System Acceptance Review

RoboJackets

POC: Priyanka Rajan [priyanka.rajan@robojackets.org]

1. Core Rover Systems

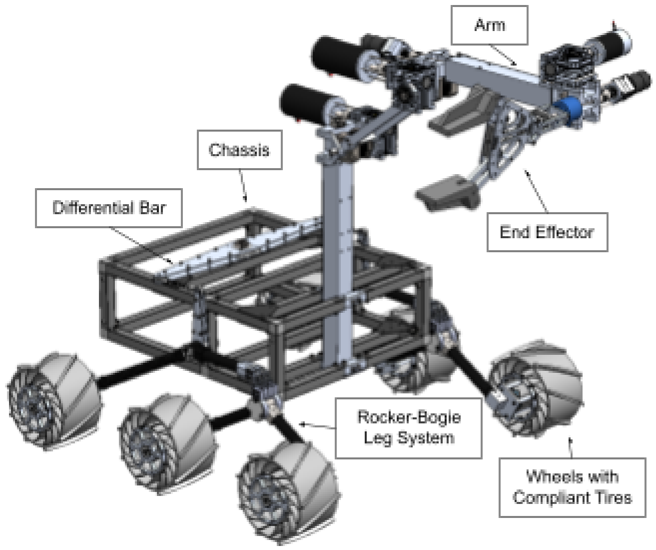


Figure 1: Rover Overview

The rover (WALL-I) is a full rocker-bogie suspension vehicle equipped with a lightweight, robust drivetrain, a high-precision manipulation system, and compact electronic and science module packages for easily interchangeable subsystems.

1.1 Mobility

WALL-I maintains extreme terrain traversal capabilities by prioritizing ground contact. The 6-wheel system features passive joints and an aluminum differential bar, creating high chassis stability by maintaining ground contact points and taking advantage of the differential system, which is designed to handle the anticipated dynamic loads applied during rough rover movement. The carbon fiber legs provide strength properties at very light weights to help maintain the 50 kg mass budget while still having the robustness to support rough terrain traversal. Major interface joints that require larger load capabilities such as the wheels include custom aluminum parts, but where possible carbon-fiber printed joints were substituted as the lightweight solution. The wheels effectively act as the suspension for this drivetrain by having a delicately measured allowed compliance. This is achieved by having multiple phases, a rigid core consisting of an aluminum frame and PLA coverings, surrounded by a compliant tire designed to compress a small amount under the maximum load to increase contact with the ground. Additionally, the 25 cm diameter wheel allows traversal over rocks up to 37.5 cm in diameter. This is paired with slanted grousers capable of both high-friction gripping on steep terrain and sand displacement on less dramatic terrain to prevent wheel slippage[1].

The chassis is made completely out of carbon fiber and is built to be adaptable and modular to support the various competition needs while still maintaining lightweight properties. Corner joints were printed out of carbon-fiber-infused filament, while the larger segments were made from braided carbon fiber square tubing. The joints are reinforced with epoxied aluminum inserts and drilled with bolts to

---

[1] Kenji Nagaoka, Kazumasa Sawada, Kazuya Yoshida, Shape effects of wheel grousers on traction performance on sandy terrain, Journal of Terramechanics, Volume 90, 2020, Pages 23-30, ISSN 0022-4898, https://doi.org/10.1016/j.jterra.2019.08.001

allow simple assembly and access if necessary. The joints that experience larger loads, such as the differential bar pivot, leg pivots, and arm mounting include more robust aluminum reinforcement and epoxied carbon fiber gussets. The electronics module is contained in a well-sealed HDPE box on the back portion of the chassis. This facilitates easy access to the module for manipulations and various mounting options for the removable modules associated with manipulation and science packages. The front region of the chassis is left open with mounting options for either the manipulator or the science package, with quick mounting for each to be done in between missions. This allows for a more comfortable weight tolerance and sizing of these payloads.

1.2 Manipulation

The manipulation package consists of a serial-kinematic robotic arm with 6 degrees of freedom (6DOF) and two quickly-interchangeable grippers. The arm actuates using three hinge joints and three swivel joints, with one of each between each pair of arm segments. The strong, mass-optimized aluminum design enables the end effector to lift up to a 5 kg payload at a distance of 1.25m from its base. A combination of incremental encoders and limit switches maintains high positional accuracy. The first end-effector configuration, designed primarily for the extreme retrieval mission, features strong milled aluminum construction with a large jaw width to accommodate larger, heavier payloads such as rocks. The second gripper sports smaller jaws as well as an Allen key attachment to accommodate the more delicate manipulation and more precise point contacts required in the equipment servicing mission.

The arm backend uses Moveit2 for control and inverse kinematics. Moveit2 offers robust control functionality out of the box. It also enables easy arm model generation that can be ported into the Gazebo testing environment for simulation testing. Using this system, the arm functionality can be efficiently tested virtually before mechanical and electrical setups are even complete, facilitating a continuous testing pipeline that promotes early error detection.

1.3 Command and Control

The rover is powered by a 7S LiPo battery, chosen for its high gravimetric energy density and high continuous discharge current. A Battery Management System (BMS) monitors its state of charge and prevents over-discharge. The brain of the rover is an Intel NUC minicomputer. It communicates with its cameras and GPS over USB. A Teensy 4.1 is used to control the status light and motor controllers. The NUC communicates with the Teensy 4.1 and its Ubiquiti M2 radio over Ethernet.

The rover runs a rosbridge WebSocket to provide low-latency communication and visualization over long distances. Using Foxglove Studio with this allows us to simultaneously view all cameras, ROS messages, and a simulation environment created from sensor data. A custom web interface is the rover's main control hub. It features a GUI map that takes a detailed GPS topographical map PDF of the environment alongside WebViewer from PDFTron to visualize the rover and the end destination in real-time. The web interface can simultaneously take in the rover and arm controller inputs, which are fed to the software stack as roslibjs messages over the rosbridge WebSocket.

1.4 Communications

A pair of Ubiquiti Bullet M2 radios with 9dBi antennae serve as the wireless bridge between WALL-I and the ground control station. The Bullet M2 radio operates in the 2.4 GHz band. The 2.4 GHz wireless band allows for megabit data rates given line-of-sight between the radios while offering decent obstacle penetration capabilities. Through the Bullet M2's web interface, the rover operator can shift the center frequency of the wireless bridge.

2 Approach to Competition Missions

2.1 Extreme Delivery

To combat the several terrain changes as mentioned in 1.c.ii of the competition guidelines, WALL-I's rocker-bogie suspension and differential bar systems allow for traversal over severe terrain deformations while maintaining central chassis stability. Compliant tires further provide sufficient traction for different soil types as well as additional suspension for smaller deformations like pebbles. The tires are also made from flexible resin from Formlabs and feature a two-spoke design that allows for compliance when driving both forward and backward. Grousers on the wheels at a 30-degree angle from the horizontal further improve terrain traversal by compacting and pushing sand away to prevent buildup. The grousers also mitigate drifting when moving on an inclined sandy path.

WALL-I's robust primary manipulator can lift a wide range of objects including the hand tools, rocks, and other graspable features listed in 1.c.iii. The light-strong construction and 6DOF arrangement easily meet the mission requirements of payload weight and positioning.

WALL-I is designed for operator convenience and ease of use. The rover operator views WALL-I's surroundings through several cameras mounted to the chassis as well as a camera mounted on the end effector. By routing the camera's cable through a slip ring, the end effector can rotate 360 degrees continuously while providing vision of what the end effector is gripping. Navigation is facilitated using an R330 Hemisphere GPS receiver and an A21 Hemisphere antenna to navigate to GNSS coordinates for mission objectives.

2.2 Equipment Servicing

The base of WALL-I's 6DOF arm mounts to the chassis such that the end effector can reach from the ground up to 1.6 meters high while remaining parallel to the ground. The smaller jaw size allows the precise secondary manipulator to grasp smaller-scale objects such as small containers, handles, and switches. The included coaxial Allen key enables WALL-I to secure the captive screw on the drawer in 1.d.i as well as type on a keyboard one key at a time. The incremental encoders that monitor each swivel and hinge joint of the arm help the operator account for backlash in the system, creating positional certainty, and to maintain a more accurate understanding of the arm's usable workspace, aiding with manual control.

2.3 Autonomous Navigation

The autonomous navigation mission will be completed using a VOXL m500 drone. A drone is better suited for autonomous navigation compared to a rover because it can more consistently navigate the more difficult terrain of the later checkpoints described in the autonomous navigation mission. The VOXL m500's onboard flight controller runs PX4 Autopilot for basic GPS point navigation, GPS point landing protocols, and wind control algorithms. The drone's onboard computer runs ROS2 Humble for more computationally complex tasks such as ARUCO tag detection and checkpoint end behavior decision-making. The PX4 Autopilot and the drone's onboard computer communicate over UART using XRCE-DDS middleware. The VOXL m500 communicates with the ground control station through the Ubiquiti Bullet M2 radio using its long-range WiFi antenna. The onboard computer runs a rosbridge server, which the ground control station uses to send the drone directives and receive telemetry data.

The host machine uses the same web interface used for the rover, enabling the drone operator to set valid landing locations for the drone on the aforementioned GPS topographical map in between checkpoints. This ensures safe landings without introducing the complex and error-prone task of drone-side optimal landing decisions.

3 Testing and Operations

Mechanical testing began with material property verification and deflection confirmations. For the wheel, it was especially important to recognize the maximum potential loads, both including the 50 kg weight of the rover as well as any additional payloads. Then, a controlled force was applied to sample wheel segments of different materials and thicknesses, each of which was recorded into a matrix for deflection and plastic deformation effects. This allowed for a decisive conclusion on the best wheel material before large-scale printing and testing based on this desired deflection. The carbon fiber segments along the legs and chassis have thin walls, so stress testing with the maximum possible dynamic case loading was conducted on each type of segment (round and square). The joint testing was approached in the same way, with 3D printed parts undergoing worst-case load angle application tests to determine proper printing orientations as well as the various system bearings and weld points. This was vital for the main differential pivot, which has some of the highest dynamic loads of the system.

Electrical testing has been conducted incrementally using subsystem prototypes. Prototypes were constructed for the actuators, status light, power distribution system, and computer setup before such systems were mechanically ready to be fit onto the rover.

Ensuring software correctness and adhering to best DevOps practice has been a key aspect of the team's design philosophy. All code is source-controlled and open source on GitHub, with predefined issue and pull request templates to make tracking errors and filing requests to merge straightforward. A CI pipeline with GitHub Actions further checks whether the code builds and adheres to style conventions, utilizing a container and providing descriptive error messages on failure. The team also uses Ignition Gazebo as a physics testing sandbox to verify the rover and drone sensors, controls, and performance prior to live testing, in addition to standard unit tests.

Future testing will involve more live hardware testing. Mock components such as arm and science module replicas will make software testing more robust. Full drone and rover tests run under competition conditions will further help verify that the complete and integrated system works when placed under the stressors of the actual competition missions. Local environments will be used to test grip on loose finer soil, especially the potential slippage from the grouser design. Once basic motion control on this terrain is achieved, the team will continue to test in more intense rocky environments, gathering data on WALL-I's maximum traversable rock diameter and most dramatic ascendable slope angles. Manipulation testing will involve measuring and calibrating for accumulated backlash sensor inaccuracy. Manipulator jaw width capabilities will also be tested, and later more organized manipulation testbeds will be created and utilized. These testbeds will mimic competition tasks as accurately as possible and will create realistic test dimensions for the entire manipulation system.

4. Team Budget and Gantt Chart

Project Costs 2022-2023

PROJECT COMPONENT	PROJECTED COST	ACTUAL COST	NET DIFFERENCE
Chassis	$1,600.00	$1,136.45	$463.55
Arm	$1,250.00	$1,079.18	$170.82
Legs	$650.00	$609.54	$40.46
Wheels	$2,100.00	$2,073.85	$26.15
Differential Bar	$100.00	$91.39	$8.61
Science Package	$2,000.00	$2,321.04	-$321.04
End Effector	$300.00	$278.60	$21.40
Drone	$4,000.00	$4,029.17	-$29.17
Electrical	$9,000.00	$8,920.93	$79.07
TOTAL	$21,000.00	$20,540.15	$459.85

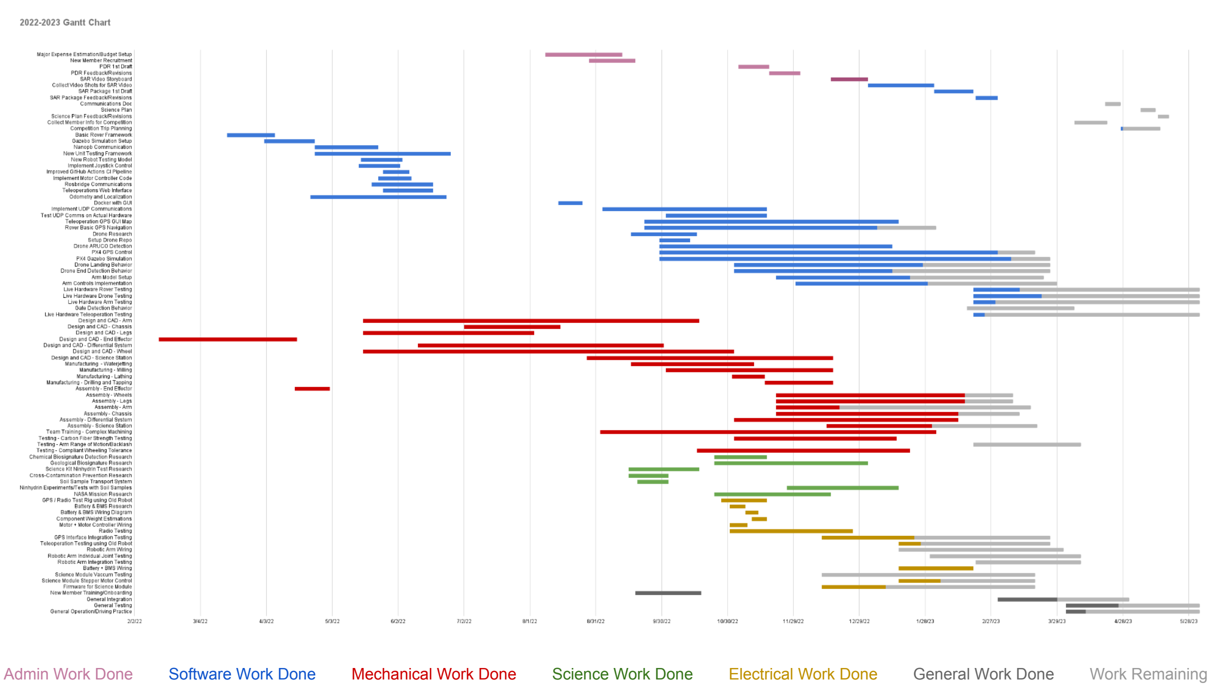
Team Budget 2022-2023

INCOME	
INCOME CATEGORIES	TOTAL TO DATE
SGA Budget	$3,640.16
SGA Bills	$16,000.00
Sponsor Donations	$6,575.45
Member Dues	$4,450.00
Carryover RJ Funds	$15,000.00
TOTAL	$45,665.61

EXPENSES			
EXPENSE CATEGORIES	ANTICIPATED EXPENSES	SPENDING TO DATE	FUNDS NEEDED
Rover/Drone Development	$21,000	$20,540.15	$460
Maintenance	$250	$0.00	$250
Travel/Lodging	$11,000	$0.00	$11,000
TOTALS	$32,250	$20,540.15	$11,710

REMAINING FUNDS	$25,125.46

2022-2023 Gantt Chart



5. Science Plan

The science package feeds a sample through a nozzle and tube using compressed air and deposits it into a beaker preloaded with a ninhydrin test. There are three beakers (one for each test site) as well as a fourth regolith container that is sealed for later inspection. These beakers are mounted onto an actuated turnstile using a NEMA17 motor that allows for the regolith to be deposited into its respective container. The module's nozzle and tubes will be sterilized to reduce their bioburden and likelihood of contaminating the science area, following NASA's technical standard for planetary protection for category IVb missions[2].

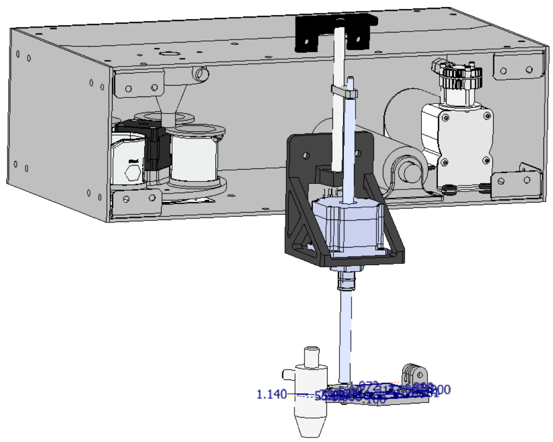


Figure 2: Science Package

Ninhydrin was chosen as the reagent due to its reactive properties when in the presence of secondary and primary amines, ammonia, and most importantly, peptides. When in the presence of an amino acid, the ninhydrin molecule and amino acid will undergo a redox reaction with ninhydrin acting as the oxidizing agent and the amino acid acting as the reducing agent. The initial reaction between ninhydrin and an amino acid will give rise to carbon dioxide, ammonia, an aldehyde and hydrindantin, which is formed via the reduction of ninhydrin. The ammonia gas produced in the reaction will react with another ninhydrin molecule and a hydrindantin molecule to form di-ketohydrin. The newly formed di-ketohydrin will form a complex that ultimately gives rise to a purple color in the solution, referred to in literature as Ruhemann's purple, and is a marker for the presence of amino acids.

The ninhydrin beakers will be monitored by a GoPro HERO11 black, allowing the operator to see if the ninhydrin solution plus the regolith produces a purple color in the beaker. To conduct a visual analysis of the science site, a camera appendage has been added onto the science module. The camera will allow for close inspection of the science area from mission control. The camera will search for biosignatures of extinct and extant life, such as bioclastic rocks, biofilms, banded iron formations, and/or fossils.

---

[2] Kenji Nagaoka, Kazumasa Sawada, Kazuya Yoshida, Shape effects of wheel grousers on traction performance on sandy terrain, Journal of Terramechanics, Volume 90, 2020, Pages 23-30, ISSN 0022-4898, https://doi.org/10.1016/j.jterra.2019.08.001