UTA Rover Team Final Report 2012

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1 Introduction

The University of Texas at Arlington (UTA) Rover team designed and constructed a rover for the Revolutionary Aerospace Systems Concepts Academic Linkage (RASC-AL) Exploration Robo-Ops (ERO) 2012 competition. The purpose of this report is to compile the team's design process taken over the course of the competition. The UTA Rover team proposed a four-wheeled platform with subsystems needed to address the requirements established in the competition guidelines. More details of the rover specifications along with drawings will be presented in the following section. This will be followed by an overview of the materials and processes used to fabricate the components for each subsystem. In addition, the methods for testing and analyzing our designs is given to validate the decisions made to arrive at our final design. Lastly, the report will include a detailed discussion about the team's effort to inspire and educate young children in grades kindergarten to twelfth (K-12) through public outreach activities.

2 Rover design

The planetary rover is a four-wheeled vehicle designed to be lightweight and capable of traversing steep slopes and uneven terrains. The rover is composed of several major subsystems, which are required to address the competition requirements. These major subsystems include: suspension and drive system, manipulator arm and gripper system, and camera mast system. Other components such as the batteries and electronics are located on the floor of the chassis and protected from the elements.

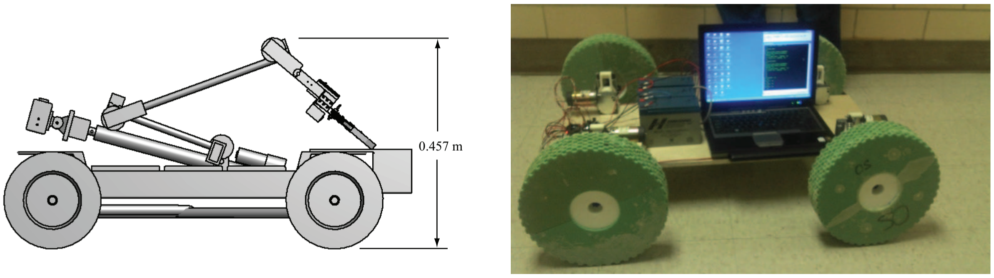

Figure 1: Conceptual and assembled views of rover design.

The rover measures at 0.94 m in length, 0.66 m in width, and approximately 0.46 m in height, when the camera mast is in its stowed position. The platform is designed to provide at least 12 cm of ground clearance, depending on the size of the payload.

2.1 Drive system

The drive system is composed of an independent, double-wishbone suspension system, which offers improved flexibility and cross country mobility. Four direct-drive motors, connected to optical encoders, will maneuver the rover using a skid, or differential steering technique to simplify the control scheme for all wheels. The wheels have a diameter of 12 inches and are 2 inches thick. A checkered tread pattern for the wheels is used for increased traction.

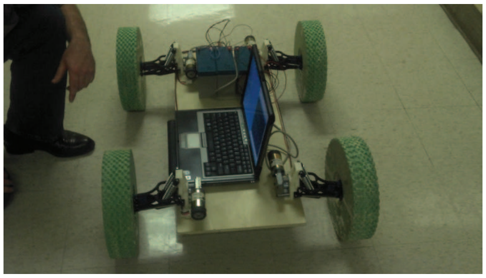

Figure 2: Setup of the drive system.

A dynamic simulation of the four-wheeled platform was conducted to select the proper drive motors to insure that the platform can climb the required grade. The wheels are assumed to experience pure rolling on the slope. The original motors used in the first iteration of the drive system assembly were designed for high speed, low torque operation. This proved to be insufficient for the uneven terrains. Thus, the second iteration of motors involved the use of high torque, moderate speed DC worm gearmotors. These motors are rated at 175 RPM, 100 lb-in which is consistent with the results obtained from the dynamic simulation.

In order to improve traction and help maintain the wheels of the rover on the ground, it was determined that a compliant suspension system was needed. An off-road RC car suspension was selected based on the required ground clearance, weight and part dimensions. This suspension was then fitted to the rover.

2.2 Camera mast

A camera mast was produced to operate independently from the manipulator arm and gripper system. The mast is designed to extend to 2 feet in height above the platform base when it is at the upright position. The mast carries a Sony box camera with 20X optical zoom; this camera provides a wide field of view that will help in navigating the rover. Additionally, it provides a clear view of the arm's workspace, which will allow the operator to pick up rocks more accurately. The camera sits atop a tilt system operated using a servo motor; if a pan movement is required to move the camera, then it will rely on the platform drive system to accomplish this maneuver. A gas spring is used to lift up the mast and is triggered using the manipulator arm and gripper system. The gas spring selected has a capacity to lift 20lb with a maximum extension of 10 inches.

2.3 Manipulator Arm

The manipulator arm was designed to increase reliability while maintaining its dexterity. The arm contains four degrees-of-freedom (DOFs) operated by three large servo motors providing 360° of rotation, and a fourth smaller servo motor at the end of the arm, providing 180° of rotation.

Figure 3: Camera mast (left), manipulator arm (right).

The lengths of the three arm links from base joint to its end are 15 inches, 11 inches, and 7 inches, respectively. This gives the manipulator arm a large workspace, capable of picking up rocks 10-12 inches in front of the rover with the arm base located in a forward position on the base. Each link has a 5/8-inch diameter cross-section.

2.4 End-effector

The original gripper solution, VEX Robotics claw, was found to be insufficiently capable of consistently securing payload samples as the claw mechanism did not allow for enough contact points. An alternate solution was proposed, which utilizes a commercially available scooper bucket mechanism.

This scooper bucket serves as the gripper and is attached to the third link of the manipulator arm using two clamps. At its open position, the gripper provides an opening of about 4 inches (10 cm) to pick up rocks, which is sufficient per competition requirements. A small pin-hole camera was added to ensure that a rock is being picked up and secure within the parameters of the scooper.

Figure 4: Scooper and gripper assembly design.

2.5 Control structure

The System Control Architecture can be broken down into three major subsystems: planetary rover controls, Mission Control Arlington (MCA) command and control facility, and the UTA Data Stream Server that will be responsible for hosting three live video feeds generated during UTA's RASC-AL operations at JSC. The first video stream will be the raw video footage captured by the Sony box camera on the mast. The second will be an image of the vehicle control interface that will be used by MCA to drive the vehicle and operate the manipulator arm. The third will be the MCA Rover Localization Interface, which will update the rover's location when it is performing in the competition. Each of the three major sub-systems will be described in greater detail below.

A pair of joints are controlled by a Motorola-based microcontroller. Numbering from the base to the tip, joint 0 and 1 are controlled by one microcontroller, and joint 2 and 3 are controlled by a second. Each joint will also include an absolute encoder that provides feedback on the position of the arm. Each microcontroller is encoded with PID controllers that output a Pulse Width Modulation (PWM) command signal to their respective joint motors. Each of these controllers is also programmed to turn on when power is provided, thereby requiring less programming knowledge from the user.

Microcontroller level programming also includes the ability to listen to mid-level programming, i.e. Controller Area Network (CAN) protocol. The CAN protocol provides the link between multiple low-level microcontrollers and the mid-level microcontroller.

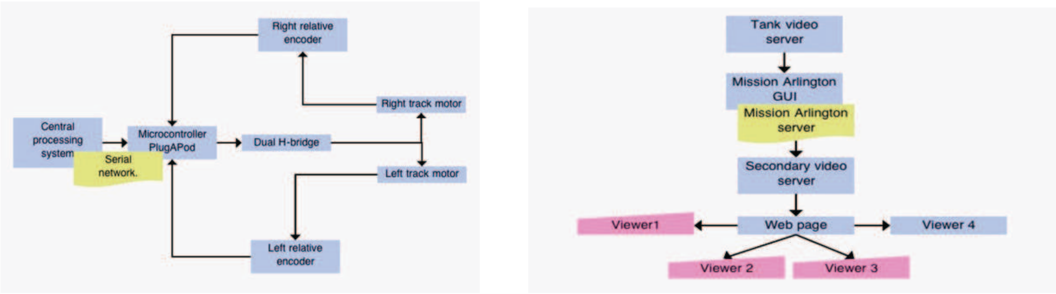

Figure 5: System control flowchart.

The mid-level controller provides a link between microcontroller-based programming and higher level programming, Fig. 5 (left). It consists of three major components:

Higher level Communication This component listens to higher level commands through a serial port and distinguishes these commands as CAN or drive wheel commands.

Drive wheel command protocol This sends PWM signals to the H-bridge which controls the drive wheels. These drive wheels are also connected to independent relative encoders to provide feedback on their speed and position.

CAN command Protocol Here, arm control commands are processed and transmitted through the CAN bus.

The mid-level microcontroller is connected to the Windows XP embedded PC which handles higher level communications. At this level the camera data is processed and the main communication link with the Verizon data card is established. The PC runs multiple servers, as in Fig. 5 (right) namely: the camera server, camera control listener, control listener, and accessory feedback listener.

3 Production and Testing

3.1 Suspension, drive system, and rover platform

The platform base is constructed using 1/4-inch thick plywood, which measures at 34 inches in length and 14 inches in width. This material was chosen because it made it easier to create mounting holes for various components that are located on the platform base. To avoid issues with the softness of the plywood at these mounting points, metal brackets and washers were added as necessary.

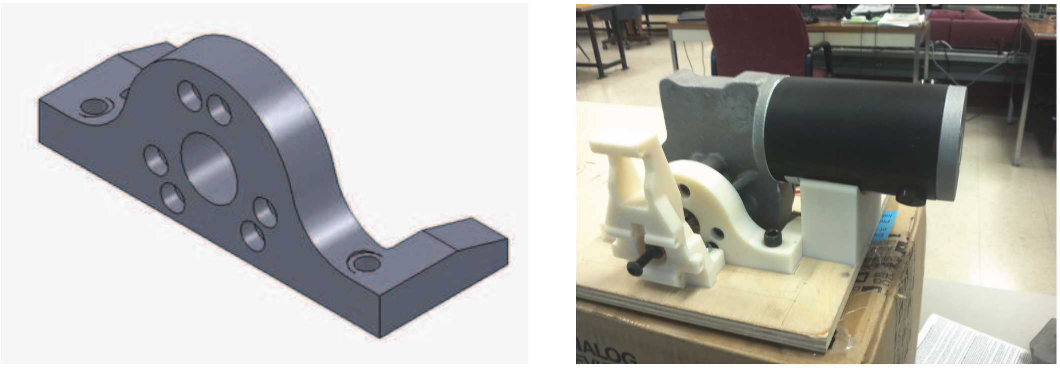

Figure 6: Motor bracket (left), motor-bracket assembly (right).

The wheels were manufactured using 1/4-inch blown PVC foam, layered and glued together using water activated epoxy glue. The motors operating the drive system required a bracket and support block, each of which were rapid prototyped using a 3-D printer and made of ABS plastic. Based on the resources available, cost and schedule, it was decided that a rapid prototyped plastic part would be the best choice. The rapid prototype material provided an adequate weight to strength ratio. This method of manufacturing also provided the added advantage of quickly printing a part for testing, as compared to machining from metal.

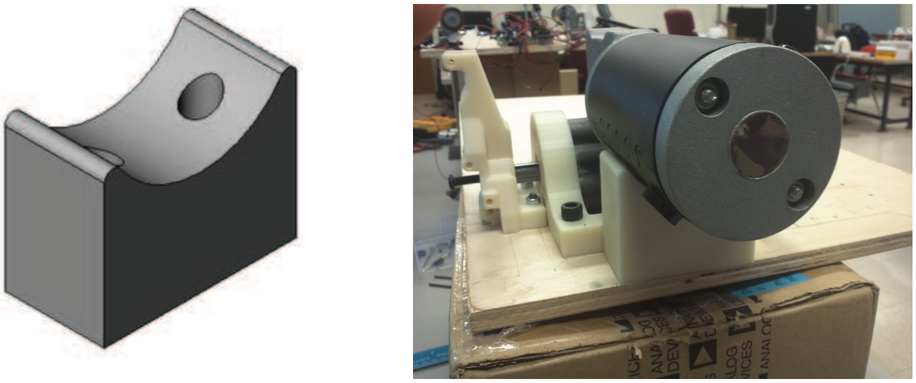

Figure 7: Support bracket (left), motor supported (right).

A simple and effective method of attaching the wheel and suspension assembly to the platform base was needed. The suspension mounting points from a toy RC car were replicated on the new suspension mount design. The mount's geometry was optimized to maximize strength and reduce weight. Steel bolts were used to secure the suspension bracket to the platform base.

This was the most cost effective method to effectively secure the suspension assembly.

The suspension system also required a mounting bracket, which was designed to minimize the number of joints required while aligning the suspension system and fixing it to the chassis. This bracket was fabricated similar to the brackets used for the motors.

Figure 8: Front views of suspension system.

To test the entire system, Doug Russell Park was chosen due to the diverse terrain and undulation it offered. Located on the south-central part of UT Arlington campus, the park provides a convenient nearby area for testing the rover's dynamics, mechanical assemblies, and the control and communications of the system from a remote location.

3.2 Manipulator arm and gripper

The manipulator arm is composed of commercially made carbon fiber tubing. This tubing was cut to size to make the appropriate lengths of the links. The purpose of using carbon fiber was due to its increased strength yet lightweight properties. The joints of the arm were connected using aluminum clamps. The manipulator arm underwent a series of tests to determine its dexterous workspace and ability to manipulate its joints. A 1 lb weight was added at the end of the arm to determine infeasible joint configurations.

By comparing the original claw design to the new scoop design, it was noted that they both function in a linear motion, where the center is fixed. This joint connection in the center creates an axis of motion that allows the scoop to rotate around, which leads to an opening and closing effect. Through iterative design and testing, an alternative solution was developed. The linear motion is created by a rack and pinion, where the rack is connected to two brackets that serve as contact points on the scoop and the spinning pinion propels the rack and these brackets upwards, opening the scoop. A plate to hold the rack and pinion was rapid prototyped but did not correctly suit the desired motion. By adding a slit down the center, rotation is allowed as the brackets drive the scoop to open and close.

A secondary issue was identified in the gripper motor, which is continuous rotation servo motor. A solution was developed with two switches that will

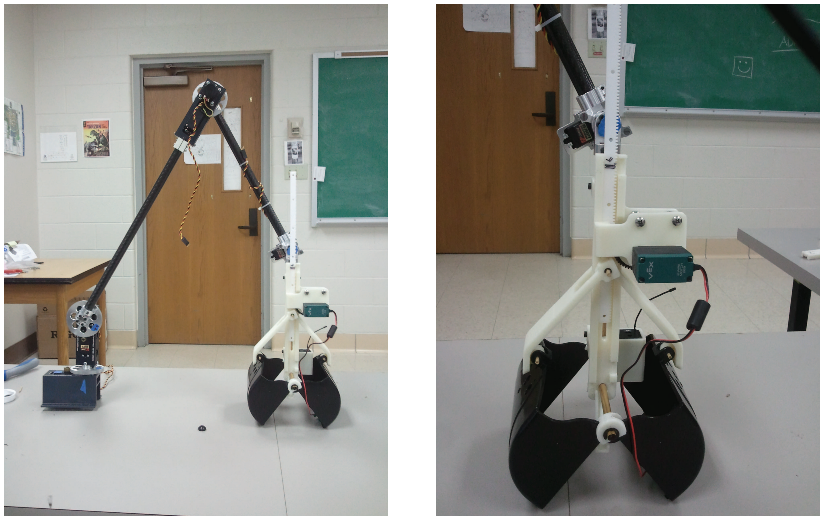

Figure 9: Manipulator arm and gripper system.

create an open-loop system to allow the user to manually control the power inputs to the motor. This creates kill switches to allow the motor to close or open without worrying about a time constraint. The switches will be triggered by the rack as it travels down along the slit on the plate that holds the rack.

The original brackets that accompanied the scoop were damaged in the testing process and were recreated. The recreation of these brackets proved to be difficult as any elongation in the brackets would result in the scoop not being able to open the desired distance. The brackets were redesigned three times until they were correctly implemented. Also, the gripper when fully assembled had some lateral movement, which would create issues when trying to pick up a rock. Stabilizers were fabricated that spanned the length of the axis between the scoop and the rack's plate. This not only stabilized the axis and reduced the lateral movement but also strengthened the axis. To make better use of time and material, an assembly drawing of the parts in working order was created to better guarantee the correct implementation of the parts. The assembly drawing showed areas of potential conflict between parts, which were able to be addressed before the parts were created.

3.3 Camera mast

The mast is mounted on the platform base by a pair of brackets and connected to a rapid prototyped clamp, which allows it to revolve. One end of the spring is mounted to the mast and the other on the platform using the same type of clamp. The spring mounting points were calculated so that when the gas spring is fully compressed, the mast is situated horizontally to the platform. Additionally, when the spring is fully extended, the mast is at an upright position. To secure the mast at the stowed position, it was proposed to use a rubber latch to hold the mast and have the manipulator arm release it. However, the idea was difficult to be implemented because there was not an ideal position to place that latch. Also, the latch was not strong enough to hold the mast against the spring force. It was noticed that the existence of a singularity in the kinematics of the camera mast system, allowed it to remain in its stowed position if it was situated below parallel with the platform base. This observation brought the idea of utilizing this threshold to fix the mast down and have the manipulator arm initiate the spring motion by initiating contact with the mast and raise it above the threshold.

3.4 System control

The remote operation of the rover was tested to gain experience with the Verizon data card and to verify the control protocols required to command the rover. The rover was taken to a remote site and commanded from MCA in order to debug the system.

The camera server provided a live video feed to the MCA GUI. The MCA PC will also be running a live video server but it will be transmitting the live screen capture of the video feed and the GUI control. This will reduce the load to the limited bandwidth provided by the Verizon data card in case of multiple hits on our website and reduce any risk of video delays to MCA. This video will be captured by a secondary server and then transmitted to our website.

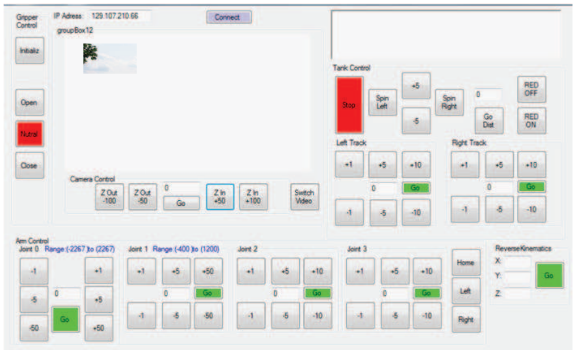

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Figure 10: Mission Control Arlington platform control user-interface.

The camera control listener provides a communication link from MCA, as in Fig. 10, to the rover to control the camera. This program listens to a predetermined port of the telephony network to redirect control commands to the camera on the rover through the VISCA command protocol. The control server provides the main communication through the telephony network to control the rover and the arm. This program also listens to a different predetermined port to redirect the commands to the rover to control its motion and the arm. An accessory feedback listener is also listening to a predetermined port on the rover that gathers various data like GPS data, Compass data and laser range finder (LFR) data, and transmits the latest recovered data to the MCA GUI only when requested, reducing the bandwidth usage.

4 Outreach

In an effort to inspire and educate the public, the team worked closely with various groups on campus to develop the following outreach initiatives: dynamic website, facebook page, team video, and participation in multiple outreach events.

4.1 Website

The intent of the website is to educate the public at large about the space program in general and the competition requirements and objectives while specifically targeting younger students to motivate them to continue learning about these topics. The graphic design was done by a local high school student and input was collected from pre-college sources regarding the layout of the site. The overall design plan called for multiple outreach sections with interactive content that caters to separate age groups, meant to engage the target audience.

4.2 Facebook page

The intent of the Facebook page was to engage as much of the individual member's social network in our efforts by serving as a portal to our website and video publications. In addition, this form of social media has allowed our team to advertise its involvement in the competition to a much broader audience, invite people to our outreach events, and present any current information about the status of our progress.

4.3 Team Video

The intent for our team video was to convey three things: the multi-disciplinary team dynamic required of the design process for this competition, the driving force of NASA as a motivator and inspiration as individuals and as a team, and the importance of continuing to educate and inspire future generations into STEM fields and space exploration. This was accomplished through a blend of individual interviews and documentation of various competition components. None of this could have been accomplished without the contributions of Mr. John Mitchell, a student in the College of Fine Arts, through his generous donation of personal time and work, and the Film Department in the College of Fine Arts for allowing the use of editing equipment.

4.4 Outreach Events

One of the major initiatives for this team was to participate in as many events as possible allowing presentation of the rover design and education of people about the history and the future of the space program. Over the course of the last four months, our team was able to present in three local area events and one formal presentation to a board of industry leaders.

The first event was RoPro Challenge at UTA. This event is held each year for students from local high schools in the Dallas-Fort Worth area. Students compete in this robot programming contest, in which a Lego Mindstorms robot must navigate through a maze and find objects using vision and touch systems.

The FIRST Robotics competitions held at local universities gives students from local area high schools a great venue where they can participate in this LEGO competition. Team members had the opportunity to interact with student teams as volunteers and through a display setup of our rover design in the competition area.

Engineering Saturday is hosted by the College of Engineering three times a year. This event is open to the general public which allows K-12 students to participate in interactive sessions presented by various groups and departments within the college. The team used this forum as an opportunity to educate students about our participation in the competition and proposed rover design.

The team also had a unique opportunity to present at a meeting hosted by the local Chapter of the Association of Unmanned Vehicle Systems International (AUVSI). This meeting was attended by a diverse group composed of industry leaders, faculty, and students. The team gave a short talk about the team's activities and participation in the RASC-AL competition. Some valuable feedback was obtained in preparation for the presentation to be given at the competition.