# System Acceptance Review
University Rover Challenge 2026

West Virginia University
Team Mountaineers

Team Lead: Logan Gold (lpg00001@mix.wvu.edu)
Faculty Advisor: Dr. Yu Gu (yu.gu@mail.wvu.edu)

Submitted on: February 27, 2026

## Introduction

Team Mountaineers from West Virginia University is made up of over 80 students from multiple engineering disciplines. The team is composed of seven technical subteams: Algorithms, Communications, Drivetrain, Electronics, Manipulation, Programming, and Science, as well as two non-technical subteams: Management and Green. Management focuses on team outreach, planning, procurement, and documentation, while the Green team focuses on training new members through introductory projects and research.

Following NASA's systems engineering approach, Team Mountaineers has designed and developed a new rover, Deimos. A commercial drone, Phobos, will accompany Deimos for the delivery mission. The rover and drone have been fully developed and tested in mission-relevant environments.

## System Overview and Architecture

### *Key Innovations*

Key innovations of this year's design emphasize simplicity, safety, operator experience, and data analytics. Learning from previous competitions, Deimos has a new chassis geometry and reduced wheel-leg (wheg) diameter to fit within size requirements without folding mechanisms, reducing complexity and points of failure. Overall chassis weight has been reduced while integrating the science, autonomy, and manipulation payloads into one chassis, eliminating major payload swaps and simplifying field operation logistics. The new science payload eliminates five actuators and utilizes a custom-designed soil collection drum for both surface and sub-surface sample collection. Safety enhancements include an additional front E-stop and improved visibility of the rover's mast light. To better support operator performance, a 2-degree-of-freedom gimbal camera is mounted on the antenna mast for increased visual perception. In addition, a suite of 70-cm and 5.8 GHz communication systems were integrated with the existing 2.4 GHz system to mitigate interference. Digital motors with absolute rotary encoders and a broader range of science sensors enable more comprehensive data collection.

### *Mechanical Architecture*

Deimos' drivetrain uses a split-body chassis joined by a center bearing (see Fig. 1), allowing independent roll of the front and rear halves of the rover, ensuring four points of contact at all times. Deimos maintains 33 cm of ground clearance and incorporates a unique wheg design with a five-spoke aluminum hub, carbon-kevlar composite feet, and custom thermoplastic polyurethane (TPU) treads for increased traction and vibrational damping. The 51 cm wheg diameter ensures a low center of gravity and reduction of the overall footprint, while maintaining a maximum rover speed of 2.0 m/s.

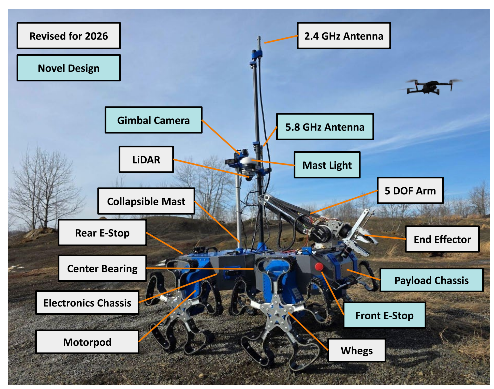


*Fig. 1: Deimos' mechanical architecture diagram for all missions excluding science components, new components shown in teal.*

The manipulator builds upon the proven 5-degree-of-freedom palletizer-style design used in years past. A redesigned linear rail reduces backlash on the manipulator to increase precision, with limit switches integrated for overtravel protection. A quick-swap interface was implemented to change between the soil collection drum and gripper end-effectors. The redesigned gripper features 0.015-220 N force sensing and compliant geometry that deforms around objects, which improves grip by increasing surface contact. A new linear actuator embedded in the gripper enables keyboard typing, while a wrist-mounted USB-C cable allows data transfer with the rover.

### *Electronics Architecture*

Deimos is powered by two 40 V, 4 Ah batteries, managed by a custom power distribution board featuring hot-swap capabilities and two emergency-stops. A new custom Payload PCB controls relays, digital sensors, and linear actuators using a Raspberry Pi Pico. A LattePanda Sigma acts as the central on-board computer and works in conjunction with a NVIDIA Jetson, which manages the visual computational load. The LattePanda interfaces with the Payload PCB, Pixhawk, and other microcontrollers (see Fig. 2) to coordinate data acquisition, rover localization, and real-time motor control. Deimos is equipped with a diverse suite of sensors, including 11 cameras, 3D LiDAR, GPS, IMU, and absolute rotary encoders.

To facilitate the transmission of up to six videos as well as controls between the rover and the base station, a 2.4 GHz system is used alongside a new 5.8 GHz system that supports high-bandwidth close-range communication in high-interference environments. For areas with geographical communication challenges, a new 70-cm system provides basic connectivity for recovery.

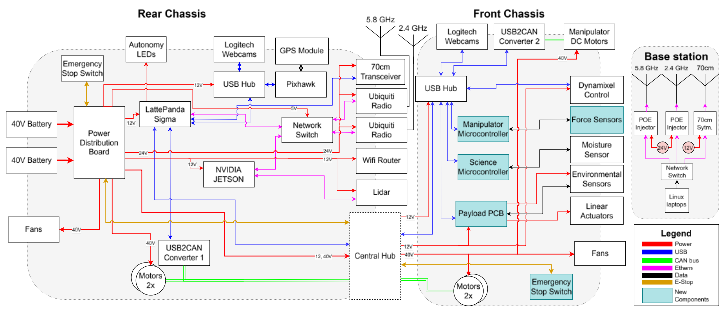


*Fig. 2: Deimos' electronics architecture diagram, new components shown in teal.*

## *Software Architecture*

Deimos integrates a custom-developed graphical user interface (GUI) to support tele-operation and autonomy with an interactive map, live camera streams, system monitoring, and direct control of mission-specific subsystems. GUI slope maps derived from USGS elevation datasets are preprocessed into georeferenced traversability cost maps and incorporated into the global planning layer to inform hazard-aware path generation. Interprocess communication between the GUI and Deimos' software architecture (see Fig. 3) is managed by Robot Operating System 2 (ROS2).

Deimos' autonomous navigation stack employs a subsumption architecture, allowing lower-level safety behaviors to autonomously override high-level planning. Global pathfinding integrates operator-defined waypoints, A* planning, and a custom search algorithm. Additionally, the system maintains human supervisory control to verify autonomy decisions in real-time and edit planned paths prior to execution. During operation, localization is achieved through GPS-inertial-based positioning fused with a newly integrated LiDAR-inertial Simultaneous Localization and Mapping (SLAM) module, which compensates for environmental drift using local scene features. Obstacle avoidance is achieved with a Dynamic Window Approach (DWA) local planner and LiDAR-based real-time terrain map updates. Additionally, visual servoing is used to approach location markers once they are detected.

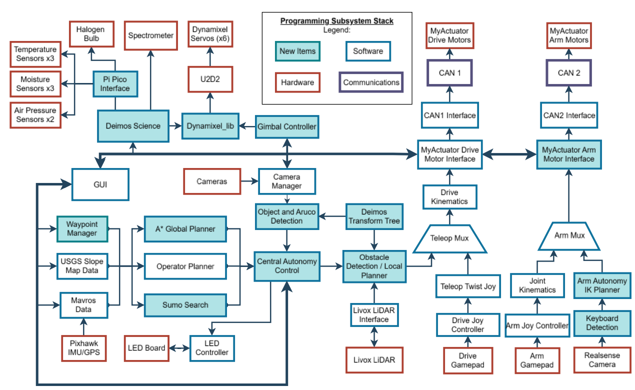


*Fig. 3: Deimos' software architecture diagram, new components in teal.*

Detecting Aruco markers and key objects is performed with OpenCV and a custom-trained YOLOv12 visual perception model with integrated time-based depth information, enabling spatial localization of mission objects. Similarly, for autonomous typing, a custom-trained YOLOv12 keyboard model is used with manipulator visual servoing to navigate and press keys.

**Integration and Testing**

To prepare for University Rover Challenge (URC) 2026, the team has brought Deimos to NASA Technology Readiness Level (TRL) 6, demonstrating rover efficacy through extensive design verification and testing in simulated physical competition environments. During the design phase, the structural integrity of major rover subsystems was confirmed through finite element analysis (FEA) performed in ANSYS Mechanical. Complementary electrical, software, and algorithm components were validated during rover assembly and mission simulation testing. To verify mobility over possible terrains found at the Mars Desert Research Station, the rover has successfully navigated through natural and manufactured features such as large rock gardens, simulated regolith, coal ash fields, and steep inclines. Deimos has also proven to be capable of manipulating and retrieving objects, recording environmental conditions, and autonomously detecting and avoiding objects.

To finish integrating and testing all required subsystems for our rover, the team established major development tasks and milestones for each mission (see Fig. 4). For example, all mission operators and autonomy stacks will complete a minimum of 100 hours of practice, specifically emphasizing off-campus field tests through training missions.

*Delivery*

The use of specialized whegs and a split body chassis on Deimos allows for operation on the challenging terrain experienced during the Delivery mission. Several cameras, including a gimbal camera, are used to provide a full range of sight for rover navigation and object search, with Phobos providing additional visual assistance. The tri-modal communication system allows for continuous operation.

Communications have been successfully tested in high-interference areas, including 164 m non-line-of-sight testing in a high-noise environment, along with 750 m in line-of-sight testing. Deimos' drivetrain has been subjected to steep slopes up to 30 degrees, and mobility testing has been conducted in multiple environments, from sandy to rocky terrain, validating the drivetrain system's capabilities. Deimos' end-effector was tested picking up a variety of objects weighing up to 10 kg, including hand tools, rocks, and an ammo box.

The climbing capability of the rover will be tested on steep, rocky terrain to determine the overall stability limit (Fig. 4, Line 35). Communications testing will involve testing effective range, data transfer rates, and obstacle penetration. Additional flight tests of Phobos will be conducted to test detection and communication capabilities, camera resolution, and flight endurance (Fig. 4, Line 20).

*Equipment Servicing*

To assist in the preparation and training for competition, a mock lander was created to replicate mission tasks. This enabled full system integration testing between perception, manipulation, and teleoperation. Using this platform, Deimos was successfully teleoperated through all mission-relevant tasks: USB-C, hose, buttons, and joystick.

Further testing for Deimos will involve supplementary tests and repetition of the ES mission tasks to ensure smooth operation (Fig. 4, Line 53). Operator training will include limited camera access and simulated actuator failures to prepare for partial system loss (Fig. 4, Line 52). Continued development of the autonomous typing will focus on refining camera-to-manipulator calibration to improve spatial alignment between detected keys and end-effector positioning. Manipulator control is also being tuned to enhance precision and repeatability during typing. Ongoing evaluation is being conducted to characterize detection distance, key localization error, and performance under varying lighting and viewing angles.

*Autonomous Navigation*

A bottom-up integration approach was followed, beginning with localization and waypoint navigation and progressively incorporating global planning and perception to ensure core functionality before adding complexity.

Waypoint navigation was tested by submitting GNSS coordinates through the GUI, validating end-to-end integration of the global planner, localization, and local planning systems. ArUco detection, visual servoing, and marker proximity stopping conditions were then validated through functional testing. Object detection performance was evaluated offline and achieved an overall mAP50-95 in the 80th percentile across mallet, keyboard, water bottle, and rock hammer classes. The mAP50-95 metric measures both classification accuracy and bounding box localization quality. To navigate in hazardous environments, Deimos practiced detecting and traversing around previously unknown obstacles, including dense vegetation, unstable terrain, and other obstructions.

Future testing includes online validation of ArUco and object detection stability during traversal, quantification of reliable detection range, and partial occlusions (Fig. 4, Line 9). Autonomous pathing and search will be evaluated in rough and cluttered terrain, assessing path length and hazard-level (Fig. 4, Lines 10-11).

**Project Management**

To assist in personal development and cross-team collaboration, each team member is part of two subteams. Subteams hold two weekly meetings to discuss updates and assign tasks to smaller working groups. Upon joining a subteam, new members complete introductory projects, such as reverse engineering a previous rover's design, radio licensing, and electrical assembly training. After these exercises are completed, a mock competition is held to familiarize new members with the URC competition environment, along with the operation of our rovers. These projects provide new members with the fundamental tools to be successful team contributors, as well as prepare them with the proper techniques and locations of all tools, algorithms, and other technical materials. Upon completion of the introductory training tasks, coordinators work to divide tasks into working groups to ensure steady progression towards deadlines (see Fig. 4). These working groups are updated regularly to align with subteam goals regardless of the stage in the design process.

The team has the funding for 11 members to travel to Utah for URC 2026, as allocated in line 8.1 of the budget in Fig. 5. To select this team, all students will begin as associate members and apply for full membership by presenting their contributions. Contingent on acceptance to the URC, all members will vote to select the full team members to represent Team Mountaineers in Utah.

Team Mountaineers has conducted extensive outreach in the Greater Morgantown area since the last competition. In total, the team participated in 10 outreach events this year, reaching over 5,000 people. These events include the Pittsburgh Robotics Discovery Day, WVU's annual Pumpkin Drop competition, West Virginia University Day at the state capital, and WVU's middle-high school VEX Robotics Competition. Throughout the spring, the team will continue to complete public outreach events, with the next event being held in early March at the Statler College Visitation Day.

Designs from the previous three competitions are already publicly available on the team's website. Following the 2026 URC competition, Deimos' CAD files, electrical documents, and software stack will also be released, continuing the team's commitment to open-source development and knowledge sharing. Team Mountaineers has also taken on a sister team: the University of Buffalo Space Bulls. The aim of this partnership is for the team to use their knowledge and experience to aid another team in its goal of making the URC competition.

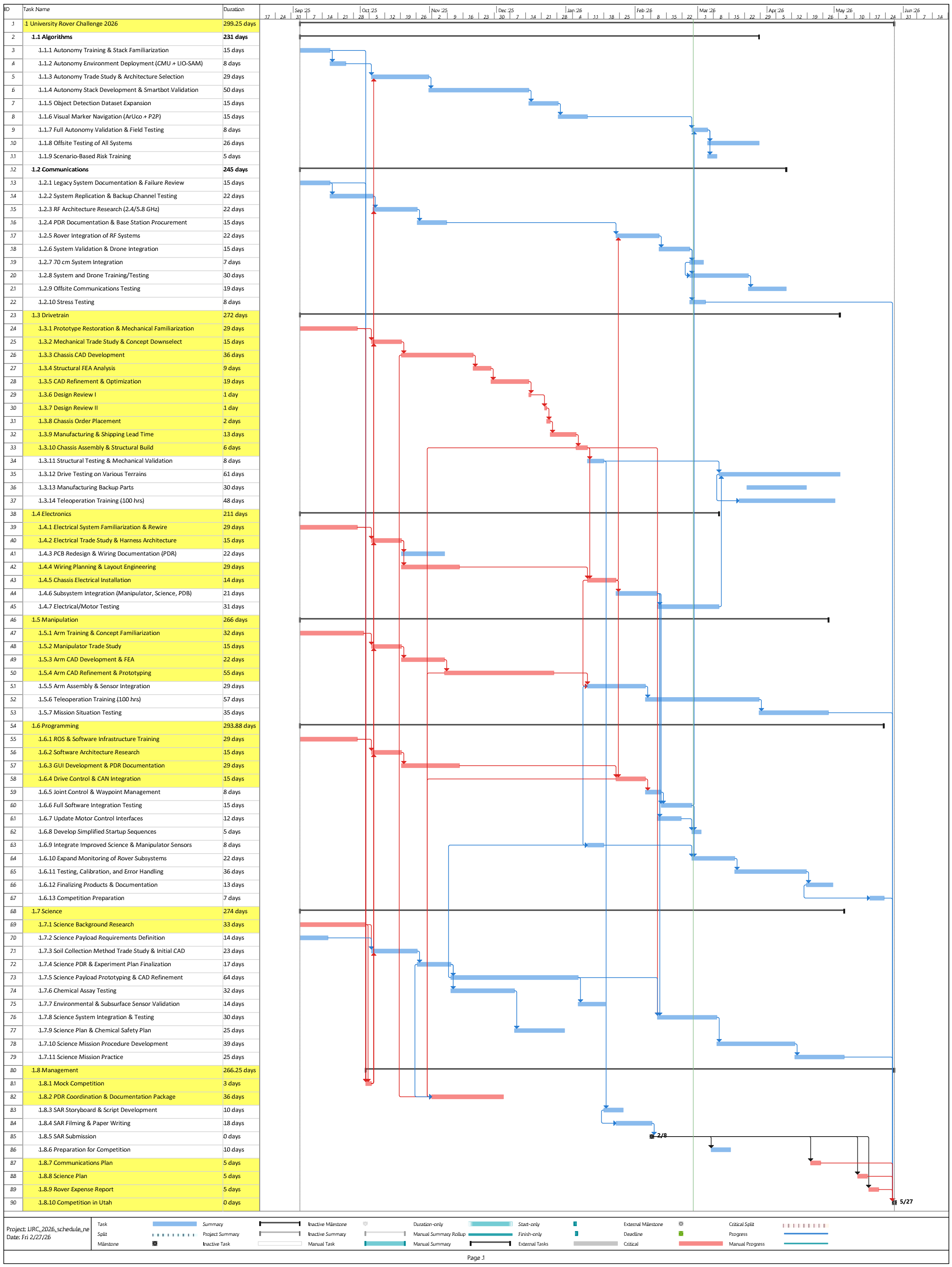


*Fig. 4: URC 2026 Gantt Chart.*

## Deimos: URC SAR BUDGET

**As of Feb. 27, 2026**

| | | |
|---|---|---|
| **INCOME** | | |
| **Actual Income to Date** | | |
| | WVU MAE Department | $20,000.00 |
| | WVU CSEE Department | $20,000.00 |
| | NASA Space Grant Consortium | $2,000.00 |
| **Total Income Received to Date** | | **$42,000.00** |
| **Anticipated Income** | | |
| | Sponsorships | $2,000.00 |
| **Total Additional Income Anticipated** | | **$2,000.00** |
| | **TOTAL INCOME** | **$44,000** |
| **EXPENSES** | | |
| **Project Expense Categories** | | |
| 1 Rover Chassis | | |
| | 1.1 Chassis | $1,703.97 |
| | 1.2 MyActuator Motors | $2,356.00 |
| | 1.3 Composites | $1,017.22 |
| | 1.4 Machined Parts | $941.89 |
| | 1.5 Hardware | $541.37 |
| | 1.6 Cameras | $719.88 |
| 2 Rover Arm System | | |
| | 2.1 MyActuator Motors | $2,772.00 |
| | 2.2 Depth Camera | $272.00 |
| | 2.3 Hardware | $494.85 |
| | 2.4 Machined Parts | $2,124.27 |
| 3 Electrical System | | |
| | 3.1 LattePanda Computer | $579.00 |
| | 3.2 NVIDIA Jetson Orin Nano | $249.00 |
| | 3.3 Livox Mid-360 Lidar | $899.00 |
| | 3.4 Pixhawk & GPS Module | $205.98 |
| | 3.5 Power Distribution Board | $516.40 |
| | 3.6 Payload PCB | $375.04 |
| | 3.7 Sensors | $159.88 |
| | 3.8 Wires & Connectors | $382.17 |
| | 3.9 Miscellaneous | $133.53 |
| 4 Communications System | | |
| | 4.1 Antennas | $347.57 |
| | 4.2 Radios | $469.99 |
| | 4.3 Drone | $1,159.00 |
| | 4.4 Wires & Connectors | $174.37 |
| | 4.5 Miscellaneous | $287.91 |
| 5 Science System | | |
| | 5.1 Spectrometer | $1,650.00 |
| | 5.2 Motors & Actuators | $817.50 |
| | 5.3 Hardware & Machined Parts | $245.19 |
| | 5.4 Chemicals | $535.17 |
| | **TOTAL ROVER EXPENSES TO DATE** | **$22,130.15** |
| 6 Facilities | | |
| | 6.1 3D Printing Filament | $404.70 |
| | 6.2 Base Station Computers | $840.00 |
| | 6.3 Miscellaneous | $406.20 |
| | **TOTAL EXPENSES TO DATE** | **$23,781.05** |
| | 6.4 Backup Parts | $4,000.00 |
| 7 URC Rover Transporation | | |
| | 7.1 Packaging and Shipping | $3,000.00 |
| 8 URC Travel Expenses | | |
| | 8.1 Travel Expenses | $12,000.00 |
| | **TOTAL ANTICIPATED EXPENSES** | **$19,000.00** |
| | **FORECAST FUNDING SURPLUS (DEFICIT)** | **$1,219** |

*Fig. 5: URC 2026 SAR Budget.*

## Science Plan

To assess for extant or extinct life, this year's science payload includes a new soil collection system, a designated soil-solution reservoir for two sample sites, three unique pre-loaded chemical assays, a spectrometer, and environmental sensors. Soil is collected with a bi-directional revolving drum, utilizing separate scooping blades and collection chambers at each site to reduce cross-contamination. Surface samples are deposited into mixing reservoirs containing deionized water, which serves as the solvent for all experiments. Deionized water is soluble for hydrophilic species, miscible with ethanol, and free of metal ions that could produce false positives. Subsurface samples are deposited into a removable two-part cache system, consisting of samples collected from two different depths.

Three new colorimetric tests (see Fig. 6) will be performed on the soil slurry. Due to limited mission time and high temperatures inside the rover, our choice of assays produces rapid, reliable color changes in the expected competition conditions. Chemical safety considerations also influenced the choice of experiments that limit the use of corrosive chemicals. The first test utilizes resazurin, which when oxidized, is a non-fluorescent blue dye due to an N-oxide group. The presence of free electrons facilitates the loss of the N-oxide group and results in the formation of resofluorin, which fluoresces in the pink spectrum [1]. Biologically, electrons are sourced from the electron transport chain as living organisms generate energy [2]. Therefore, this reaction can serve as an indicator for active metabolism occurring in the soil. The second test utilizes the redox reaction of methylene blue, which is blue in its oxidized form and becomes colorless when reduced by electron donors [3]. However, strong oxidants like perchlorates can re-oxidize the reduced form and restore the dark blue color. Since the resazurin and methylene blue tests both rely on the detection of electron transfer, comparing the results of both tests helps distinguish true metabolic activity from interference from oxidizing compounds. The third test employs ninhydrin, which reacts with free amino groups in biologically relevant amino acids, proteins, and nucleotides [4] to form Ruhemann's purple. Taken together, these tests analyze samples for metabolic activity, screen for species that may inhibit life detection signals, and detect amino acids needed to support organic molecule development.

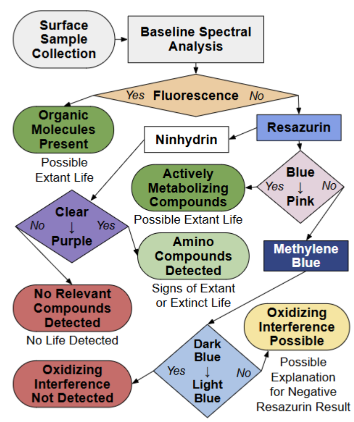


*Fig. 6: Logic flowchart for colorimetric assays.*

The use of UV-visual spectroscopy allows for quantification of colorimetric test results, beyond analysis with a visual camera. Spectral data from each solution is collected and compared to spectra of positive controls, prepared in-lab, to determine if solutions underwent chemical changes from the presence of suspect species described above. Naturally occurring pigmented molecules, such as photosynthetic chlorophyll, also display distinct spectral patterns from photon absorption, which can be a direct indication of biological activity within the sample [5].

The rover is equipped with environmental sensors that collect the ambient and in-rover temperature, humidity, and air pressure. External sensors verify suitable atmospheric pressure for liquid water and appropriate temperatures for life, while in-rover sensors evaluate conditions that may affect the accuracy of chemical reactions. A temperature probe and soil moisture sensor gather additional data about the subsurface sampling environment, providing support for biological activity found in samples.

**[1]** R. De Fries, et al, "Quantification of mitogen induced human lymphocyte proliferation: Comparison of alamarBlue assay to 3h-thymidine incorporation assay," Journal of Clinical Laboratory Analysis, 1995. doi:10.1002/jcla.1860090203.

**[2]** P. Mitchell, "Coupling of phosphorylation to electron and hydrogen transfer by a chemi-osmotic type of mechanism," 1961. doi:10.1038/191144a0.

**[3]** R. L. McCreery, "Advanced Carbon Electrode Materials for Molecular Electrochemistry," Chemical Reviews, 2008. doi:10.1021/cr068076m.

**[4]** M. Friedman, et al, "A kinetic study of the ninhydrin reaction," Biochemistry, 1966. doi: 10.1021/bi00866a012.

**[5]** H. Hashimoto, et al. "Carotenoids and photosynthesis," Subcellular Biochemistry, 2016. doi:10.1007/978-3-319-39126-7_4.