ROCbot Final Technical Report

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I. INTRODUCTION

The RASC-AL Exploration Robo-Ops design competition is held annually for graduate and undergraduate students. The goal of the competition is to design, assemble, and demonstrate a successful sample collection rover. The contest will be held on the “Rock Yard” at the NASA Johnson Space Center in Houston, TX.

Several design requirements drive the design of the rover. Firstly, it must fit within a stowed volume of 1m x 1m x 0.5m and weigh less than 45kg. It must be able to traverse obstacles of up to 10 cm in height, climb slopes of up to 33% grade, and travel through loose sand.

The main objective of the rover is to collect rock samples. Collectible rocks will be painted different colors where each color awards a different amount of points. The rock samples will range in diameters from 2 to 8 cm weighing between 20 and 150 grams.

To achieve an effective rover, several design choices were made. These included a bevel gear differential for a passive averaging suspension, large wheel diameters, a large, dexterous arm to maximize collection area and speed, a compliant grasper, optimal camera locations, and the implementation of ROS for programming and organization. The passive averaging was designed to use four bevel gears located in the center of the rover. This feature maintains wheel contact regardless of terrain and allows each wheel of the rover to climb rocks larger than its diameter without upsetting the chassis. The large wheel diameters both increase the scalable obstacles and create smoother travel. This is important when looking through a mast camera that will shake significantly more than the chassis.

A large, dexterous arm was designed to increase the effectiveness of collection. The arm can reach out up to 48 inches and rotate 135° in both directions to grasp samples. Six degrees of freedom (DOF) were developed to allow the collection of rock samples located in nearly any orientation or location. In addition to six DOF’s and a large workspace, a compliant grasper allows the collection of very odd shaped rocks. The grasper relies on many spring-loaded fingers that independently apply contact. These fingers thus “form” to the rock which creates an encapsulating and reliable grasp.

Lastly, efficient camera placement helps the operators navigate the environment easily. These cameras include two drive cameras (one forward and one backward), a pan-tilt-zoom (PTZ) camera on the mast for general surveying, a stereo camera pair at the base of the arm to simulate 3D vision for grasping, and, lastly, a webcam on the grasper to create a “floating” camera that is valuable, not only for grasping, but for surveying and driving. Each of these cameras should be valuable during the operation of this rover.

ROS was implemented to create a robust software package. Within ROS are several libraries that perform common actions such as reading in Xbox controller information and analyzing sensors. Additionally, it simplifies the communications between the command station and the rover.

In addition to all of these design choices, the team stressed sound mechanical design practices. These included properly constrained components such as axles and motors. Misalignment couplers were used in nearly all locations. Setscrews on shafts were only used in addition to a keyway or a flatted shaft. The type of bearings was also taken into consideration. For example, angular contact bearings were used at the wheel hip to accommodate side loads during turning with a skid-steer system. Even kinematic couplings were used to provide highly repeatable assembly of the bearing block for the passive averaging system. Many of these design choices were not necessary. However, using these practices creates a very reliable system.

All of these design choices have yielded a very capable rover. However, largely due to accounting problems here at the University of Nebraska, the UNL Robo-Ops team is behind schedule. As of March 1st, funding had yet to be available to the team and manufacturing could not begin. This was noted in the Mid-Progress Review. At this time, the rover is capable of tethered operation but not wireless. Furthermore, only basic testing has been performed.

The team is still confident, however, that the rover will be ready for the June 4th competition.

II. SYSTEM DESCRIPTION

A. *Rover Capabilities*

The rover designed by the University of Nebraska Robo-Ops team is capable of all completing the requirements established in the contest rules. The rover is capable of climbing rocks as large as 12 inches and should be able to climb grades greater than 33% (hill climbing has yet to be tested). With the large and wide wheels, sand poses no challenge to the rover.

The arm is capable of reaching out 48 inches and rotating 270° to grasp rocks. The grasper can open to 6 inches and can “form” to oddly shaped objects.

Through ROS and a VPN, the rover is completely teleoperated from the University of Nebraska Lincoln. At the command center, a many camera views are available including a pan-tilt-zoom IP camera for general viewing and a 3D stereo camera pair for grasping.

B. *Subsystems*

1) *Wheels*

The Rover of the Corn (ROCbot) has four wheels with a differential averaging system connecting the left and right sides. This differential system passively averages the leg angles as obstacles are traversed and applies that lesser angle to the chassis. This arrangement will provide a more stable chassis as a better base for the cameras and the arm. Given the known size and relative infrequency of the obstacles, a six wheel system was not necessary and represented additional weight. Tank steering was selected as the steering type based on simplicity since it eliminates 2 to 4 additional motors required for other 2 or 4 wheel steering types. The four wheels are then rigidly supported by the legs of the rover. The freedom that is gained through the differential averaging system provides the necessary freedom to traverse large obstacles that are sized near the radius of the wheel.

The differential averaging system is passively actuated through a four-gear differential. A four-gear differential was used instead of a three-gear differential to reduce the gear tooth stress, reducing the required size of each bevel gear. The input/output from the differential is then coupled to the legs through a jaw type misalignment coupler. A jaw type misalignment coupler was used because it is a fail-safe, backlash-free coupler that provided additional misalignment correction within the differential averaging system. Alternative differential averaging systems were also considered such as a differencing bar which was used on the Mars Science Laboratory rover Curiosity. A four-gear differential was selected based on the compact size and simplicity of the mechanism, which is fully contained within itself, unlike a differencing bar.

To effectively constrain the four-gear differential, a precision machined bearing block is required. To help reduce required tolerances, kinematic coupling was used. Kinematic coupling is a method which precisely locates two components with respect to each other with high repeatability. The two parts are constrained by a total of six contact points, which fully constrains all six degrees of freedom. The simplest form of kinematic coupling is three spheres and three mating vee-groves. Both the spheres and vee-groves are precision ground.

The four-gear differential bearing block is comprised of two halves. These halves are responsible for precisely locating each bevel gear to reduce backlash in the differential averaging system. Each bevel gear is supported by two deep-grove ball bearings. The ball bearings are supported by precision machined holes within 0.00025” of the nominal diameter. To ensure that the bearing surfaces are concentric, kinematic coupling was used to precisely locate the top and bottom of the bearing block. A quasi-static kinematic coupling method was used for this application because of the high repeatability and rigidity [1]. Additionally, extremely high stress concentrations are present for spheres with small diameters, reducing the load carrying capacity of the system. To help reduce the high stress concentrations precision ground rod was mated with two vee-groves. This configuration has six line contacts instead of six point contacts, effectively distributing the load across a larger area. The final bearing block design is shown in Figure 1. The bearing block was machined from 6061-T6 aluminum.

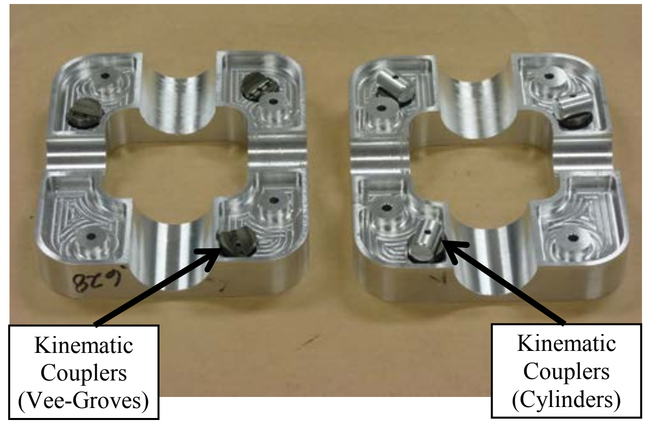

Figure 1: Differential bearing block with quasi-static kinematic coupling.

The main advantage of kinematic coupling over traditional locating methods such as locating pins is that only a location has to be precisely machined not an entire surface. Additionally, for locating pins the precision machined surface requires a hardening process to prevent addition misalignment from wear over time. A cross section view of the differential assembly is shown in Figure 2.

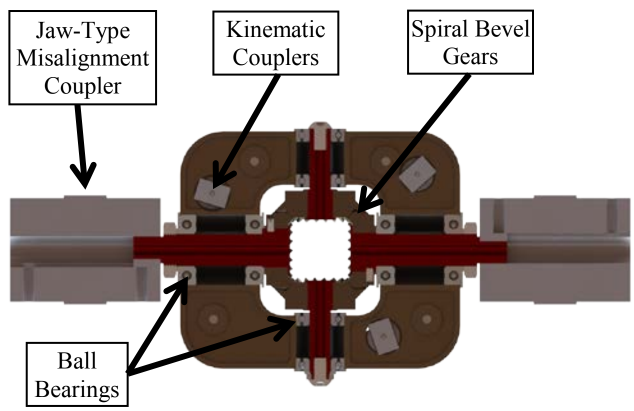

Figure 2: ROCbot differential averaging system differential bearing block cross section view.

From the differential bearing block the ROCbot is symmetric from left to right. The hip joint of the rover which is rigidly attached to each of the legs is coupled to the differential bearing block through the jaw-type misalignment coupler. The hip joint is supported by two angular contact ball bearings, which are designed for radial and axial loading. These bearings are required because of the steering type that was selected for the ROCbot. The hip plate, which is rigidly coupled to the hip shaft, rigidly couples the legs to the hip joint. The hip plate also has variable mechanical limits which prevent the legs from rotating past a specified angle. A cross section view of the hip joint is shown in Figure 3. The hip bearing block was machined from 6061-T6 aluminum.

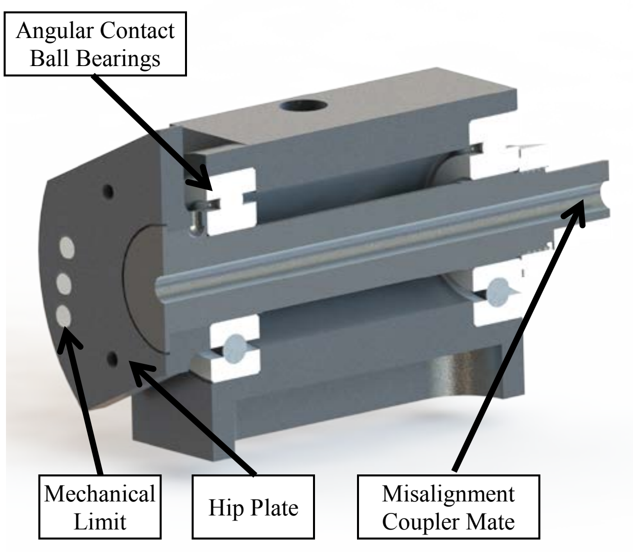

Figure 3: Cross section view of the hip joint.

The differential averaging system was designed to support a 100 pound load at one of the wheels, 1500 in-lbs of torque. Finite element analysis (FEA) was used to ensure that all shafts within the averaging system would not fail under 1500 in-lbs of torque. The results from one of the differential shafts are shown in Figure 4 with a maximum deflection of 3 degrees. All shafts within the averaging system are 416 stainless steel.

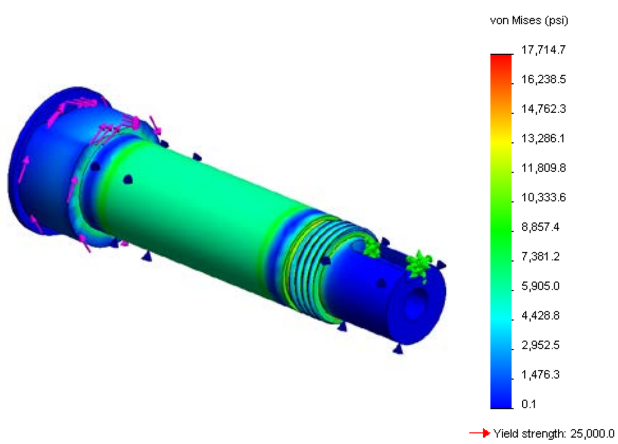

Figure 4: Differential shaft finite element analysis.

The legs then rigidly attach the wheels to the hip plate. The right side of the ROCbot suspension is shown in Figure 5. The legs are machined from 1" x 2" x 0.125" hollow, rectangular aluminum tubing. The legs also provide a channel for the motor wires to the chassis. Cord grips are used to provide strain relief for the motor wires. Two cord grips are used per leg to provide separate channels for the motor power and signal cables.

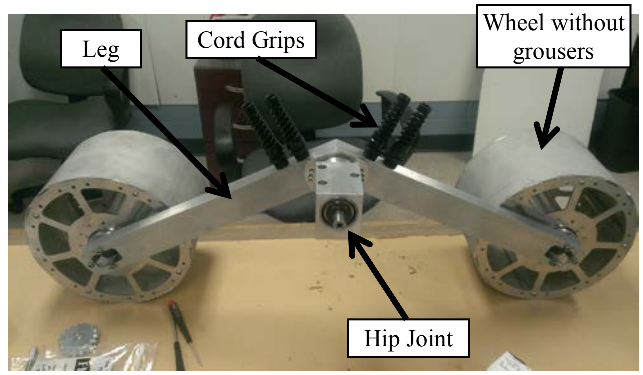

Figure 5: Right side of the ROCbot suspension.

At the center of each wheel is the drive motor. This design effectively reduces the width of the rover by housing the motor inside the wheel. The wheel is then supported by two thin-wall, deep-grove ball bearings, providing a bearing spacing greater than twice the inner diameter of the ball bearing. The motor is then coupled to the wheel through a custom 16-tooth spline. The spline is used to transmit torque and rotation, while allowing misalignment between the motor and wheel. Thin walled aluminum tubing was used for the outer surface of the wheel. The tubing was rigidly coupled to the bearing support through two hubs. A cross section view of the wheel is shown in Figure 6.

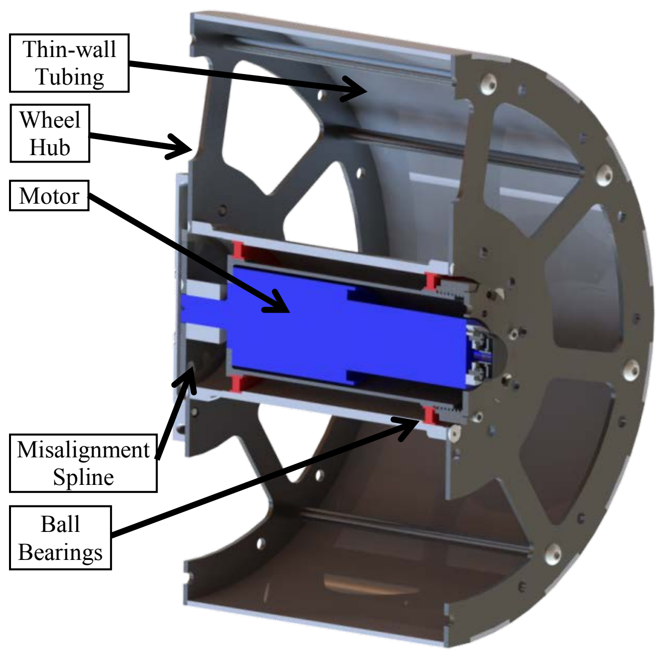

Figure 6: ROCbot wheel cross section view.

Two different grouser designs were then developed. The first design used a chevron shaped grouser to provide grip during straightaways as well as during turning. The grouser was created with 3/8" wide by 1/4" tall rubber strips. A Durometer hardness of 60A was selected for the rubber strips. This rating was specified just below the hardness of an

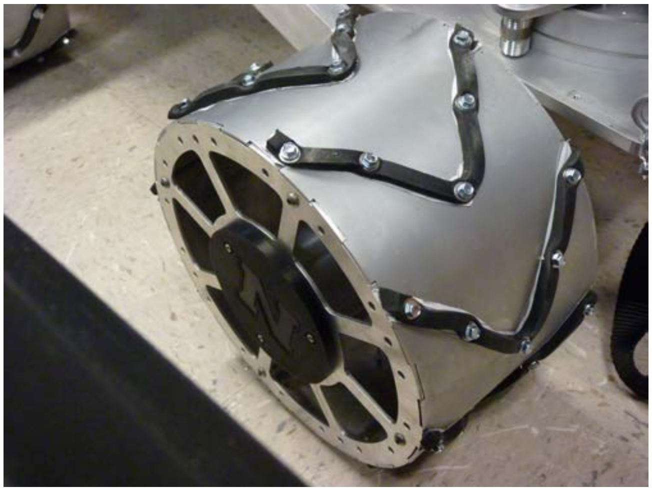

Figure 7: ROCbot chevron style grouser design.

automotive tire. The rubber strips were then secured to the outside of the aluminum tubing using self-tapping sheet metal screws. The chevron style grouser design is shown in Figure 7. The final weight of the chevron style wheel with motor is 6.2 pounds. The chevron style grouser design added approximately 0.6 pounds to the final wheel weight.

A second wheel design was developed specifically for weight reduction. The same thin-wall aluminum tubing was used but a lattice structure was cut into the wall of the tube for weight reduction. Finite element analysis (FEA) was used to ensure that the lattice structure was strong enough to prevent the wheel from failing under standard loading conditions. A worst case scenario, a 50 pound point load, was then used to illustrate the toughness of the structure. The results from the FEA are shown in Figure 8 with a maximum deflection of 0.138”. The lattice structure removed approximately 1 pound from the final wheel weight.

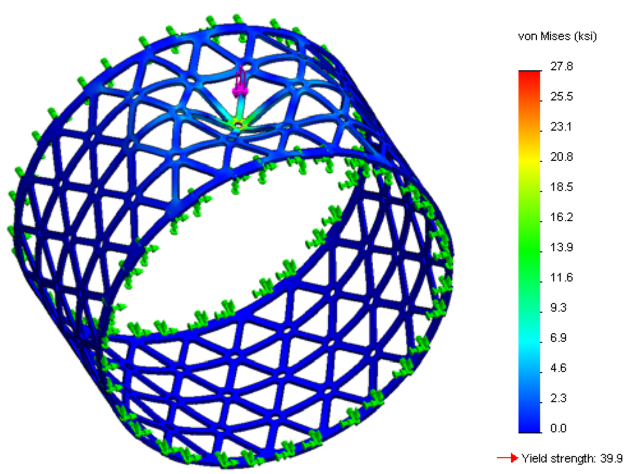

Figure 8: ROCbot wheel tubing with lattice structure finite element analysis.

Then, to prevent the wheel from sinking in sand and to provide additional traction a textured conveyor belt will be attached to the surface using contact cement. The textured conveyor belt has rectangular grousers running parallel to the axis of the wheel. This wheel design is currently being manufactured and will be tested within the next coming weeks before the competition. A final wheel design will be selected based on efficacy in sand and gravel and final weight.

The motors at the center of each wheel are rated at 200 watts with a no-load speed of 16700 rpm and max continuous torque of 127 mNm with an integrated 113:1 gearhead. These motors were selected based on being able to accelerate to its max speed within one second while traversing up a grade of 33% with a rover mass of 100 pounds. Based on these parameters the maximum theoretical velocity of the ROCbot is:

$$V_{max} = 16700 * \frac{1}{113} * \frac{10\pi}{12} = 386.9 \frac{ft}{min}$$

2) Chassis

The chassis was designed from a 3/8” thick sheet of 5052-H32 aluminum. This specific alloy was selected based on the available alloys from our material sponsor. FEA was used to ensure that this alloy met our requirements. Two 100 pound loads were applied to the far edges of the chassis plate. The results are shown in Figure 9 with a maximum deflection of 0.213”.

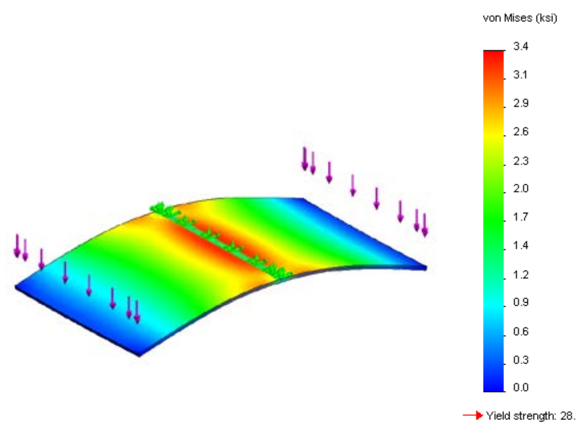

Figure 9: Chassis plate finite element analysis.

To reduce the weight of the chassis plate a lattice structure was machined into the bottom of the plate. The chassis plate mounted in the CNC is shown in Figure 10. Approximately two-thirds of the weight was removed. The final weight of the chassis plate was 11.5 pounds.

Figure 10: ROCbot chassis plate in the CNC.

The overall dimension of the ROCbot chassis plate is 38.25” long by 22.16” wide. A standard and custom bolt pattern was machined into the chassis plate. The standard bolt pattern will allow additional payload integration and the custom bolt pattern is used to secure all payloads that will be used during the 2013 RASCAL Robo-Ops competition. Additionally, holes are provided to allow handles to be secured to the front and back of the chassis plate for transportation. A cable trough was created exiting the arm base to provide a clean exit for some of the arm’s motor and signal cabling. The overall dimension of the ROCbot is 38.5” wide by 38.75” long by 24.37” tall. These dimensions are shown in Figure 11. The current mass of the ROCbot is 106 pounds. This is over the allowed mass limit. We have identified more than 7 pounds that can be cut from the rover including the 4 pounds that can be cut from the wheels with the redesign. Additionally, we are in the process of cutting weight from the legs, averaging differential system, arm and camera mast.

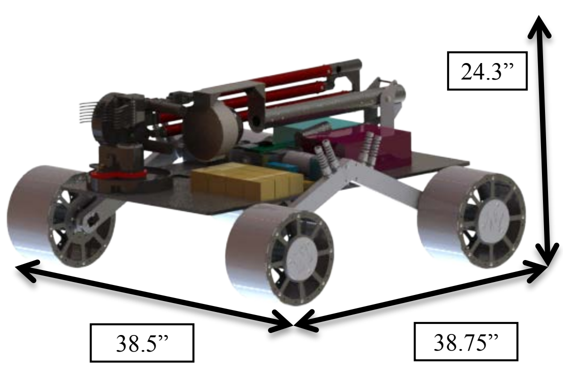

Figure 11: ROCbot overall dimensions.

The chassis of ROCbot was sized as large as it could be within the constraints. Even with the additional area, the top of the plate is very full of the components. In order to provide the maximum amount of the clearance beneath the chassis, the space above was limited by the overall height of the arm's shoulder. The available area was separated and filled with electrical, mechanical, and networking components, as shown in Figure 12: ROCbot chassis layout.The organization of these different components was set to adequately balance the weight of the components while maintaining reasonable cable runs between the electrical subsystems. Furthermore, access to each of the critical components was arranged to allow for in-field access and swapping as necessary.

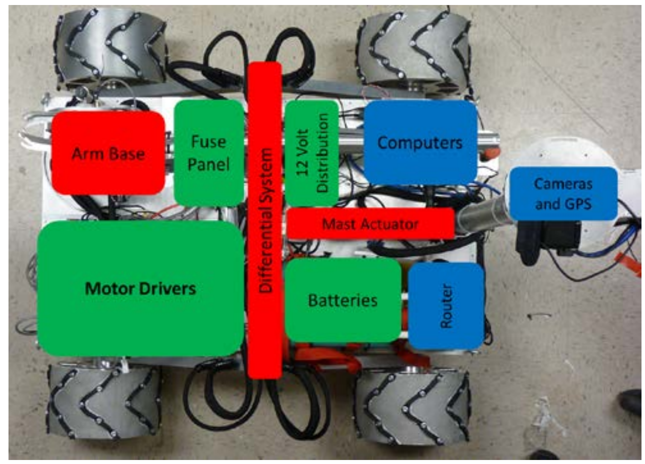

Figure 12: ROCbot chassis layout.

3) Cameras

There are five different camera locations on ROCbot. The necessary cameras include a forward facing drive camera, a rear facing back-up camera, and a mast mounted Pan-Tilt-Zoom camera. Two additional camera locations were found to be advantageous and are currently being evaluated. These are a wrist mounted camera and a shoulder mounted stereo pair of webcams.

The forward facing drive camera is a Logitech C920 HD Pro Webcam. This camera can provide full 1080p Video at 30 fps. This resolution will be realized on-board for processing, but will be down sampled as needed for the transmission back to the command center. The location of this camera on top of the camera mast allows the driver to see approximately 18 feet in front of the rover while on flat ground. With this perspective, the driver has a good third person view, providing a view of both front wheels as well as the arm and most of its workspace. This view does block nearly 1.5 feet of the ground immediately in front of the rover, but with the addition of arm mounted cameras, this area can be visualized as necessary.

The rear facing back up camera is a Microsoft LifeCam Cinema. This camera is a 720p webcam and is positioned looking downward from the top of the camera mast. This viewpoint provides a view of both rear wheels as well as nearly two feet beyond the rear of the rover.

The primary camera used in the search for rocks is a mast mounted IP camera whose center is just over 3 feet from the ground. This camera is an Axis 215 PTZ dome security camera. This model was selected for its compact nature as well as its simplicity. Due to its normally inverted design, the camera hangs from the top of the camera mast. For support reasons, approximately 50 degrees are blocked by the camera mast bracket.

The arm camera is also planned to be a Microsoft LifeCam. This camera provides a repositionable camera view for the capturing of the target rocks. Its location on the end of the arm also allows it to be used as a repositionable hazard camera in certain situations. The large reach of the arm will also allow this camera to be a secondary mast-style camera that can reach to approximately the same height of the mast camera while providing more positioning freedom.

To aid in grasping of rocks, a stereo-pair of cameras is proposed for the base of the arm. This location allows the cameras to pan with the movement of the arm and ensures that the target always is near the center of the frame. These two streams will be broadcast back to the University and will be used with an available 3D viewer. The cameras used throughout the ROCbot rover are shown in Figure 12.

Figure 13: ROCbot camera system.

4) Manilpulator System

The rover's six DOF arm is capable of grasping objects as far as 48 inches from the base of the arm, Figure 13. However, when packed it fits within the design constraints. This design greatly decreases the duration of the collection process and eliminates the need to accurately position the rover. The spherical wrist of the arm allows the rover to grasp objects on side slopes, objects behind obstacles, and objects that would otherwise be difficult because of their orientation. Additionally, with a camera mounted on the grasper, a "floating" camera is available for any unavailable viewpoints. The collection process is to simply get the rock within a reasonable distance, unpack the arm and activate control, grab the rock, and use automatic depositing and automatic packing while the operator begins travelling again. At this moment, a kinematically matched master controller is being used for testing. Transitioning to a Phantom Omni is in the works. Additionally, more automation of the collection systems are being developed and tested. To effectively use advanced automation routines, an Omni is preferred due to its positional ambiguity.

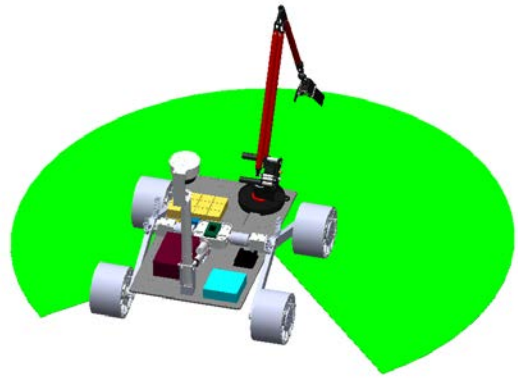

Figure 14: Dexterous workspace of the ROCbot arm.

The mechanics of this arm are unique, a cable driven parallel mechanism is used to drive the shoulder and elbow joints – joints two & three. The parallelogram transfers any angular changes at the base to angular changes at the elbow. This then drives the forearm tube. The main benefit of this system is the relocation of the elbow motor (joint three) to the base where it rotates about the same axis as the main arm motor (joint two). This, in turn, allows the use of a single drum for the cable transmission of these joints. Each section of the arm is shown in detail in Figure 14. The joint ranges of the arm are shown in Table 1.

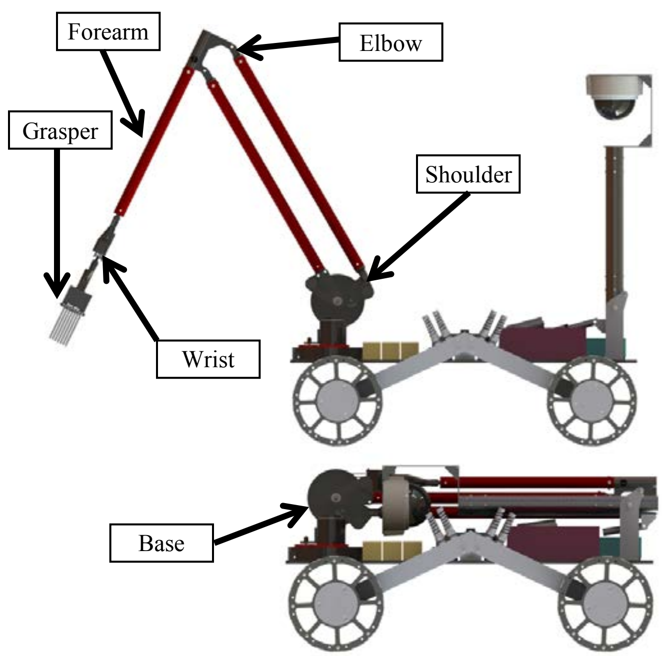

Figure 15: ROCbot six degree of freedom arm.

Table 1: ROCbot arm joint ranges.

Joint Number	Alternate Name	Rotation Limits	
1	Shoulder Yaw	-135°	135°
2	Arm Pitch	-90°	75°
3	Forearm Pitch	0°	165°
4	Wrist Roll	-180°	180°
5	Wrist Bend	-90°	90°
6	Grasper Turn	-180°	180°

The ability to accurately control this large arm stems from several design choices including structurally reliable components, high quality motors and servo drives, absolute position sensors, and cable transmission systems. The base of the arm is assembled from four machined 6061-T6 aluminum components and several sheet 6061-T6 aluminum parts. High quality deep-grove bearings were used for the base rotation joint with cable access through the center to allow for proper strain relief. The arm tubes are 1.25 inch diameter aluminum tubes with 0.035 inch wall thicknesses. In total, the tubes for the arm weigh only 10 ounces.

Standard hobby servos are simply not sufficient for control of an arm this large. Instead high quality Maxon motors and Advanced Motion Control servo drives were implemented. The base motors include two 40 watt brushless motors for base rotation and forearm pitch (joints one & three), while the main arm pitch (joint two) is driven by a 60 watt brushless motor. These motors were selected based on the ability to hold a 1 pound rock at maximum extension while each motor is within the maximum continuous torque range. The second constraint that was imposed was that the arm should be able to unpack itself to full extension within two seconds.

The three DOF wrist and grasper is driven by 10 mm Maxon brushless motors. These motors were selected based on their size and power density. The spherical wrist and grasper consist of milled aluminum components with sheet metal 6061-T6 aluminum fingers. The DOFs of the wrist from proximal to distal is roll, pitch, and roll. This is a very common kinematic wrist design that is seen on commercially available robotic manipulators such as the Barrett Technologies WAM arm [2]. Each DOF of the wrist is comprised of a 10mm motor, an output gear, and an absolute position sensor, Figure 15. The pitch DOF of the wrist has an additional bevel gear set.

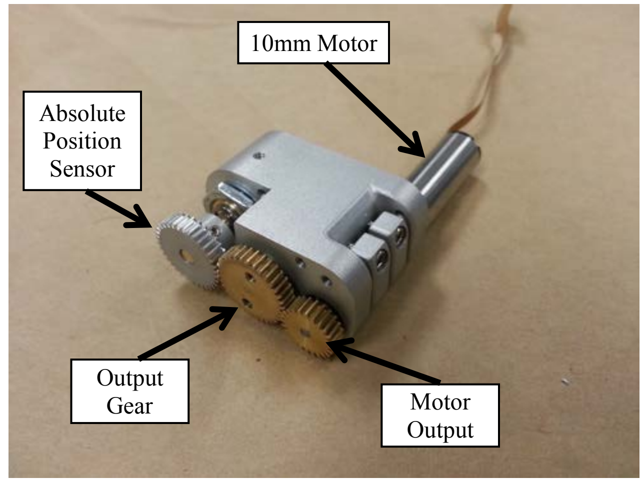

Figure 16: ROCbot wrist design: roll joint.

In addition to motor encoders, absolute position sensors are used on all joints of the arm. Because of this homing is never required and encoder count errors are periodically removed. The built-in encoders on the motors are relative position sensors and are dependent on their location upon first receiving power. Additionally, these encoders can drift over extended periods of time due to noise in the lines. With the exception of the grasper, the absolute position sensors used for the rover are US Digital MA3 Miniature Absolute Magnetic Shaft Encoders. For the grasper, a linear potentiometer was used instead. The use of absolute position sensors greatly improves the reliability of automatic procedures such as automatic depositing of samples and automatic packing and unpacking.

The most important feature of this arm is the cable transmission systems. As you can see in Figure 16, motors two & three are attached to capstans that both rotate about a larger drum. This low backlash, low friction, high torque transfer method allows very precise but powerful movements. The cable used in this design is 0.048” low-stretch, high-fatigue stainless steel cable rated at 270 lb. force and is mounted in a way that accommodates the pitch of the cable on the drum. One end of the cable is fixed while the other is mounted to a threaded slider. A single #10 screw is then used to tension the cable. The diameter of the drum for joints two and three is six inches in diameter while the nominal diameters of the capstans are 0.75 inches. Each capstan is supported on both ends because the tension in the cable exceeds the allowable radial load of the gearboxes. Backlash with this design is calculated to be less than 0.2 degrees. Ultimate load for this arm is calculated to be five pounds at full extension. The base rotation also uses a cable transmission drive on a nine inch drum.

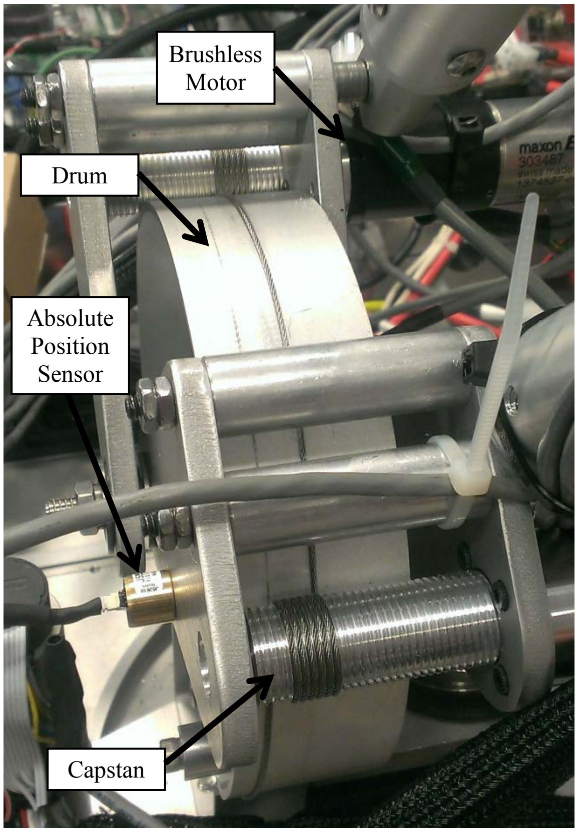

Figure 17: ROCbot shoulder: capstan drive system.

The grasper of the rover focusses on compliance to obtain a good grasp. Each finger of the grasper is spring loaded, as shown in Figure 17, to a carriage. The carriage is driven by a 12 start lead screw. As each finger comes in contact with the object, it stops moving and its spring begins to stretch. As the carriage reaches its final position, several fingers are in contact with the rock. Together they provide enough force to pick up the object. The benefits of this system include that oddly shaped objects can be grasped as easily as blocks and spheres.

1) Control and Communication System

a) Computers and Communication

The communications and control system for ROCbot are comprised of two computers onboard the rover, one VPN server on the UNL campus, and three control stations at UNL. Willow Garage's ROS robotics software architecture is implemented on the two computers onboard the rover and the three control station computers. ROS allows multiple computers to seamlessly share data and computing tasks, but to work effectively the computers need to all be on the same local network.

A VPN server running OpenVPN was utilized to avoid the port access problems that can occur when computers on separate firewalled networks try to communicate. Local network access between all computers provides open access to the ports ROS and ROCbot use to communicate.

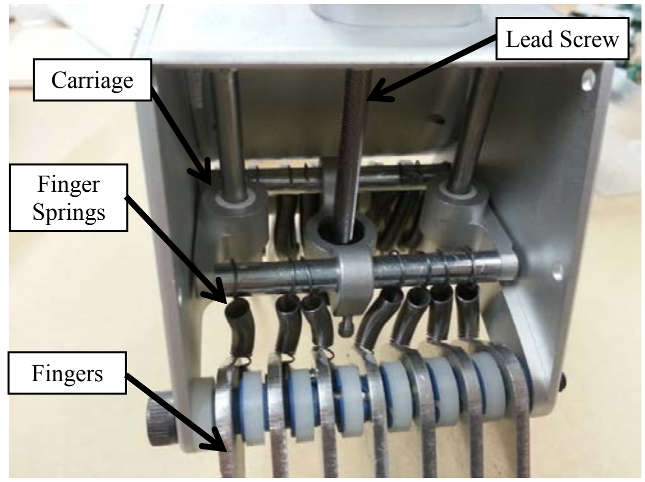

Figure 18: ROCbot compliant grasper.

The computing tasks on the rover are separated onto two machines. The first computer handles the telemetry and motor driver commands and is a low power Intel DN2800MT with an Atom processor, 4 GB of RAM, and a 64 GB hard drive. The other computer is used to encode video for transmission to the control station and run computer vision algorithms such as stereo reconstruction. It is an efficient, yet higher power computer with an Intel i7-3770s, 128 GB solid state hard drive, and 8 GB of RAM.

The communications between the control station and the computers on the rover is provided by two 4G LTE UML290 modems. On Verizon's network here in Lincoln, the average 4G connection has a latency of 86.7 milliseconds, a download rate of 20.14 Mbps, and an upload rate of 10.335 Mbps. One of these modems is attached to the low powered Atom computer, and the other is attached to an ASUS RT-N16 router running DD-WRT firmware. This router and firmware are capable of using the attached modem to share internet connectivity with the Axis IP camera, and the high powered computer that is used for video processing.

b) Sensors

There are four main sensors that are employed on the rover. The first is a GPS receiver mounted on the top of the camera mast. This, combined with an IMU mounted on the top of the differential block will provide reliable spatial orientation and position information of the rover. These two sensors will be combined with the data from wheel encoders into an extended Kalman Filter to provide a very robust position and orientation estimate of the rover. This data is displayed on the GUI and will help the drive team in navigating the rover.

The final type of sensors on the rover is rotary potentiometers. These position sensors appear on all joints of the arm to provide the absolute position information of the arm. A potentiometer also measures the angular displacement between the two sides of the rocker system as terrain is traversed. This data will be used to indicate the position of the rockers to the drive team through the GUI.

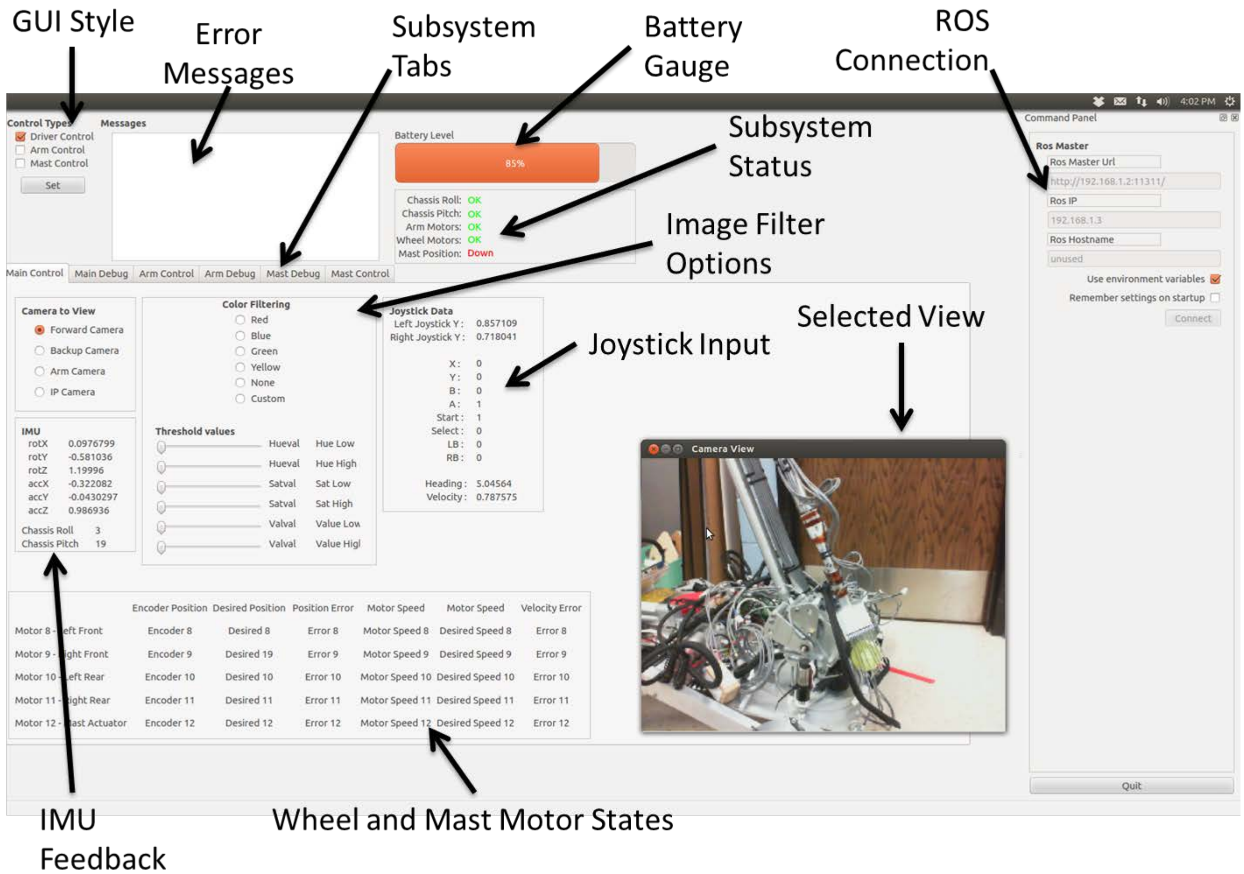

Figure 19: The main GUI will be split onto two screens for the competition. One screen dedicated to camera views and the other to telemetry.

c) Graphical User Interface

The user interface for the rover plays a critical role in the performance of the system as a whole. The decision was made to separate the GUI into three different workspaces. These workspaces are for the driver, arm operator, and the mast camera operator. For simplicity, a single GUI was created with the option to opt into any combination of those areas. This arrangement will allow easy implementation on multiple control computers.

Early during the development, the camera views were decoupled from the main GUI window. This arrangement was selected so that on a multiple monitor control computer, the images can be seen at their largest while still maintaining access to the telemetry data. This setup also provides more screen space for the feedback to be displayed, minimizing the number of tabs that need to be manipulated to see all data. The development computer is single monitored, but the PC that is to be converted to Linux for the competition has the graphics capabilities to support two monitors. The GUI layout is shown in Figure 18.

The GUI will have a couple of features that will aid in the operator's efficient use of the rover. The first of these will be an intuitive set of controls with designated shortcuts for some of the more common operations. These shortcuts will be implemented through either keyboard, on-screen events, or through a series of foot pedals. The second feature to be included is the integration of the GPS/IMU data into a map overlay. This overlay will provide the operator knowledge of where the rover has been and what areas have not yet been searched. Given the GPS information, the operator will also be able to have the GUI guide the driver back to the transportation zone through the use of heads-up-display style

Figure 20: Overlays will help direct the driver towards the travel pad for transportation.

information on the drive camera. In one implementation, this feedback is shown to the operator as a series of arrows that will guide the driver onto the correct heading as in Figure 19.

III. TECHNICAL SPECIFICATIONS

The wheels of the ROCbot combined with the large grouser depth and the differential system allow the rover to climb an estimated 12 inch rock. The communications to and from the rover is being completed using two 4G network cards. One card will be used primarily for motor driving and motor state tasks. The second card is dedicated to sensor and camera input. The overarching software system is within the Robot Operating System (ROS). Both python and C++ have been leveraged within the ROS architecture. For Graphical User Interface development, the QT IDE was used and coupled with ROS.

IV. TESTING STRATEGY

With the delays in the final assembly of ROCbot, fully powered tests of the rover have not been completed on the different terrains that will be encountered. Drive tests have been conducted within the lab, hard tile floor, and have shown good levels of maneuverability on a surface that provides very little traction. In manual testing of the grouser design on the wheels in woodchips and sand, the grip on the ground is sufficiently sound, Figure 21.

With the systems ready in the next week, full mobility tests will be conducted to prove the efficacy of the tread design during turning. The secondary wheel design that is being manufactured will provide a tread that is not as deep and will provide less resistance to turning.

The wheels are six inches wide and provide sufficient contact area to prevent sinking in the terrains provided for the competition. The wheels staying on the top of the ground will enable better turning without digging in.

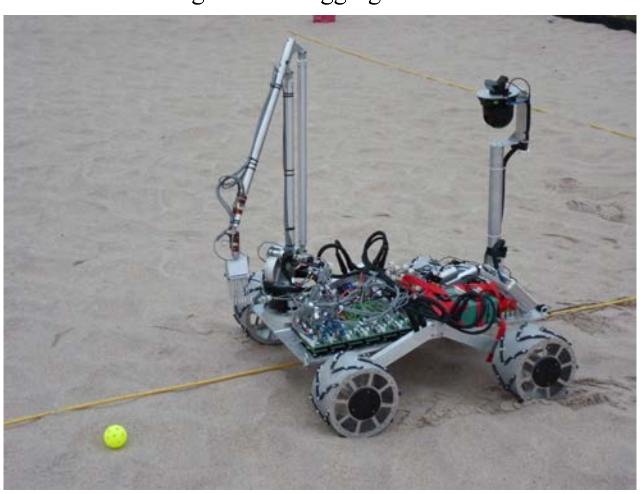

Figure 21: Manual testing in sand.

V. OVERALL STRATEGY FOR THE COMPETITION

ROCbot has a simplistic four wheel design with four, ten inch diameter, six-inch wide wheels. The chassis plate has nearly nine inches of clearance. The combination of wheel size and clearance under the body will allow ROCbot to traverse all of the expected obstacles with ease. This means that less time/energy need be expended in avoiding rocks that were intended as insurmountable.

The inclusion of an arm with a four foot wingspan means that precise positioning of the rover as the rock is approached will not be necessary. This length of the arm and the inclusion of a wrist mounted camera allow the arm to capture rocks that are approached and lay on either side of the rover. This may be important since 'parallel parking' along a rock may be much faster. For rocks that are in front of the rover, the rocks will be captured using the shoulder mounted stereo camera set. Controlling the arm and capturing rocks while using a three-dimensional viewer will significantly improve the performance and speed of ROCbot's grasping ability.

VI. PUBLIC OUTREACH

The UNL RASC-AL Robo-ops team participated in several outreach events. The larger of the two was during the University of Nebraska's Engineering week (April 8^{th} – 12^{th}) where the team helped organize a Robotics Zone.

Figure 22: UNL E-Week robotics zone.

There were several different areas of the Robotics Zone, two of which were hosted by the UNL Robo-Ops team. At the Robo-Ops section, the team introduced younger children, high school students, and adults to the competition. They showed them SolidWorks models of the rover and several 3D printed and laser cut prototypes. Prototypes included three different grasper designs, a model of the passive averaging system, and a working prototype of the cable driven arm.

The second section maintained by the UNL Robo-Ops team focused on surgical robotics – the research topic shared by all members of the team. Several different surgical robots were on display including four designed by current and former graduate students. A Raven II surgical robot was performing arbitrary movements to show how it performed surgery. Again, the students introduced the goals of the designs and discussed challenges. The presenters asked interactive questions to get the visitors thinking while making it entertaining.

While transitioning between these two rooms, several other, smaller, robots were presented. These included robotic road cones and cliff-climbing robots. The road cone robots include a robotic base for standard road cones. Visitors were quizzed on the good and bad of these things. The cliff-climbing robots, which use cooperation to climb a cliff face, were displayed on a model cliff.

Other sections of the Robotics Zone included UAVs (Computer Science Department) and CEENbots (Computer Engineering & Electronics Engineering Departments).
In total, an estimated 500 visitors passed through the Robotics Zone.

Several small presentations have been given to small student groups through April 1st. These groups, typically between 10 and 25 elementary students, were given tours of the Robo-Ops areas and surgical robotics areas, similar to the Robotics Zone of E-Week. Between 6 and 8 groups were given tours with an estimated visitor count of 150 students.

A final outreach event was held at Zeman Elementary School on May 15th. The fully assembled rover was shown to roughly 50 students. The students asked questions for nearly an hour and seemed to really enjoy talking with the team. They cannot wait for the live video stream during the competition!

Figure 23: Outreach event held at Zeman elementary school.

VII. SPONSORS

There are several different agencies and companies that have helped ROCbot become what it is. These companies provided funds, components, manufacturing, materials, or software for the completion of this project. These resources are separated in Table 2.

Table 2: ROCbot sponsors.

Funding Organizations	Components	Manufacturing and Materials	Software
National Institute of Aerospace	Advanced Motion Control	Eagle Precision Machine	Solidworks
NASA Nebraska Space Grant Consortium	Bal-Tec	Hastings Irrigation	
UNL Department of Mechanical and Materials Engineering	Gigavac	Metal Tech Partners	
UNL College of Engineering	Lovejoy	MetalQuest Unlimited	
	Maxon	Proto Labs	
	Quality Transmission Components	Rivers Metal Products	
	UNL Communications Office	RPDG	
	UNL Phone Shop	State Steel	
	VXB	TMCO	
		UNL Engineering & Science Research Support Facility	

VIII. REFERENCES CITED

[1] Hart, Anastasios John. *Design and analysis of kinematic couplings for modular machine and instrumentation structures*. Diss. Massachusetts Institute of Technology, 2001.

[2] http://www.barrett.com/robot/products-arm.htm