University of Maryland RoboOps 2016: Kokopelli

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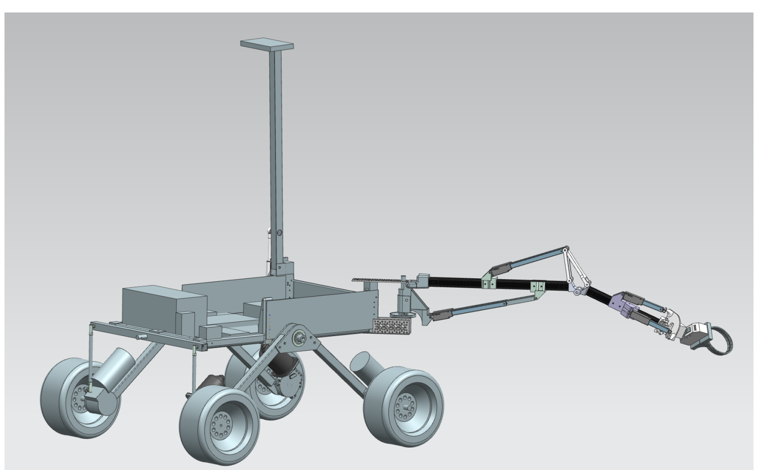

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1 Introduction

The University of Maryland is pleased to participate in the NASA RASC-AL RoboOps competition for the sixth straight year, and submits this final report to NASA and the NIA contest staff to document the design, development, and testing of the system. Considering the record success of the 2015 University of Maryland vehicle, Frigg, at the competition, the goal of the 2016 vehicle is to improve on the performance of Frigg while reducing the weight of the vehicle. Additionally, with the new mystery challenge, the arm needed to undergo a redesign to allow for six degrees of freedom. To continue the current trend of naming the University of Maryland after deities of the harvest, the 2016 vehicle was named Kokopelli, after the Native American god of fertility.

2 System Description

2.1 Chassis Design and Drive System

Considering the overwhelming success of Frigg in the 2015 NASA RASC-AL RoboOps competition, this year's team sought to improve upon the design from last year. One of the major concerns about Frigg, was its weigh in at 29.4 kilograms. Since RoboOps' inception, average vehicle mass has continually decreased. This trend has emphasized that Kokopelli must be significantly lighter than Frigg to take advantage of the later start time and remain competitive. However, there is a delicate balance between the advantages gained by reducing mass and going later in the competition. Lighter vehicles get lass traction on the loose grains of the Moon and Mars Yards. These vehicles also tend to be smaller and less robust than larger vehicles. This tradeoff could be seen last year as some of the extremely light competitors had structural failures and trouble gaining traction. For this reason, University of Maryland had to design Kokopelli to be lighter than Frigg without compromising its robustness.

2.1.1 Motors and Wheels

One major improvement the team attempted to make was with the drive system. The motors that the University of Maryland team used in the past had a mass of 1.25 kg, which accounted for one-sixth of the total vehicle mass. A comprehensive search was conducted to find motors that could provide levels of stall torque greater than 15 N/m, require stall current draw less than 25 amps, and run at least 100 RPM. Ultimately, no lower mass options were found that satisfied these requirements. The option to replace them for weaker motors after they performed so well traversing rocks, climbing vertically and absorbing impacts with rocks in the past was determined unacceptable. As a result, Kokopelli will be using four 218 Series Gearhead Motors by AM Equipment.

The 10 cm wide wheels used on Frigg provided excellent performance across the wide range of terrain at the NASA Johnson Mars Yard. This performance was reflective of the wheels intended use on remote control monster trucks. Weighing 750 grams each, the wheels are 18 cm in diameter and made from flexible rubber with a sponge rubber interior. The foam interior helps reduce rock-impact accelerations and cushion falls while the aggressive tread pattern gives the wheels great traction on the small, loose grains of the simulation environments at Johnson Space Center. The wheel is attached to the motor via an aluminum, CNC milled, hexagonal collar designed to rigidly secure the wheel to the half-moon shaft of the motor. As reflected in the course records set by Frigg, this particular wheel and motor combination can exceed speeds of 1 meter per second and allow quick traversal of the course to maximize sample collection time. This year Kokopelli will drive with skid-steering. Individually drivable wheels like those on Curiosity were considered, however, this concept would add significant mass to the rover and was not chosen due to the harsh penalty imposed on the heavier vehicles.

2.1.2 Rocker

Kokopelli's rocker provides a vertical clearance of approximately 28 cm. This was determined by talking with prior UMD teams to determine the average size of rocks in the Mars yard and how prior vertical clearances dealt with the obstacles. Once this was determined, the rocker tubes and gusset plates were designed to handle the expected bending, torsion, and compression loads during normal driving operations as well as impulses from hitting rocks at 1m/s. Ultimately square composite tubes with an omni-directional layup were chosen for the rocker and omni-directional composite plates were chosen for the rocker gusset plates.

The rocker to chassis interface piece is a C-clamp with an axle to mount the rocker on. The axle has two through holes located 1.6 mm away from the edges of the rocker. These holes have cotter pins that hold the rocker in place and prevent large amounts of lateral movement during drive. The rocker connects to this piece through two steel ball-bearings and is allowed to rotate.

(a) Differential Bar Interface (b) Rocker Gusset (c) Motor Mounts

Figure 1: Chassis Components

Attached to the ball bearings are rockers' gusset plates. The gusset plates are made of two epoxied 2.5 mm thick omni-directional carbon fiber plates as these plates were the most cost-efficient solutions. Each gusset plate has four rivet holes and a large central hole that the steel ball-bearings are press-fit into. The hole patterning of the gusset plates allows one design to be used for all eight plates to connect to the rocker tubes without the opposite side's rivets preventing the final rivets from being added. The rocker tubes and gusset plates are connected using 3M DP420 epoxy and four steel rivets.

The bottom of each rocker tube has two holes to mount the motors and wheels. There are two sets of specially machined mounts that connect the motors to the rocker. The difference between the set being a connector for the rod ends that attach to the differential bar. The motor mounts are 6.35 mm thick aluminum plates that were made on a CNC mill. They allow the wheel shaft collar to rotate without issue and position the motor to allow it to take the majority of rock impacts instead of the carbon fiber tubing. This should prolong the lifetime of the rocker and also provides the additional benefit of creating a hard stop for the rocker while climbing large rocks.

The differential bar design on the back of the rocker allows the rover's body angle to be half that of the angle between the two sides of the rocker. This increases the total angle that the rocker can handle with less danger of tipping over. The differential bar is attached to the chassis through a mechanism very similar to the one that attaches the rocker to the chassis. A 1.9 cm square aluminum tube serves as the differential bar that connects to the rocker through two rods with ball and socket rod ends.

2.1.3 Chassis

This year's chassis design has focused on bringing the University of Maryland into the growing number of teams that use advanced ultra-light materials in their rover design. The team examined ultra-lightweight materials to reduce the large amount of aluminum that has been used with previous robots and ultimately settled on carbon fiber composites to replace the majority of the structure. This provides a unique opportunity to significantly reduce structural mass while maintaining a similar strength but also poses a new challenge of longer machining times, more difficult interfacing, and less warning time before failure. Where possible the team reduced the use of aluminum to save weight, but the combination of low cost and ease of machining kept the material as an integral part of the differential bar and rocker. The chassis itself consists of four machined carbon fiber tubes with rivet holes for the rocker to chassis interface and through holes to secure 3-D printed PLA corner connectors. Thin aluminum rods connect the corner pieces and vertical posts and provide the required stiffness to resist torsion and bending of the chassis. The chassis' skin is made of non-structural lightweight PVC to reduce mass. The chassis is 38.1 cm wide by 58.9 cm long and 11.7 cm tall. It has three machined components that connect the rocker and differential bar to the chassis. The chassis size was ultimately driven by the required vertical clearance of the vehicle and the need for a wide base to avoid tipping over on large inclines or obstacles.

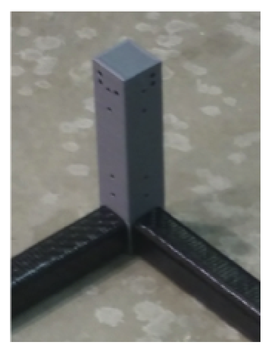

Figure 2: Corner Chassis Piece

Four 3-D printed corner pieces were designed to hold the chassis together and two were uniquely designed to support the arm and mast. These specially designed pieces provide the large majority of Kokopelli's structural interfaces, a unique experiment for UMD. They include mounting points for the skin, arm, mast, mast deployment mechanism, carbon fiber tubes, and chassis stiffeners. In addition, there are two vertical posts that slide around the carbon fiber tubes and help add stiffness to the chassis. This highlights the increasing capabilities of 3-D printed parts as legitimate structural materials for low-mass, low-load applications. These 3-D printed components have satisfactory strength to weight ratios in every condition other than shear along the print layers and as a result, each piece was printed in a way to ensure the print layers were aligned with the plane that experiences the lowest shear loads to avoid structural failure.

2.1.4 Sample Container

Kokopelli will have a curved basket with an aluminum frame and cloth exterior that curves up and outwards from the front of the chassis instead of a traditional rectangular basket. The reasoning for curved panels is to have a more "terrain-friendly" design that will help deflect the bottom of the chassis over any rocks it encounters. The basket design is driven by a volume requirement of 40 golf ball sized rocks and requirement that it stay carefully within the workspace of the robotic manipulator without being in the way. The limited aluminum frame is to provide some rigidity to the basket and provide a way to rigidly attach the basket to the chassis. A fully rigid basket was considered but the idea was dropped due to concerns that vibrations might knock out many of the collected samples if the rover drove too fast over the rocky terrain.

2.1.5 Mast and Deployment

Kokopelli's mast will have a number of cameras and electronics mounted to it, which will create a significant moment for the deployment system to counteract. The team decided to solve this problem by ordering a small gas-spring with built in damping that can output 178 N of axial force. The mast is 58.42 cm long and is pinned to the chassis and allowed to rotate through brass bearings. The location of the gas spring allows stowing of the mast to a near horizontal position and also allows Kokopelli to remain inside the bounding box. The gas spring location also provides a horizontal force to maintain the mast's deployed position and reduce vibrations during deployed drive.

2.1.6 Cameras

There are a total of five cameras on the vehicle: a main Ethernet camera located on the mast and 4 USB C920 Logitech webcams. The main Ethernet camera is a 1.8 MP Point Grey Cricket with a 8.5 mm CS mount with a Fujinon lens connected via power over Ethernet (POE) to the Motherboard and 48 volt buck converter. The Point Grey was chosen due to its effectiveness on Frigg providing optimal resolution video feed along with its minimal overall mass. The Point Grey orientation is controlled by two Futaba servos mounted in a pan-tilt configuration to 3D printed mounts providing a pan-tilt-zoom overall orientation method. The USB C920 Logitech cameras were chosen due to the small cost yet excellent quality of video imaging. The positions of the Logitech camera mounts were chosen for the most effective views to maneuver the rover and operate the arm manipulator system. One Logitech is attached to the bottom of the rover via mushroom head Velcro to serve as a crotch-cam and observe the ground pathway. Another Logitech is attached from the original support frame of the camera to an angle bracket on the front of the mast 25.4 cm from either end to collect constant forward video feed for guidance and double as a field of observable workspace for the arm. One C920 Logitech is mounted on the top of the mast plate via the original support frame to provide constant rear-facing video feed and the last Logitech is mounted near the end effector for the arm via a 3D printed mount to provide accurate end-effector positioning. All of the cameras are connected over USB cable to the motherboard and the 7-port Anker 3.0 aluminum USB hub. Each camera has audio streaming capabilities.

2.1.7 Microphone

For Koko's audio stream, an HDE 3.5 mm computer microphone is attached to the support mast of the rover that collects the data and connects to the Motherboard via the audio jack. The dampening cover for the 3.5 mm microphone provides optimal noise reduction while still receiving quality audio data. The microphone was also chosen due to the low cost for budget constraints and the small size for optimizing overall rover mass.

2.2 Manipulator System

The manipulator is required to pick up various sized rocks of 2-8 cm in length and 20-150 grams in mass, from multiple terrains and challenging placements such as being partially buried or above larger rocks. Koko's manipulator sports 6 degrees of freedom in a Yaw-Pitch-Pitch-Yaw-Pitch-Roll (Y-P-P-Y-P-R) configuration. Differences between Koko's manipulator and that of her predecessor Frigg's 4 degrees of freedom, Y-P-P-P manipulator include carbon fiber tubing to reduce mass from the aluminum previously used, increased shoulder yaw range of motion, as well as the new yaw and roll degrees of freedom to allow for Koko to have the necessary degrees of freedom to complete the new mystery contingency task in the 2016 competition. The additional shoulder yaw range of motion was created by replacing the linear actuator providing yaw with a rotary actuator 45 off the corner of the rover. The additional degrees of freedom are the results of a 3D printed universal joint controlled by two linear actuators offset by 90 in addition to a servo. This extra mass at the end of the manipulator required the addition of a second linear actuator to support the elbow pitching moment. Koko's end effector has been modified slightly from the version used on Frigg. Whereas the backing of the previous grippers were 3D printed plastic, in an attempt to save some mass and increase maneuverability, volume, and flexibility the new end effector has a meshed-fabric backing. These end effectors were made sufficiently thick to support a compression mass of up to 22 kg each, which exceeds the expected mass of the rover. The user controlling the manipulator will continue using cameras for positioning, but will also now have proximity measurements to use via an ultrasonic rangefinder with a resolution of 1 cm tested to work up to 0 cm. In stowage, the manipulator will lay over top of the right

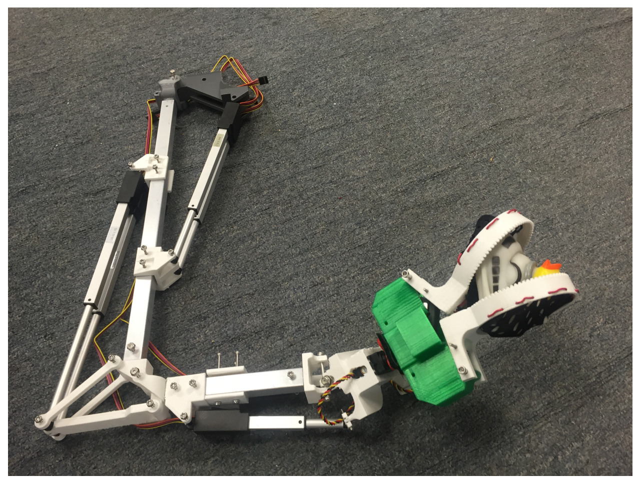

Figure 3: Aluminum Version of Manipulator System

wheels.

2.2.1 Overall Strategy

The manipulator was based off of the manipulator Frigg showcased in 2015, which worked very well and helped to set a new course record. However, there were problems that needed to be addressed and additional modifications to improve the manipulator's capabilities for whatever the unplanned contingency task ends up being. Frigg's end effector had problems with linear actuator oscillations resulting in dropped rocks, which ended up being a software issue that was later addressed.

2.2.2 Shoulder Yaw

The shoulder yaw range of motion was increased to allow for more convenient stowage along the side of the rover and the capability to work to in areas in which the rover could not face.

2.2.3 Mass Considerations

Along with the overall attempt to reduce mass, the tubing of the arm is now made of carbon fiber. The 55.9 cm tubing of carbon fiber has a mass of 95.2 grams as opposed to 167.3 grams from the 6.4 mm 6061 aluminum.

Because of the additional mass that was added to allow for 6 degrees of freedom, the elbow required additional support. Therefore both the shoulder and elbow now use two actuators in parallel.

2.2.4 Wrist Joint

The wrist was designed beyond the requirements of the competition to help the rover reach into places and to complete the mystery challenge. A universal joint was added to this location to allow for additional dexterity and give comparable range of motion to a human wrist. The universal joint was custom made with one side fitting into the carbon fiber tubing and the other end housing the servo motor used for end effector rotation.

2.2.5 End Effector

The current primary end effector is composed of two small-toothed, oval-shaped claws with a mesh fabric backing. Each claw is moved in a sweeping motion with a linear actuator. The small teeth should help with pinch gripping samples, while the oval shape and mesh backing shoulder help to allow a wide variety of samples to fit within the claws. The team has prepared for the mystery challenge to be similar to opening a valve or faucet. Different kinds of end effectors will be ready at the competition to be mounted onto the rover pending the overall best end-effector for the task. All end effector designs have different shapes and therefore provide different grips. Because a weight variation of no more than 200 grams is allowed after rovers are weighed, the two end-effectors were designed to vary by no more than a few grams in mass.

In the case that the rover flips over during the competition and the entire weight needs to be supported by the arm, several compressive tests have been performed to find the optimum design for the end effectors that would bear the rover's weight without breaking.

With a total width of 1.78 cm, each end effector can handle a maximum load of 22.13 kg vertically and 25.4 kg horizontally.

Figure 4: Compression force tests on the primary end effector

2.2.6 Sensor and End Effector Housing

In order to improve the performance of the rover when collecting rocks and avoiding obstacles, an ultrasonic sensor has been placed in between the end effectors. The sensor reads distances to an accuracy of 1cm. As can be seen in Fig. 5, the angle of visibility of the ultrasonic sensor is 45, and therefore the end effectors have to be half open when looking for rocks. The ultrasonic sensor has been tested both on ground and on sand in order to both ensure that it is receiving the expected values and to verify its suitability on sand.

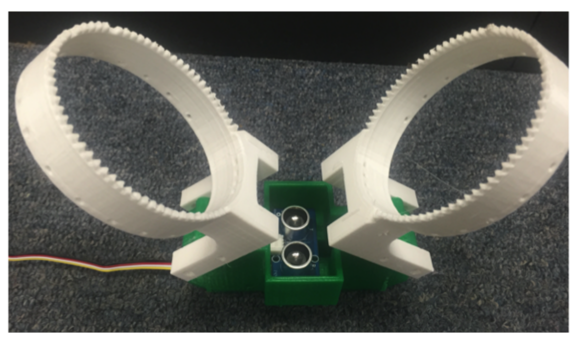

Figure 5: Ultrasonic sensor placed inside the end effector housing

2.3 Control and Communication

2.3.1 Control System

The control scheme for Koko can be broken down into two main components, arm control and driving control. For the rover, the team is writing all of the control software with C++ implemented in the Robot Operating System (ROS). Using ROS to build all of the software provides the distinct advantage of easy communication between the ground station and the rover. With a Cradlepoint router and a static IP address provided by the T-Mobile network, team members are able to log onto and interact with the rover from any location. ROS has built in networking capability that automatically coordinates nodes and messages between machines as long as they connect to each other.

To control the robotic arm the team primarily uses a joint-by-joint control scheme. Using an Xbox controller the user can select which of the primary arm joints or end effector they want to control. Then by tilting the joystick on the controller, the user can actuate the necessary joints. When controlling the arm joints, the end effector cannot be opened or closed. This prevents the operator from accidentally dropping any payloads out of the end effector if they accidentally press an incorrect button during operation. The team also worked on developing and implementing a control mode based around the kinematic equations that govern the arm. This allows the user to control all three arm joints simultaneously. In addition, the ground station graphical user interface (GUI) will include options to automatically control certain arm movements, such as deploying and depositing payloads.

The driving control of the rover is somewhat simpler in design. Again, it makes use of an Xbox control to provide the user inputs. The rover utilizes a skid steer design in which each side of the rover is controlled independently. This allows the rover to fully rotate without any lateral movement, as well as allowing for forward and reverse functionality. Each side of the rover is controlled by one of the joysticks on the Xbox controller that provides intuitive control for anyone familiar with the controller design.

2.3.2 Communication System

Koko's communications system was designed to be very similar to its predecessor, Frigg, due to the success of Frigg's communication system. A Cradlepoint IBR600 modem allows Koko to communicate over the T-Mobile LTE wireless wide-area network. Internally, the computer communicates with all of the subsystems so that the rover can complete the required tasks. Connection to the motor controllers is made through a USB-to-CAN adapter while the following components are connected via USB: Logitech webcams, Phidget Inertia Measurement Unit (IMU), U-blox GPS, and the Arduino Mega microcontroller that controls the servos and linear actuators to drive the manipulator. Finally, the main mast camera is connected over an Ethernet cable. The overall power and communications system block diagram is shown in the Appendix.

2.3.3 Video and Audio Compression

Audio and video are streamed from the rover using the H.264 codec.

2.3.4 Latency Information

The primary driving camera is expected to have less than one second of latency, which is essential to operator performance. Secondary cameras experience between 1 to 2 seconds of latency, which is somewhat higher than last year. Reasons for the increase include primarily new software for streaming video namely the VLC media player in place of the GStreamer software utilized on the 2015 rover, Frigg. The decision to use VLC streamer software despite its larger latency revolves heavily on the reliability of VLC to begin the stream, an essential part of the competition. However, GStreamer software is still currently runnable on Koko and will be considered in place of VLC.

2.4 Power System

The electronics package on Koko is powered by a 12.8V, 19.8Ah Lithium Iron Phosphate (LiFeP04) battery which was chosen for its long lifetime, constant discharge voltage, relatively quick charging time, and its light weight. The battery line is fed into the main power relay which is triggered by the power switch mounted on the side of the rover. Power is distributed to the various components using a power distribution board (PDP) produced for FIRST robotics. For circuit protection, the PDP has 20, 30, and 40 amp circuit breakers attached to every power line and also allows for current monitoring over an existing CAN bus. Furthermore, an emergency stop switch is located on the side of the rover and cuts power to the drive and manipulator system relays when activated. The PDP powers the following systems: safety relays, drive system, M-ATX power supply, power-over-Ethernet (POE) injector, and a 5V USB hub. The M-ATX supplies power to the motherboard including a quad core Intel i5 processor. The POE injector powers the Point Grey main mast camera. Finally, the USB hub powers the Logitech webcams, the Arduino Mega, the U-blox GPS unit, and the servos for the arm and mast camera.

3 Technical Specifications

3.1 Arm Specifications

Category	**Value**
Degrees of Freedom	6
Shoulder Yaw	270°
Shoulder Pitch	86°
Elbow Pitch	182°
Wrist Yaw	47°
Wrist Pitch	47°
Wrist Roll	180°
Shoulder-Elbow Length	44.5 cm
Elbow-Wrist Length	17.8 cm
Wrist-Tip Length	23.5 cm
Total Length	85.7 cm
Vertical Reach (relative to horizontal shoulder plane)	-57.8 cm to 80.0 cm
Horizontal Reach (relative to vertical shoulder plane)	-3.8 cm to 79.4 cm
Rated Payload	1.5 kg

3.2 Manipulator Mass

Component	Mass
End Effector Design 1 (small teeth)	50 g
End Effector Design 2 (larger teeth)	52 g
Total Mass of Arm	1.3 kg

3.3 Electronics Mass

Component	Mass
Electronics in Chassis	5.50 kg
Electronics on Arm	0.42 kg
Electronics on Mast	0.60 kg
Electronics on Rocker (including motors)	5.28 kg
Est. 10% of total for wiring	1.18 kg
Electronics Total	12.98 kg

4 Testing Strategies

4.1 Motors

Figure 6: Testing of Motors and Wheels

As discussed previously, it proved to be quite the challenge trying to find wheel motors that surpassed last year's selection in terms of weight, current draw, and necessary supplied torque. Last year's R-18 motors were set up in a test environment within an oversized sandbox in order to ascertain the nominal current being drawn for each motor when executing certain maneuvers and navigating different terrains. For level drive at full speed, each motor from last year's rover drew about 13.93 amps, which is well within the required 25 amp maximum per motor. However, the supplied current tended to shoot up to around 23.51 amps when driving over midsized rocks with relatively steep faces to them. This value does not deviate from the measured stall amperage of around 24.03 amps. This recorded data was expected and even though these motors proved to be successful on a winning rover last year, such values were desired for comparison purposes to other candidate models.

For the motors of the drive system there were many choices that were considered, however, there was always a limiting factor that made specific motors unsuitable for the rover. Some examples of limiting cases include the fact that motors were out of the allotted price range, did not provide bidirectional drive capabilities, required too much of a current draw, and did not supply sufficient torque needed for competition. It was finally decided, after several weeks of research and testing, that the R18 motor which were used on Frigg were the best choice for Koko.

4.2 Manipulator

The manipulator arm required various tests because it was being built without much precedent. For the end effectors, functionality was tested by running simulations in a sand box. A new end effector design would be attached to Frigg's arm and rocks would be spread throughout the box. The end effector would then open and close around variously shaped rocks to see how well the end effector could capture and secure samples.

Loading tests were also conducted. Each plastic component was loaded to ensure the structural integrity of the piece during the competition. Damaging components or subsystems of the manipulator when bumping into obstacles was an area of concern, so collision testing took place to make sure the manipulator can withstand expected collisions during the competition.

4.3 Software

Software utilized on Koko required testing to ensure functionality. Tests were conducted to explore the feasibility of using ROS for rover to ground station communication, to determine the best software for the GUI, and to establish the most stable camera streams. The Software System Block Diagram, shown in Figure 7 illustrates the workflow approach we took when writing the software.

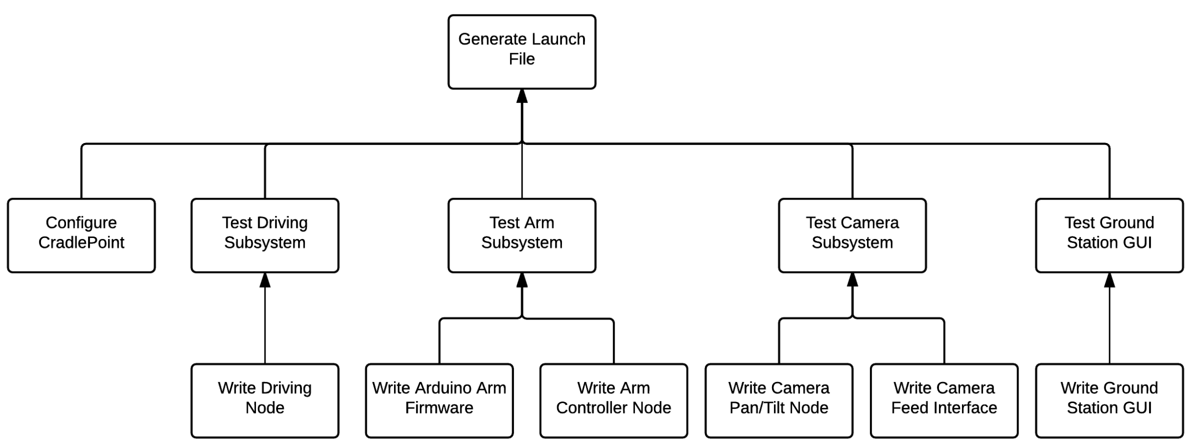

Figure 7: Software System Block Diagram

5 Overall Competition Strategy and Mission Control Plan

5.1 Staffing

Mission and competition day operations follows a similar setup to the 2015 Frigg team due in large part to the success of the team in addition to ease of operations. As the regular University of Maryland semester concludes in advance of competition day, only a portion of the original team will remain on campus (or in the vicinity) and be able to participate in the competition itself. Two different teams will be assembled; an away team and a home team.

The away team currently consists of three students and one faculty member. This includes one student from each of the sub-disciplines designated at the beginning of the current semester namely software, electronics, and mechanisms. Each away team member is well versed in their particular discipline as it relates to the rover and will ensure the rover is functioning properly post arrival at the NASA Johnson Space Center. Should any repairs or alterations be required, the away team will take responsibility and alter or adjust the rover at their own discretion. Additionally, the away team will prepare themselves for the presentation of the rover and, as such, will be familiar with the important technical aspects (including total mass, maximum operation time, etc.) for concise and eloquent deliberation.

The home team consists of at least five team members in addition to a part of the Space System Laboratory's staff whom currently double as advisors. The home team will include members well practiced in driving the rover over various terrains and obstacles, adjusting cameras to angles valuable for operations, and manipulating the arm and end effector for collection purposes (in addition to the mystery challenge requiring six degrees of freedom). The current scenario features one team member for each of the aforementioned tasks: driving, cameras, and arm control, though it is worth mentioning that this plan is tentative and subject to change should an alternative scheme prove more effective. While the entire home team will assist in watching the live camera feeds of other teams along with constructing a map with which to plot the team's particular trajectories, those members not physically interfacing with the rover during the competition will monitor camera feeds for items of interest. Additionally, one team member will be designated the esteemed title of Captain, and be responsible for time management and in-action decisions.

5.2 Practicing

As the rover itself is complex to operate, practice is key for competition day success. Identifiable points requiring practice include GUI interfacing (namely debugging), driving (over various terrains), camera control, and manipulator control, in addition to replicating competition day scenarios.

Methods to practice working with the GUI are minimal as the GUI itself is designed to be self-explanatory. However, should a function of the GUI malfunction during the competition, it is vital for team members to be familiar with its different components and exploit methods to resolve predictable issues. Currently these include failure to launch camera streams and failure to connect with the rover itself; foreseeable problems may also involve autonomous tasks that the GUI may define later (such as returning a sample to the basket after collected by the end-effector). Solutions to these problems will be defined in greater detail once practicing begins.

Driving and camera control practice will be conducted by the team members designated to these positions for competition day. Practice will revolve mainly around operating the rover in the Space System Laboratory's rock-bed though may later include locations at greater distances from the control station for tele-operation and latency testing. Various obstacles will be introduced into the path of the rover to determine the maximum obstacle size and best methods to avoid or maneuver around said obstacles. Slopes of differing degrees of inclines will also be climbed and descended in order to determine the maximal degree for each direction.

Arm control practice will be similarly conducted by the individual responsible for operating the arm during the competition. Practice will include collecting objects of various sizes and shapes in addition to removing hazards such as rock debris. Furthermore, the manipulator will be tested in its ability to perform a six-degree of freedom task by performing various tests including, but not limited to, removing and inserting a screw from a socket.

Finally, a competition day scenario will be simulated in which the entire home team will participate in a practice run. This will include various objectives to be accomplished including collecting objects, removing hazards, climbing inclines, driving to particular locations, and the previously discussed six degree of freedom manipulator test. The home team will practice in competition day arrangement, namely one team member will drive the rover, one will operate the cameras, one will control the arm, one will act as captain, and the remainder will monitor camera streams for points of interest. The culmination of the varying practice strategies will ensure a higher rate of success during the competition.

5.3 Decision Making Strategy

Competent competition time decision making has proven to be a key component of successful contention. Current strategies include assigning one home team member the position of Captain, whom will dictate all high level and final decisions during the competition. The Captain will be held responsible for monitoring the time, as previously discussed, and ensuring point allocation during the run is maximized. The Captain will be supported by the remaining home team members, who will advise and offer real-time inputs based off information they receive from the live camera streams. As stated, all final decisions will be deliberated by the Captain to the members of the home team responsible for interfacing with and operating the rover itself.

5.4 Plan for Contingencies

Rover components are often found to be sensitive and prone to malfunction, as such a number of redundancies and contingencies have been implemented to ensure success. Strategies for combating system failures are divided into two distinct categories; redundancy for real-time operations and contingency for system failures during transportation and practice.

A number of different components on board are designed with redundancies including the drive, power, and software systems. The rover features four individual drive motors, one mounted on each wheel. Should one motor fail (on either side) the rover will still be operational (albeit becoming less responsive) and will still be able to turn, steer, and drive to a particular location. Koko also features a battery capable of holding 253.44 W-hr of energy, allowing for an operation duration of 63.36 minutes. Should the battery experience large power draws, the excess energy will provide the power needed to ensure continuous operations. The rover features multiple software solutions for items including camera streaming and arm control. Should one software solution encounter bugs during the competition, a secondary solution will be easily implementable through the GUI.

Multiple components on Koko have incorporated spare parts in case of failures including but not limited to the 3D printed joints, linear actuators, cameras, and computer. 3D printed parts are fragile in nature and prone to damage during practice, testing, and perhaps even transportation. As such each 3D printed part has had a duplicate (and in some cases more) constructed should replacement be required. Similarly, spare linear-actuators (and other related equipment) have been ordered should the ones currently on board Koko fail at any time. Furthermore, extra cameras and a second hard-drive have been purchased in the case that these components fail. As discussed previously, the away team will be familiar with all of the sensitive components of Koko, and will be readily able to replace parts should they become damaged before the competition.

6 Budget

A basic estimation for the 2016 Maryland RoboOps budget is shown in the table below. One major difference between this year and last year's rover is that parts could not be scavenged from Frigg due to the stipulation that Frigg had to be in working condition for another competition in which it was competing. This meant that an entirely new rover along with parts had to be purchased for this year's competition. Many of the parts and methods were chosen to be able to drastically reduce the cost such as a cheaper yet effective structure design along with not upgrading parts unnecessarily. The overall methodology was that if it worked on last year's rover and could be accomplished using the same amount or less money, then it would be implemented.

Category	**Estimated Expenses (USD)**
Arm System	\$873.54
Chassis System	\$631.63
Electronics System	\$3697.12
Travel Expenses	\$5,000.00
Total Expenditure	\$10,202.29

7 Public/Stakeholder Engagement

Since one of NASA's objectives in this competition is to engage as many people as possible in space exploration missions, a social media page has been used for public outreach. The social media platform used is Facebook, since it is the most popular free social networking website that allows to easily create pages and upload photos and videos. Since last February, the team has been working on the Facebook Maryland RoboOps page by posting different pictures and videos, and sharing the process of building the rover. There have been weekly features of the different members of the team with the aim of showing the diversity of the profiles involved in the design and construction of a rover. There are a variety of posts ranging from the explanation of the name "Kokopelli" to the display of the brand new 3D printer working on Koko's pieces. Also, some other Facebook pages related to the University of Maryland such as the "A. James Clark School of Engineering" Facebook page have liked and shared posts relating to Koko in order to reach a bigger audience.

On April 2nd, The Women in Aeronautics and Astronautics (WIAA) group hosted "WIAA Day" here at UMD, which is a recruiting event for high school juniors and seniors interested in studying aerospace engineering in college. Both students and parents came to the Space Systems Laboratory for tours and were able to see the rover and the workspace.

On April 21st the University of Maryland celebrated Maryland Day, and the RoboOps team worked hard in order to bring and share the team's experiences with students, alumni and parents here at the University of Maryland. Everyone was able to drive and test the rover. Specifically, children attending the event had so much fun running over team members with the rover! There are plenty of pictures and videos available also at the Facebook page.

Appendix

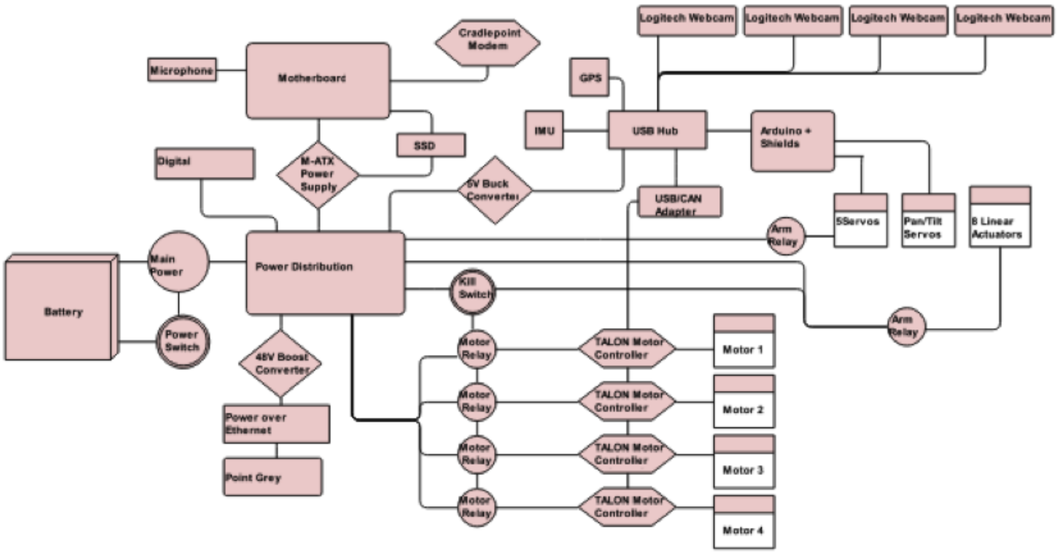

Figure 8: Electronics System Block Diagram

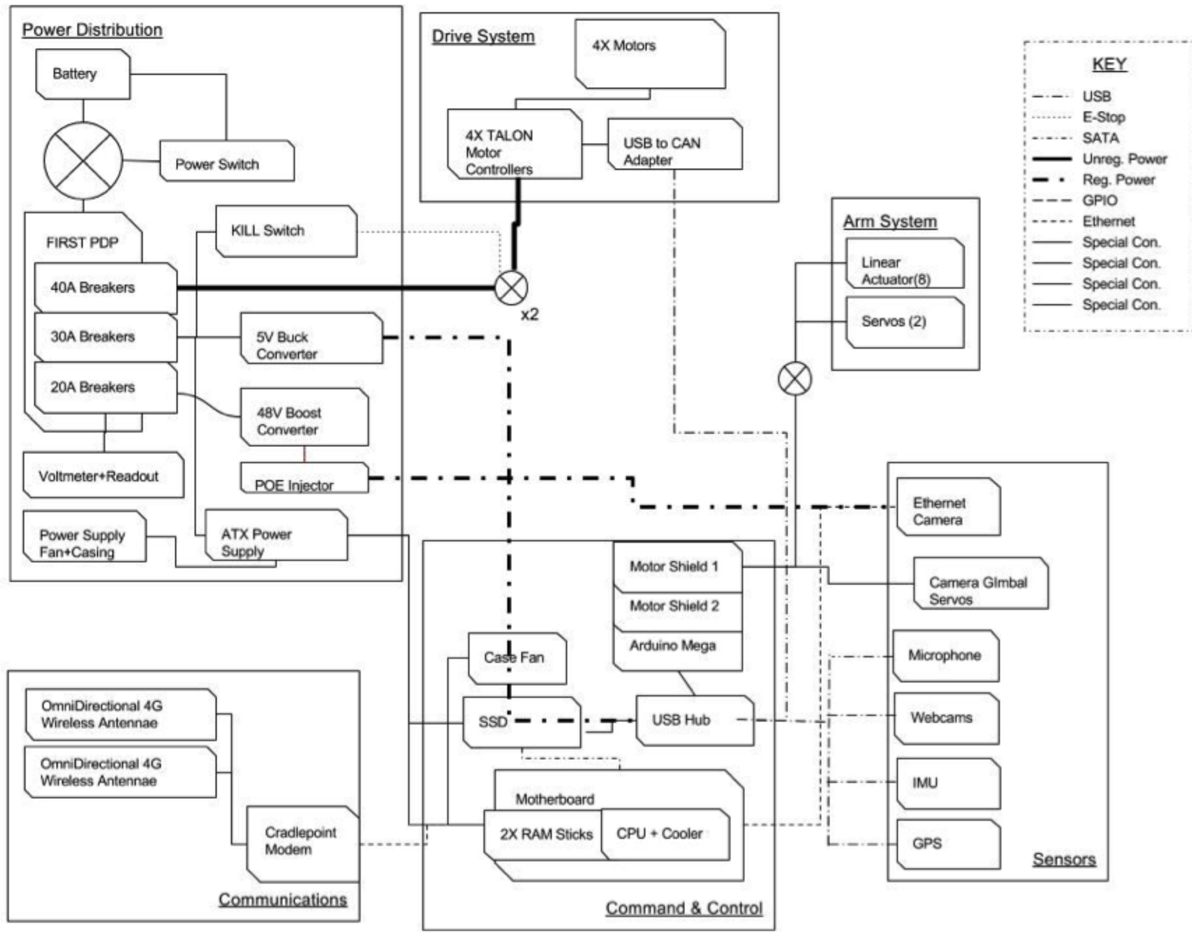

Figure 9: Power and Connections Diagram

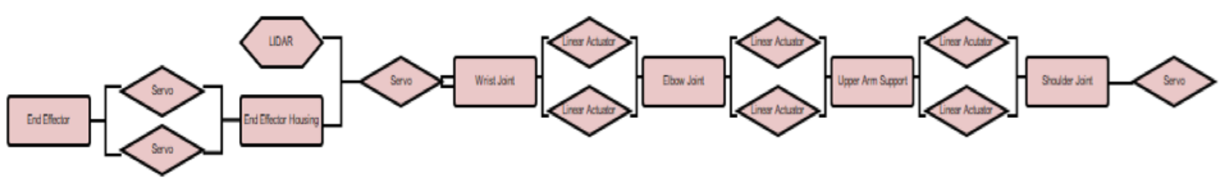

Figure 10: Arm System Diagram

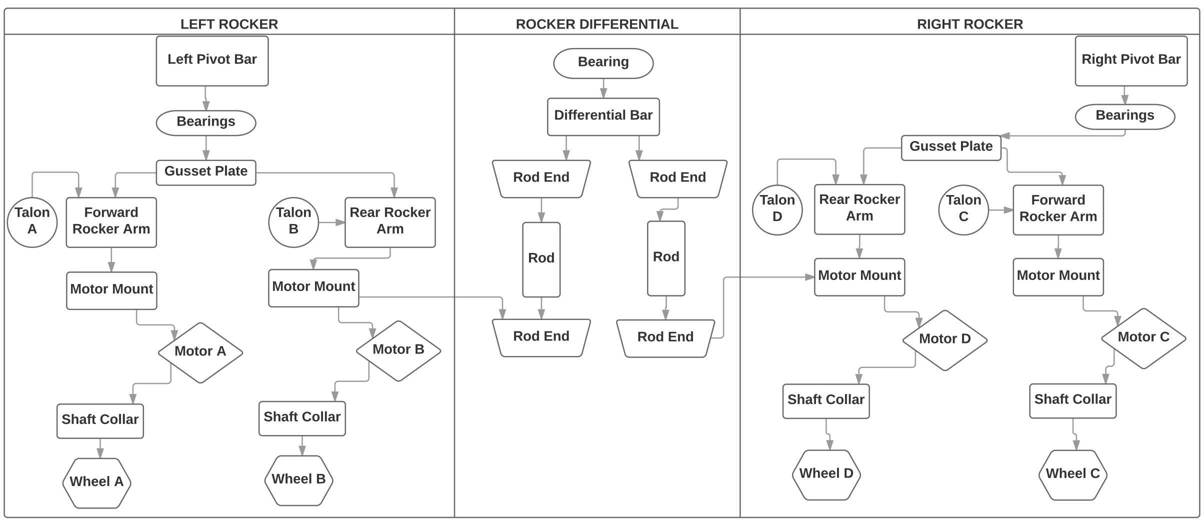

Figure 11: Chassis Diagram