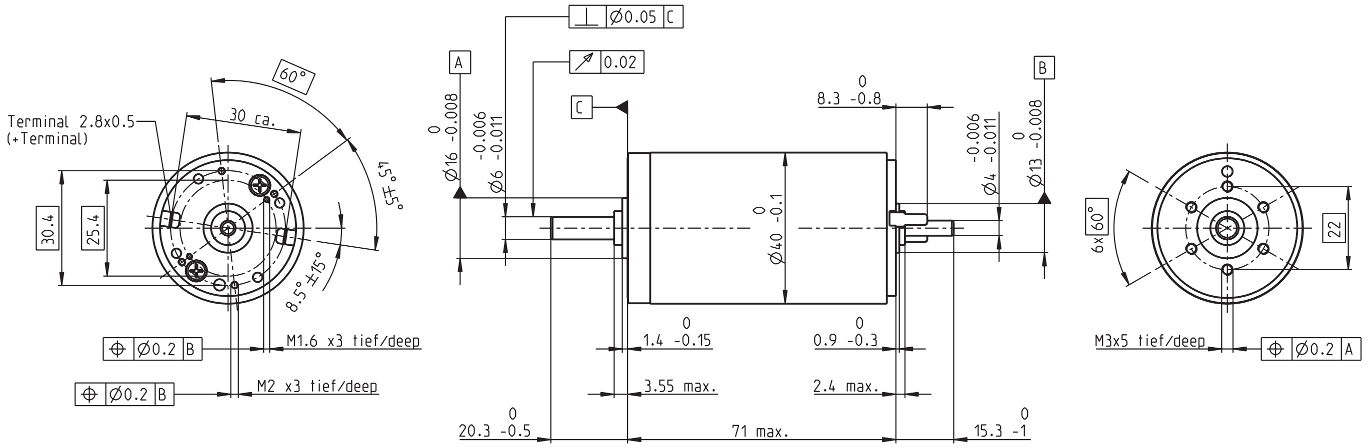




maxon Modular System

+ Motor	Page	+ Sensor	Page	Brake	Page	Overall length [mm] = Motor length + gearhead length + (sensor/brake) + assembly parts									
EC-max 30, 60 W	193					105.1	119.6	119.6	134.1	134.1	134.1	148.6	148.6	148.6	148.6
EC-max 30, 60 W	193	MR	302			117.3	131.8	131.8	146.3	146.3	146.3	160.8	160.8	160.8	160.8
EC-max 30, 60 W	193	HEDL 5540	308			125.7	140.2	140.2	154.7	154.7	154.7	169.2	169.2	169.2	169.2
EC-max 30, 60 W	193			AB 20	346	140.6	155.1	155.1	169.6	169.6	169.6	184.1	184.1	184.1	184.1
EC-max 30, 60 W	193	HEDL 5540	308	AB 20	346	161.4	175.9	175.9	190.4	190.4	190.4	204.9	204.9	204.9	204.9
EC-max 40, 70 W	194					99.1	113.6	113.6	128.1	128.1	128.1	142.6	142.6	142.6	142.6
EC-max 40, 70 W	194	MR	303			115.0	129.5	129.5	144.0	144.0	144.0	158.5	158.5	158.5	158.5
EC-max 40, 70 W	194	HEDL 5540	308			122.5	137.0	137.0	151.5	151.5	151.5	166.0	166.0	166.0	166.0
EC-max 40, 70 W	194			AB 28	347	133.4	147.9	147.9	162.4	162.4	162.4	176.9	176.9	176.9	176.9
EC-max 40, 70 W	194	HEDL 5540	308	AB 28	347	151.7	166.2	166.2	180.7	180.7	180.7	195.2	195.2	195.2	195.2
EC-4pole 30, 100 W	201					88.1	102.6	102.6	117.1	117.1	117.1	131.6	131.6	131.6	131.6
EC-4pole 30, 100 W	201	MR	302			100.3	114.8	114.8	129.3	129.3	129.3	143.8	143.8	143.8	143.8
EC-4pole 30, 100 W	201	HEDL 5540	309			108.7	123.2	123.2	137.7	137.7	137.7	152.2	152.2	152.2	152.2
EC-4pole 30, 100 W	201			AB 20	346	124.3	138.8	138.8	153.3	153.3	153.3	167.8	167.8	167.8	167.8
EC-4pole 30, 100 W	201	HEDL 5540	309	AB 20	346	145.1	159.6	159.6	174.1	174.1	174.1	188.6	188.6	188.6	188.6
EC-4pole 30, 200 W	202					105.1	119.6	119.6	134.1	134.1	134.1	148.6	148.6	148.6	148.6
EC-4pole 30, 200 W	202	MR	302			117.3	131.8	131.8	146.3	146.3	146.3	160.8	160.8	160.8	160.8
EC-4pole 30, 200 W	202	HEDL 5540	309			125.7	140.2	140.2	154.7	154.7	154.7	169.2	169.2	169.2	169.2
EC-4pole 30, 200 W	202			AB 20	346	141.3	155.8	155.8	170.3	170.3	170.3	184.8	184.8	184.8	184.8
EC-4pole 30, 200 W	202	HEDL 5540	309	AB 20	346	162.1	176.6	176.6	191.1	191.1	191.1	205.6	205.6	205.6	205.6
EC 45 flat, 30 W	219					53.9	68.4	68.4	82.9	82.9	82.9	97.4	97.4	97.4	97.4
EC 45 flat, 50 W	220					58.8	73.3	73.3	87.8	87.8	87.8	102.3	102.3	102.3	102.3
EC 45 fl, 70 W	221					64.2	78.7	78.7	93.2	93.2	93.2	107.7	107.7	107.7	107.7
EC 45 fl, IE, IP 00	222					72.7	87.2	87.2	101.7	101.7	101.7	116.2	116.2	116.2	116.2
EC 45 fl, IE, IP 40	222					74.9	89.4	89.4	103.9	103.9	103.9	118.4	118.4	118.4	118.4
EC 45 fl, IE, IP 00	223					77.7	92.2	92.2	106.7	106.7	106.7	121.2	121.2	121.2	121.2
EC 45 fl, IE, IP 40	223					79.9	94.4	94.4	108.9	108.9	108.9	123.4	123.4	123.4	123.4
MCD EPOS, 60 W	343					161.1	175.6	175.6	190.1	190.1	190.1	204.6	204.6	204.6	204.6
MCD EPOS P, 60 W	343					161.1	175.6	175.6	190.1	190.1	190.1	204.6	204.6	204.6	204.6

RE 40 ∅40 mm, Graphite Brushes, 150 Watt



M 1:2

🟥 Stock program
☐ Standard program
▨ Special program (on request)

Part Numbers

Motor Data

			148866	148867	148877	218008	218009	218010	218011	218012	218013	218014
	Values at nominal voltage											
1	Nominal voltage	V	12	24	48	48	48	48	48	48	48	48
2	No load speed	rpm	6920	7580	7590	6420	5560	3330	2690	2130	1720	1420
3	No load current	mA	241	137	68.6	53.6	43.7	21.9	16.6	12.5	9.66	7.76
4	Nominal speed	rpm	6380	6940	7000	5810	4930	2710	2060	1510	1080	781
5	Nominal torque (max. continuous torque)	mNm	94.9	177	187	186	180	189	190	192	192	190
6	Nominal current (max. continuous current)	A	6	6	3.17	2.66	2.23	1.4	1.13	0.909	0.73	0.6
7	Stall torque	mNm	1720	2420	2560	2040	1620	1020	814	655	523	424
8	Starting current	A	105	80.2	42.4	28.6	19.7	7.43	4.79	3.06	1.97	1.32
9	Max. efficiency	%	87	91	92	91	91	89	89	88	87	85
	Characteristics											
10	Terminal resistance	Ω	0.115	0.299	1.13	1.68	2.44	6.46	10	15.7	24.4	36.3
11	Terminal inductance	mH	0.0245	0.0823	0.329	0.46	0.612	1.7	2.62	4.14	6.4	9.31
12	Torque constant	mNm/A	16.4	30.2	60.3	71.3	82.2	137	170	214	266	321
13	Speed constant	rpm/V	581	317	158	134	116	69.7	56.2	44.7	35.9	29.8
14	Speed / torque gradient	rpm/mNm	4.05	3.14	2.97	3.16	3.45	3.29	3.31	3.27	3.29	3.37
15	Mechanical time constant	ms	5.89	4.67	4.28	4.2	4.19	4.16	4.15	4.15	4.15	4.16
16	Rotor inertia	gcm^2	139	142	137	127	116	121	120	121	120	118

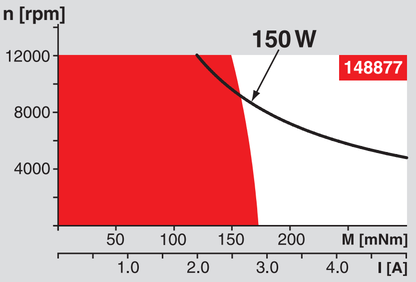
Specifications

	Thermal data	
17	Thermal resistance housing-ambient	4.7 K/W
18	Thermal resistance winding-housing	1.9 K/W
19	Thermal time constant winding	41.5 s
20	Thermal time constant motor	736 s
21	Ambient temperature	-30…+100°C
22	Max. permissible winding temperature	+155°C
	Mechanical data (ball bearings)	
23	Max. permissible speed	12000 rpm
24	Axial play	0.05 - 0.15 mm
25	Radial play	0.025 mm
26	Max. axial load (dynamic)	5.6 N
27	Max. force for press fits (static)	110 N
	(static, shaft supported)	1200 N
28	Max. radial loading, 5 mm from flange	28 N
	Other specifications	
29	Number of pole pairs	1
30	Number of commutator segments	13
31	Weight of motor	480 g

Values listed in the table are nominal.
Explanation of the figures on page 71.

Option
Preloaded ball bearings

Operating Range



Comments

🟥 **Continuous operation**
In observation of above listed thermal resistance (lines 17 and 18) the maximum permissible winding temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit.

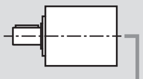
⬜ **Short term operation**
The motor may be briefly overloaded (recurring).

— **Assigned power rating**

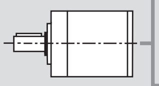
maxon Modular System

Overview on page 20 - 25

Planetary Gearhead
∅42 mm
3 - 15 Nm
Page 270



Planetary Gearhead
∅52 mm
4 - 30 Nm
Page 273



Recommended Electronics:

ESCON 50/5	Page 321
ESCON Module 50/5	321
ESCON 70/10	321
EPOS2 24/5	331
EPOS2 50/5	331
EPOS2 70/10	331
EPOS2 P 24/5	334
EPOS3 70/10 EtherCAT	337
Notes	**22**

Encoder MR
256 - 1024 CPT,
3 channels
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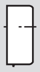

Encoder HED_ 5540
500 CPT,
3 channels
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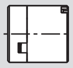

Brake AB 28
24 VDC
0.4 Nm
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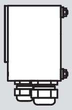

Industrial Version
Encoder HEDL 9140
Page 310
Brake AB 28
Page 349
End cap
Page 353