System Acceptance Review

RoboJackets
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1 Team Overview

The RoboJackets (RJ) RoboNav (RN) team consists of approximately 60 students belonging to a wide variety of majors including mechanical engineering, aerospace engineering, electrical/computer engineering, computer science, biology, and chemistry. The team is split into 5 major sub-teams: Mechanical, Electrical, Software, Science, and Drone.

This year, new members have been onboarded through the returning Mini Rover Challenge (MRC), an introductory program offering incoming students mechanical design, manufacturing, electronics, and controls experience. Teams of around 10 members build a miniature rover over one semester, preparing for internal competitions while attending technical lectures and workshops hosted by experienced team members. This creates an engaging training program for all experience levels, allowing members to learn and apply the engineering design process from ideation to iteration. Upon completion of the program, they are integrated into their respective sub-teams and subsystems.

Community outreach is conducted through RJ. Every year RJ hosts a FIRST Robotics Competition Kickoff, which draws hundreds of local high school students[1]. In addition, RN members volunteer at local robotics competitions throughout the year. RN members also regularly conduct tours of the RJ workshop for prospective students and grade-school robotics groups.

2 Core Rover and Drone Systems

The rover (WALL-II) is a four-wheel rocker suspension vehicle equipped with a lightweight, modular carbon-fiber chassis with easily interchangeable subsystems: a high-precision manipulation system, a compact coarse manipulator, a high-power science package, and an autonomous package.

2.1 Mobility

WALL-II replaces the previous 6-wheel rocker-bogie drivetrain with a redesigned 4-wheel rocker suspension system. The update primarily serves to reduce the weight budget of the rover wheels and allow for a stronger chassis-leg connection, which presented several issues in last year's design. The chassis-leg joint support plates have been topologically optimized to maintain rigidity while minimizing material and weight. The differential bar positioning has also been updated from a top mount to a rear mount to increase maintenance access to the rover electrical enclosure without sacrificing maneuverability. While the design of WALL-II’s custom urethane tires has not changed, the wheel-to-leg mounts have been improved to increase rigidity and ease of assembly. With this configuration, the suspension system offers over 16 inches of independent vertical leg displacement, allowing Wall-II to easily traverse uneven terrain and climb large boulders.

WALL-II's mobility is further enhanced by the modular design of the electrical subsystems. The main electrical module is housed in a protective polycarbonate and acrylic enclosure at the rear of the chassis, ensuring both durability and easy access for maintenance. The front section of the chassis offers flexible mounting options for additional modules, allowing for quick swapping between the manipulator and the science packages depending on mission requirements. Additionally, weatherproof aviation connectors provide secure, detachable links between these modules and the main electronics bay, ensuring reliability in various operating conditions.

2.2 Manipulation

This year, the architecture of WALL-II’s 5 degree of freedom arm has been fully redeveloped. The previous design had heavy aluminum segments connected with blocky actuated joints. Segments are now carbon fiber tubes, which provide greater stiffness with less weight. Actuation is accomplished with belt-driven links, reducing the moments from bulky gearboxes and motors acting on each joint. A major

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[1] https://robojackets.org/first-kickoff/

architectural modification is the development of a belt-driven differential wrist, which combines the arm's last two degrees of freedom into one lightweight joint.

The end of the arm can be equipped with two new gripper configurations: the fine and coarse end effectors. The fine end effector is a leadscrew-driven linear gripper with an independent, linearly-actuated finger that can extend to push buttons and type on a keyboard. In this configuration, fine control after the wrist joint removes the need for bulk movement of the other arm joints during dexterous manipulation tasks. The new coarse end effector design replaces last year's bulky linkage design with a compact worm drive gripper. This unique gripper features opposable underactuated fingers, allowing WALL-II to grasp irregular objects of up to 5 kg instead of simply clamping them[2].

Another new addition is the custom, two-stage cycloidal gearbox designed for WALL-II's shoulder joint. This unique design offers a 180:1 gear reduction not by chaining single-stage, dynamically-balanced reducers in series, but by transferring torque between dissimilar cycloids using an intermediate carrier disc[3]. Manufactured using a combination of wire EDM, CNC milling, and manual machining, the design offers high-precision motion with minimal backlash. As the experimental gearbox is a high-risk component, we are continuing to conduct load testing on the fully assembled system. Once its behavior is fully qualified, the gearbox will be integrated into the base of WALL-II's arm.

The arm software interface consists of a custom ROS2 package for control and inverse kinematics. This package offers robust control functionality enabling arm model generation that can be ported into the Gazebo testing environment. Using this system, the arm functionality can be tested virtually prior to mechanical and electrical systems completion, facilitating a continuous testing pipeline that promotes early error detection.

2.3 Command and Control

Significant upgrades have been made to WALL-II’s control system to improve reliability and efficiency. The previous control protoboards have been entirely replaced with custom-designed PCBs, ensuring stable performance across various environments. The Teensy 4.1 microcontrollers on the PCBs receive data packs from the Jetson Orin Nano computer via Ethernet and subsequently send commands to motor controllers and other peripherals for execution. The four SoloUno motor controllers for the drivetrain motors now feature an improved hardware interface and are housed in 3D-printed enclosures, enabling them to function as independent modules with hot-swapping capabilities for enhanced accessibility and maintenance. The revised layout of the electrical subsystems further enhances accessibility, including easier access to the network switch that extends Ethernet ports from the Jetson for communication. Power and data lines are separately routed to prevent signal interference and ensure efficient data transmission. Additionally, to maintain battery health, a battery management system monitors its state of charge and prevents over-discharge.

All motor controllers now support PID feedback control, enabling precise position and velocity regulation using relative encoders. To further enhance position control accuracy, the arm motors have been equipped with new magnetic absolute encoders. These encoders are fully compatible with the Roboclaw motor controllers, significantly improving closed-loop control performance. The hardware and firmware tools are designed for rapid device debugging, including a CAN transceiver that simultaneously calibrates all motor controllers on the data line.

For the base station, a pair of Ubiquiti Bullet M2 radios with 9dBi antennas form the wireless bridge between WALL-II and the ground control station, operating in the 2.4 GHz band. The Bullet’s web

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[2] Y. Tlegenov, K. Telegenov and A. Shintemirov, "An open-source 3D printed underactuated robotic gripper," 2014 IEEE/ASME 10th International Conference on Mechatronic and Embedded Systems and Applications (MESA), Senigallia, Italy, 2014, pp. 1-6. https://doi.org/10.1109/MESA.2014.6935605.

[3] Blagojevic, M., Marjanovic, N., Djordjevic, Z., Stojanovic, B., and Disic, A. (August 8, 2011). "A New Design of a Two-Stage Cycloidal Speed Reducer." ASME. J. Mech. Des. August 2011; 133(8): 085001. https://doi.org/10.1115/1.4004540.

interface allows the rover operator to adjust the center frequency, ensuring reliable communication with line-of-sight and obstacle penetration capabilities. The radio connects to the base station computer through an Ethernet cable. A GPS receiver is also mounted that publishes GPS correction data (RTCM) to the rover.

The rover hosts a ROSBridge web socket to connect the web interface to the ROS network. The improved web interface includes a real-time map (with rover, base station, and waypoint positions), an editable queue of waypoints, real-time ROS2 console output, rover and controller statuses, IMU and command velocity readouts, a software E-stop, and a toggle between autonomous and teleoperation modes.

3 Approach to Competition Missions

3.1 Delivery

With our first experience at URC, we determined that the weight savings and rigidity improvements offered by reducing the 6-wheel drivetrain to 4 wheels would be critical to our success in the Delivery mission. This year's arm redesigns also increases dexterity without negatively affecting the drivetrain's agility across rough terrain. For the Delivery mission, the arm will be configured with the coarse end effector, allowing WALL-II to manipulate irregularly shaped objects, like rocks and toolbox handles, of up to 5 kg.

WALL-II is designed for operator convenience and ease of use. The rover operator views WALL-II’s surroundings through a 360-degree view camera, an end effector-mounted camera, and a wide-angle camera mounted on the radio tower. Navigation is facilitated using a differential GNSS powered by two Ublox ZEDF9P GNSS receivers and Ublox ANN-MB02 antennas. WALL-II’s 7S LiPo battery has high energy density and provides high continuous discharge current, ensuring reliability throughout the course of the mission.

Using lessons from our experience at URC 2024, version 2 of our reconnaissance drone EVE was developed with communications integrity as our priority. EVE has 3 layers of communication: long-range telemetry operating at 900MHz via RFD900x radio modems, a 2.4GHz local network for transmitting large volume data (such as high-quality imaging and redundant telemetry), and a redundant 5.8GHz analog video system. Both the 5.8GHz and 2.4GHz systems have their range extended via the newest addition to the RoboNav team: AUTO (Autonomous Uplink via Tracking Operations). AUTO is a unique tower-mounted panel antenna that uses ground station and drone GPS data to determine and assume the optimal signal orientation. This operation allows us to take advantage of the antenna’s directionality and extend its range dramatically. Additionally, we’ve fitted the frame with a self-stabilizing and controllable gimbal, which will enhance our ability to conduct reconnaissance in the vast desert.

3.2 Equipment Servicing

For the Equipment Servicing mission, WALL-II's arm will be equipped with the fine end effector, which will allow it to pick up and move objects of a regular shape to a height of 1.5 m. This year's differential wrist allows for precise position and orientation control of the linearly-actuated finger, which serves as the primary mechanism for interacting with buttons, switches, and other lander elements. Since the finger is mounted on the moving jaw of the linear gripper, WALL-II can access large regions of the keyboard without having to move any arm joints before the end effector. In addition, the new absolute encoders that monitor each swivel and hinge joint of the arm help the operator account for backlash in the system, ensuring positional certainty.

3.3 Autonomous Navigation

The rover utilizes ROS2 to implement an improved autonomous algorithm on the new onboard NVIDIA Jetson computer. The algorithm consists of three pillars: localization, perception, and planning. For localization, we use two new Ublox ZEDF9P GPS modules–one on the rover and one on the base station for Real Time Kinematics (differential GNSS). This GPS data is fused with wheel encoder feedback and data from a new VectorNav VN-100 IMU using an Extended Kalman Filter (EKF) to provide up to 2.5 cm accuracy. For perception, an all-new Sick MultiScan100 LiDAR gives us ultra-dense and accurate point clouds compared to the Intel RealSense depth camera used last year. The LiDAR point clouds are run through our custom traversability mapping algorithm to generate a costmap using a weighted sum of roughness (calculated using covariances of points) and slope (calculated using gradients of points). This costmap is inflated using a Gaussian kernel for better obstacle avoidance. For planning, a custom implementation of A* generates a path from the robot's current location to the goal, and we adapt to the changing environment by replanning periodically. We also use ROS2 nodes to detect ArUco tags and transform the position of the tag into a high-precision GPS coordinate. A similar node runs a fine-tuned object detection model to detect and locate mallets and water bottles.

4 Testing and Operations

The rover drivetrain was validated by driving through various terrain expected at competition, including sandy environments, rocky terrain, and over large boulders and slopes. Velocity control PID values were finely tuned for optimal performance across a variety of scenarios. Further testing will be performed with the arm attached due to the extra loading on the drivetrain. Additionally, operator training on rough terrain, over long distances, and beyond line of sight will be conducted.

Testing of the 5-DOF arm was conducted by first ensuring that the rover arm could lift and move with various items up to 5 kg. Closed-loop control can then be implemented to ensure precise and accurate position holds for ease of arm command. Specifically for the equipment servicing mission, the operator practices their robot manipulation skills on various components mounted on a peg-board similar to those on the URC lander.

The electrical subsystem has been shown to operate reliably in harsh environments due to its robust protective enclosure. Additionally, the analog video cameras enable long-range video streaming while minimizing bandwidth consumption for radio communication, ensuring efficient data transmission. The radio has provided stable connection to the base station over long distances, and further testing will be conducted to determine its maximum effective operational range.

System-level testing of the science module has demonstrated full mechanical functionality of in-situ sample collection, but further validation will be conducted to ensure that scientific procedures can be carried out with minimal environmental contamination.

Every software feature was tested before it was merged into the main codebase by demonstrating expected behavior of all nodes both in simulation and on the rover's physical systems. We used tools such as the ROS2 CLI, Rviz, and Gazebo simulation extensively during software development to iterate quickly. A CI pipeline on GitHub automatically tests every feature with a static linter, build tests, and a code formatter to ensure the consistency and functionality of the main codebase at all times.

5 Team Budget and Gantt Chart

RoboJackets: URC SAR Budget 2024-2025

As of: Feb 2025

INCOME	
Actual Income to Date	
Student Government Bills	$4,682.84
RoboJackets Foundation	$1,235.48
Member Dues	$3,000
In-kind External Sponsor Donations	
DragonPlate	$353.23
MaxAmps	$766.80
VectorNav	$1,250.00
SICK	$4,827.00
ProtoCase	$2,196.18
Total Actual Income to Date	**$18,311.53**
Anticipated Income	
Student Government Bills	$1,317.16
GT College of Computing	$5,000.00
RoboJackets Foundation	$4,764.52
Member Dues	$3,200
In-kind External Sponsor Donations	
SoloUno	$554.16
Total Additional Income Anticipated	**$14,835.84**
TOTAL INCOME	**$33,147.37**
EXPENSES	
Project Expense Categories	
Rover/Drone Development	
Drivetrain	$1,289.45
Arm	$1,379.66
Cycloidal	$2,603.83
Electrical System	$9,502.40
Science	$1,311.99
Drone	$1,082.39
Maintenance & Spares	$3,000
URC Travel Expenses (Estimated)	$11,630
New Member Training	$319
TOTAL EXPENSES	**$32,118.26**
FORECAST FUNDING SURPLUS (DEFICIT)	**$1,029.11**

2024-2025 Gantt Chart

6 Science Plan

The team plans to collect 11 cm core samples from all four sample sites within the competition area. The sampling mechanism consists of a leadscrew-actuated hollow, cylindrical coring bit with a serrated cutting edge. This design enables swift and efficient entrance of the soil, followed by the core extraction. A side slot in the bit provides a clear view of the stratigraphic layers within the sample. In order to prevent cross-contamination, each bit features a passive rotation-lock mechanism at the top, allowing for easy swapping of the bits between sample sites. The rover's turnstile will be equipped with four of these bits.

Before any tests are run, a sterilization procedure must be performed on the beakers to ensure that no bacteria or microorganisms interfere with test results. Dry heat sterilization will be performed on the beakers for 6-12 minutes at 190°C (375°F) to kill microorganisms that are attached to fats and oils. The sterilization procedure will be run with a heat gun on the beakers. Meanwhile, the drill bits will be washed in a 70% ethanol bath due to material constraints.

The 11 cm long drill bits are used to obtain the sample from below 10 cm. After a soil core is drilled and extracted, the rover will photograph the stratigraphy of the core using a high-resolution camera through the cutout in the bit. This stratigraphy will display the geological history of the sample site, including patterns of sediment deposition and evidence of water flow through the area. The core will then be transferred to its corresponding beaker on the turnstile. There are four beakers within the turnstile–two prepared with ninhydrin in an acidic solution, and two containing DMSO solution for chlorophyll fluorescence. A color change within the solutions will be detected using an on-board camera which points towards the reaction beakers. The fourth sample will be cached in a removable, sealed container on the turnstile.

The ninhydrin life-detection reaction occurs through a multi-step mechanism. Ninhydrin first forms 1,2,3-indandione through tautomerization. 1,2,3-indandione then reacts with the dehydrogenated amino acid and a CO2 group leaves to form aldimine, which reacts with water twice under acidic conditions and loses a RCHO group to form 2-amino-1,3-indandione. This compound reacts with ninhydrin once again to form the Ruhemann's purple complex[4]. Chlorophyll fluorescence takes advantage of electron excitation to high-energy states via UV light. Upon returning to the ground state, electrons re-release this energy as a photon with a wavelength in 650-800 nm, causing red fluorescence.

The ninhydrin assay is applicable since alpha amino acids are a good indicator of life due to their primarily biological origins. They are not, however, perfect indicators, since they can be synthesized abiotically through Strecker Synthesis. Furthermore, beta amino acids, which have been detected on meteorites but are not indicators of life due to their optical inactivity, might lead to false positives in the ninhydrin test. Chlorophyll is another complex molecule that can only be produced by biotic processes. Additionally, biological surface crust in arid soils is known to contain a variety of chlorophyll-containing organisms. However, depending on the concentration of chlorophyll in the sample, weak fluorescence may make it difficult to detect positive results. Both chlorophyll fluorescence and ninhydrin require a dark enclosure to prevent degradation when exposed to UV radiation. The rover addresses these issues by protecting the beaker turnstile with an opaque enclosure.

Since neither test is a perfect indicator of life, observations of the surroundings must be taken for additional context about the sample. A DFRobot SEN0601 temperature and humidity probe will be used to take readings below the soil surface near the sample borehole area. A landscape camera will be used to capture panoramic views of the area surrounding the sample site. An additional high-resolution camera will capture magnified images of the soil surface at the core site. The rover will determine its spatial coordinates and elevation using the onboard GPS system.

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[4] Bottom, C. B.; Hanna, S. S.; Siehr, D. J. Mechanism of the Ninhydrin Reaction. *Biochemical Education* **1978**, *6* (1), 4–5. https://doi.org/10.1016/0307-4412(78)90153-x.