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THE ANALYSIS AND THE OPTIMIZATION OF AN AUTONOMOUS MOBILE PLATFORM EQUIPPED WITH A MANIPULATOR ARM FOR SAMPLE RETRIEVAL IN ROUGH TERRAIN

The current study delves into a detailed analysis and optimization of an autonomous mobile platform, meticulously designed to navigate, and operate within the complexities of rough and challenging terrains. This platform isn't just an ordinary machinery; it's equipped with a manipulator arm, strategically designed to facilitate smooth sample retrieval, even in the most rugged environments. The autonomous mobile platform is suitable even for remote and hostile terrain, inaccessible to most conventional means of exploration. With a robust design and advanced capabilities, it's crafted to navigate through obstacles effortlessly, ensuring that no potential sample remains uncollected. But the autonomous mobile platform doesn't stop there, as it's further distinguished by the integration of communication technology, which elevates its functionality to a whole new level. Real-time data transmission is one of the defining features of the platform. It allows for the continuous flow of information between the platform and its operators, facilitating swift decision-making and seamless coordination. This real-time data transmission isn't limited to basic telemetry but encompasses a wide range of sensor data, providing valuable insights into the surrounding environment and the platform's status itself.

But perhaps one of the most revolutionary aspects of this platform is its ability to stream live video feeds to its operators. The opportunity to witness the sample retrieval process unfold in real-time, from the comfort of a remote command center, can be one of the advantages offered by the autonomous mobile platform. This live video streaming feature isn't just a luxury; it's a game-changer. It provides operators with a visual perspective that surpasses mere data points, enabling more informed decision-making and better situational awareness. Additionally, the manipulator arm of the platform isn't just a passive tool; it's a versatile asset that significantly extends its capabilities. With a range of motion and precision that rivals even the most skilled human operators, the manipulator arm ensures that samples can be retrieved from almost any location, regardless of accessibility or terrain. Whether it's collecting geological samples from a steep slope or extracting soil samples from beneath the surface, the manipulator arm gets the job done with unmatched efficiency and precision.

Keywords: Autonomous Mobile Platform; Manipulator Arm; Sample Retrieval; Data Transmission; Arduino

1. Introduction

In our rapidly advancing technological age, the exploration of remote and inaccessible terrains, as well as the collection of samples from these regions, pose significant challenges. Autonomous mobile platforms equipped with manipulator arms represent a notable innovation in this field, offering efficient and safe solutions for sampling from hostile and hard-to-reach environments without risking human safety. The focus of this introduction is to provide a detailed description of such a platform, emphasizing its necessity and relevance in various scientific and technical fields, without delving into aspects related to human rescue.

The need for developing autonomous mobile platforms to collect samples from inaccessible environments has become increasingly clear in recent years. Geological research, climate studies, and biological explorations often require access to extreme regions such as mountain peaks, arid deserts, polar regions, or volcanic terrains. These areas are challenging to explore using traditional methods due to extreme conditions, associated hazards, and geographical inaccessibility. Furthermore, obtaining precise and detailed data from these environments is essential for understanding natural processes and developing effective conservation and resource utilization strategies.

The autonomous mobile platform, fitted with a manipulator arm, is specifically engineered to seamlessly navigate and operate

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in rugged and challenging terrains. It boasts a sturdy design and cutting-edge technologies that enable it to effortlessly traverse obstacles and gather samples from areas that are inaccessible to human explorers. The manipulator arm, renowned for its wide range of motion and exceptional precision, is adept at retrieving samples from demanding environments like steep slopes, subsurface areas, and volcanic craters. This capability holds particular significance for geological research, as it provides vital access to samples from deep or hazardous locations, thereby aiding in the comprehension of the Earth's structure and composition.

An innovative feature of the autonomous platform is the seamless integration of advanced sensor and communication technologies [1]. These sensors gather intricate data about the surrounding environment and the platform's status, offering crucial information for navigation and sampling. The communication technologies allow for real-time data transmission to operators at a distance, enabling swift decision-making and operational adjustments based on encountered conditions. This capability is especially crucial in scientific explorations, where immediate access to precise data can greatly impact research outcomes.

Moreover, the autonomous mobile platform is outfitted with live video streaming capabilities, enabling operators to gain a comprehensive real-time visual understanding of the sampling process. This functionality facilitates close monitoring of operations and swift assessment of field conditions. Real-time visualization of the sampling process not only enhances operational precision and efficiency but also allows for prompt resolution of unforeseen challenges or impediments.

It's crucial not to underestimate the significance of obtaining samples from hard-to-reach environments. Samples from these areas yield vital information for understanding natural processes and developing accurate predictive models. For instance, in the field of geology, gathering rock and soil samples from great depths or hazardous locations can provide insights into the Earth's internal structure, tectonic activity, and geological evolution of specific regions. Similarly, in climatology, ice samples collected from polar regions contain valuable data about atmospheric composition and climate changes over time, thus enhancing our understanding of the impact of human activities on the environment.

Our planet is home to a variety of crucial samples, located in remote or challenging-to-access areas. These samples, including rocks, soil, vegetation, and other natural elements, hold vital information for a range of research disciplines. Regrettably, many of these samples aren't fully utilized due to accessibility constraints. The autonomous mobile platform presents an innovative solution to this issue by enabling the collection and distribution of samples to research laboratories.

In geological research, samples of rock and soil collected from remote locations can yield crucial insights into the Earth's mineral composition, chemical makeup, tectonic processes, and geological history of the studied areas. Similarly, in climate research, ice samples gathered from polar regions can harbor air bubbles and other elements that offer valuable data about atmospheric composition and long-term climate variations. This data is indispensable for constructing precise climate models and comprehending the influence of human activities on the environment.

2. Creating the prototype of the autonomous Platform V1

2.1. The CAD design of the V1 platform

Based on the requirements, the first concept of the autonomous mobile platform was developed in the form of a prototype assembly.

To complete the entire robot, a three-dimensional model was required. The virtual model was created using the CATIA V5R20 computer-aided design software. The virtual model was used to visualize each component of the robot as well as their assembly process.

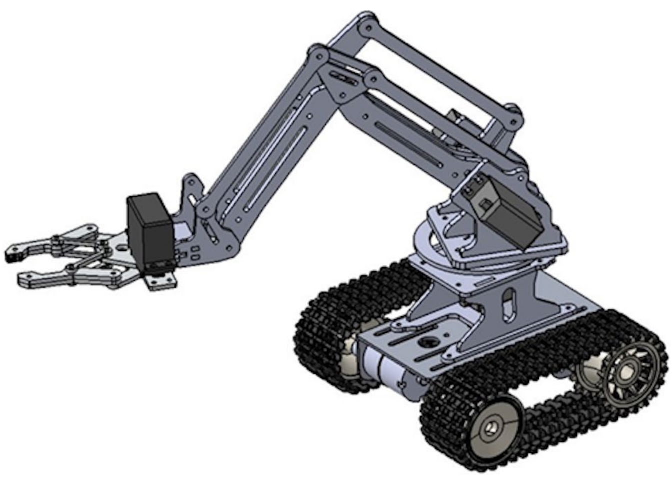

Fig. 1. CAD model for V1 platform

2.2. The Physical construction of the V1 platform

From a construction simplicity perspective, standardized components were used.

One of the subassemblies used is the wheel, tensioner, and track subassembly, which serves to move the entire robot assembly. The mobile platform contains two such subassemblies. Each wheel is driven by a stepper motor. Alignment was achieved using bushings.

Another subassembly was designed to enable rotation around the Z-axis, thus connecting the mobile platform to the robotic arm. To reduce friction, an axial ball bearing (DIN 711_D_85_d_45_H_28) was used.

Additionally, another subassembly used is the robotic arm gripper. The role of this gripper is to grasp, hold, and release samples. Through this mechanism, the robot will be able to handle various samples.

Additionally, a subassembly consisting of a servomotor and a connecting element was used to enable the robotic arm's movements along the X and Y axes. The motion is achieved through the engagement of two gears: an externally toothed gear fixed to the motor shaft and an internally toothed gear fixed to the mobile connecting element.

Besides these subassemblies, both fixed and movable connecting elements for the motors were used, as well as an element that connects the robotic arm to the gripper.

Thus, the robotic manipulator assembly with a gripper was created, featuring a robotic arm with five degrees of freedom. At the end of the arm, a gripper for handling samples can be observed. The robotic arm performs one rotational movement around the Z-axis, three rotational movements around the Y-axis, and one rotational movement around the X-axis. An axial ball bearing (DIN 711) is located at the base of the robotic arm to reduce friction.

Additionally, a mobile platform with tracks was created. Its movement is achieved through two stepper DC motors. To improve the track's adhesion to the contact surface, adjustable tensioners were used. The third motor, which enables the rotation of the robotic arm around the Z-axis, is identical to the motors used for moving the mobile platform. The structural parts were connected using flexible, detachable elements to facilitate access to the interior of the autonomous mobile platform [2,3].

A physical prototype of the concept was also created, utilizing the following components:

- Nema17 stepper motor,
- HC-05 Bluetooth module,
- Turnigy 1000 mAh 6S 65C Lipo battery,
- L298N H-Bridge,
- Arduino Mega,
- SG90 servo motor,
- Acrylic robotic arm kit,
- T101 tank chassis kit, aluminum, 12 V motors.

It was decided to use direct current (DC) motors because they are among the easiest to control. They have two terminals, positive and negative, and if the wires are connected in reverse, the motor will rotate in the opposite direction. By using an H-bridge, this can be achieved without reversing the wires.

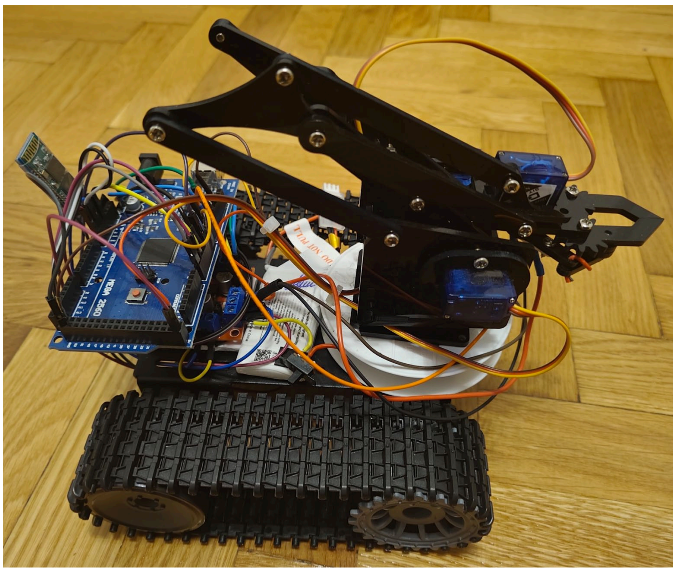

Fig. 2. The physical assembly of the V1 platform

By putting together all these components, the assembly shown in the following figure was achieved.

2.3. Testing the Prototype Assembly

To verify the functionality of the V1 platform, a specific test was proposed. This test involved traveling a distance of 100 meters, collecting a sample at the destination point, and returning to the starting base. This procedure was chosen to simulate a real task the platform might need to perform under normal operational conditions.

The desired current limit for the platform is presented in the following graph.

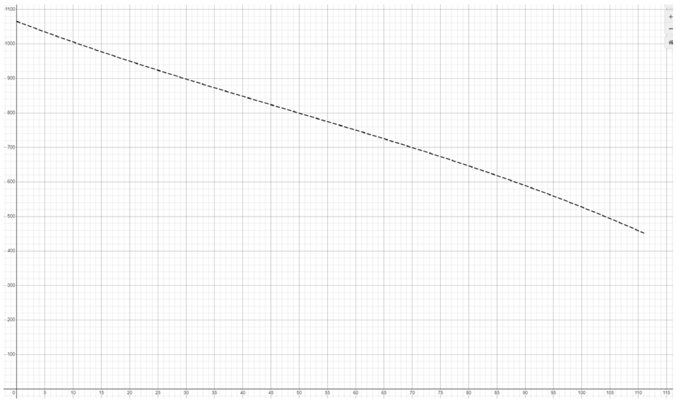

Fig. 3. Current limit

This limit was established to ensure that the platform operates within optimal parameters and can meet the load requirements. The goal is to prevent the current consumption from falling below this limit to ensure that the system has enough power to complete the task without issues.

During the execution of the test, it was observed that the V1 platform registers a high current consumption over the specified distance, indicating very low efficiency. This is clearly shown in the graph below, where the current consumed by the V1 platform is marked in red, compared to the predetermined consumption requirement.

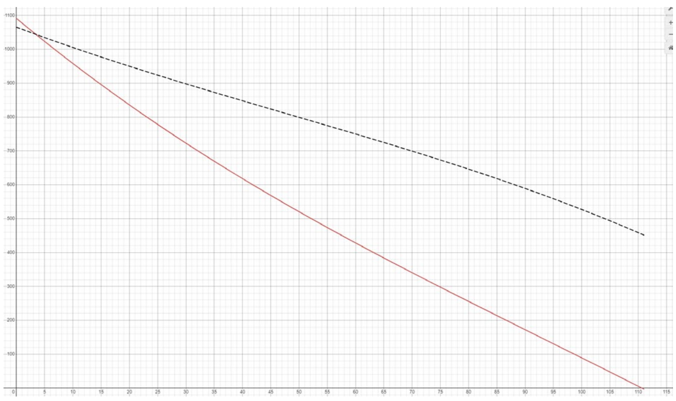

Fig. 4. The current consumption of the V1 platform

The high current consumption indicates that the platform struggles with the load, which could lead to performance and reliability issues in the long run.

Considering these data, the redesign of the mobile platform is aimed at meeting the imposed requirements. This involves a detailed analysis of the platform's components, including the motor, control system, and power source. Additionally, optimizing control algorithms might be necessary to reduce energy consumption without compromising performance.

3. The development of the V2 platform, an improved prototype assembly

The advancement of autonomous mobile platforms capable of collecting samples from rugged terrains signifies a significant progression in remote exploration and scientific research. These platforms play a crucial role in accessing environments that are challenging or perilous for humans to reach, including remote deserts, high-altitude mountain ranges, polar regions, dense forests, and underwater ecosystems. By facilitating the collection of environmental samples in such demanding conditions, these platforms yield invaluable data for various scientific disciplines, comprising geology, biology, environmental science, and climatology.

The V1 platform, as an initial prototype, was purposefully crafted to meet the requirements of rugged terrain exploration. It integrated essential functionalities for navigating challenging landscapes and gathering samples. However, its deployment uncovered several critical limitations. A primary issue was its restricted storage capacity, which constrained the number of samples that could be collected during a single mission. Additionally, the design of the V1 platform included a serial manipulator, which, though functional, lacked the necessary flexibility and precision for efficient sample collection in highly variable and unpredictable environments.

Energy consumption also presented a notable challenge for the V1 platform. The rugged terrain necessitated high energy expenditure, diminishing the operational time and efficacy of the platform. Without an effective energy replenishment system, such as integrated solar panels, the platform's autonomy was significantly restricted, leading to frequent recharging breaks that disrupted missions and diminished overall productivity.

Considering these limitations, the development of the V2 platform has been proposed. The V2 platform seeks to address the shortcomings of its predecessor through a series of significant modifications and enhancements [4,5].

3.1. Limitations of the V1 platform

3.1.1. Space Limitations

The V1 platform, despite its compact design, has limitations in sample storage capacity. Although its small size is beneficial for maneuvering through narrow and rugged terrains, it prevents the installation of sufficiently large and diverse collection boxes to prevent sample cross-contamination. This becomes a crucial issue during missions that involve collecting a large number of samples or bulky samples. The limited storage space can result in sample mixing, which compromises the accuracy and reliability of the results. Furthermore, the platform's small size restricts its ability to accommodate additional instruments that may be necessary for various on-site analyses.

3.1.2. Limitations of the Serial Manipulator

The serial manipulator utilized on the V1 platform has several notable drawbacks. Firstly, its limited mobility restricts the ability to access and retrieve samples from challenging or hard-to-reach locations. In rugged terrain conditions, the manipulator's precision and stability are compromised, potentially resulting in difficulties during sample collection. The extended duration required for each sample pickup and storage significantly reduces the platform's overall efficiency. This increased operation time can be crucial in missions where speed and efficiency are imperative. Furthermore, the design of the serial manipulator does not permit simultaneous handling of multiple sample types (liquids and solids), limiting the platform's versatility and functionality.

3.1.3. Energy Limitations

The V1 platform is outfitted with a set of batteries that offer limited autonomy. In challenging terrain, energy consumption is significantly higher due to the necessity of traversing difficult surfaces and powering the platform's various components and sensors. As a result, operational time is reduced, potentially impacting mission duration and success. The absence of an efficient recharging system during operation requires frequent pauses for battery recharging, continually limiting the overall mission duration. In crucial scenarios, the platform may exhaust its power supply before completing necessary sample collection, potentially jeopardizing the entire mission.

3.1.4. Sample Collection Limitations

The current design of the V1 platform hinders efficient sample segregation, resulting in cross-contamination between collected samples. This issue compromises the reliability and utility of the acquired data, particularly for sensitive samples or those with specific storage requirements. Cross-contamination introduces uncontrollable variables into analyses, thereby impacting the conclusions of studies. The absence of dedicated compartments for liquid and solid samples limits the platform's adaptability across diverse terrains and complicates the correct collection and storage of samples. It also hinders the capability

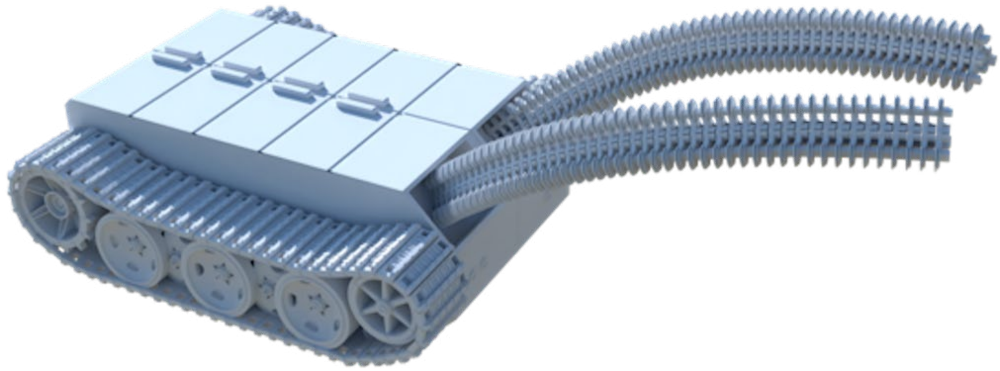

Fig. 5. CAD model for V2 platform

to conduct sophisticated analyses directly in the field, necessitating the transportation of samples to specialized laboratories for comprehensive analysis.

3.2. Proposed Improvements for the V2 platform

The V2 platform is engineered to address all the issues identified with the V1 platform assembly and is designed to overcome all the challenges faced by the previous version, integrating improved management strategies [6]. Currently, the V1 platform has been designed as shown in the following figure.

3.2.1. Larger Dimensions and Individual Collection Boxes

The V2 platform is designed with larger dimensions, allowing for the integration of a greater number of individual collection boxes. These specifically designed boxes prevent cross-contamination between samples and feature separate compartments for liquid and solid samples. The increased capacity of the collection boxes, made possible by the larger dimensions of the platform, enables the storage of a larger volume of samples without the risk of mixing. Each box is equipped with isolation and sealing mechanisms to maintain the integrity of the collected samples. Furthermore, the extended dimensions allow for the installation of additional instruments for preliminary sample analysis directly in the field, reducing the need to transport samples to specialized laboratories for detailed analysis.

3.2.2. Tentacle-Type Manipulators

The V2 platform will feature two tentacle-type manipulators instead of the serial manipulator. These advanced manipulators provide increased flexibility and mobility, enabling the collection of samples from challenging locations with greater precision. They are capable of executing complex and precise movements, easily adapting to different terrains and sample types. Additionally, the manipulators are capable of simultaneously handling multiple samples and executing diverse operations, thereby enhancing the overall efficiency of the platform. During periods of inactivity, they have the capacity to retract, thus mitigating the potential for damage and reducing the likelihood of accidents. Ultimately, these features serve to prolong the lifespan of the manipulators while concurrently lowering maintenance costs.

3.2.3. Improved Energy System

The V2 platform is set to benefit from an enhanced energy system, featuring larger batteries with a capacity of 36V 4400 mAh. These batteries will significantly extend the platform's operational autonomy, enabling it to function for prolonged periods without interruptions [7]. Additionally, the platform will be equipped with solar panels to facilitate battery recharging during operation, a technology that conducts to the replacement of limited battery [8]. This continuous recharging solution will ensure nearly unlimited autonomy when provided with sufficient sunlight, thereby reducing reliance on external power sources. At the same time, it must be taken into consideration that solar panels also have some limitations, such as photovoltaic end of life [9,10]. For this reason, a periodic maintenance will be the best choice to prevent any errors [11]. The improved energy system will also accommodate the integration of additional components, such as advanced sensors and communication modules, without compromising the platform's autonomy. This enhancement will notably augment the platform's capabilities for exploration and sample collection in challenging terrains, minimizing the need for frequent recharging.

3.2.4. Dedicated Compartments for Liquid and Solid Samples

The V2 platform incorporates dedicated compartments for both liquid and solid samples, prioritizing sample integrity and contamination prevention, being able to store samples even in dynamic scenarios [12]. Liquid samples will be housed in specialized drawers designed to prevent leaks and maintain optimal temperature and humidity conditions. These drawers will feature isolation and sealing mechanisms to safeguard against evaporation and contamination. Meanwhile, solid samples will be stored in their own dedicated drawers, ensuring proper handling and preservation. These compartments are specifically designed to shield samples from external contaminants and uphold optimal preservation conditions. Moreover, the arrangement of dedicated compartments will streamline sample organization and quicken sample identification, ultimately saving time during handling and analysis.

3.3. Benefits of the V2 platform

3.3.1. Increased Sample Collection and Storage Capacity

With its expanded dimensions and individual collection boxes, the V2 platform is poised to gather and store a significantly larger number of samples without compromising their integrity. This advancement will support the execution of more intricate and comprehensive studies, broadening our research and exploration capabilities. Additionally, the increased storage capacity will diversify the range of sample collection, offering a more thorough and precise portrayal of the studied environment. The systematic arrangement of samples in individual boxes will also streamline the subsequent analysis process, ultimately reducing the time and resources required for handling them.

3.3.2. Improved Efficiency and Precision

The utilization of tentacle-type manipulators will greatly enhance precision and flexibility in sample collection, resulting in reduced operation time and improved overall efficiency of the platform. The incorporation of a retractable feature in the manipulators is designed to mitigate potential damage and extend their operational lifespan. In addition, the flexibility of tentacle-type manipulators will facilitate the execution of intricate and precise operations, including sample retrieval from challenging-to-reach cracks or cavities, something that can be very challenging for the actuators that will be used [13]. This advancement will significantly expand the platform's exploration capabilities, providing access to previously unreachable or difficult-to-obtain samples.

3.3.3. Extended Energy Autonomy

The enhanced energy system, which features larger batteries and solar panels, will enable the V2 platform to function for extended periods without interruptions. This increased autonomy will greatly enhance the platform's ability to explore and collect samples in challenging terrains, reducing the need for frequent recharging. Furthermore, the solar panels will provide a steady energy supply, making it possible to operate the platform even in low light situations [14]. This will lessen its reliance on external power sources and facilitate the completion of longer and more intricate missions.

3.3.4. Protection of Sample Integrity

The presence of dedicated compartments for liquid and solid samples ensures proper storage, preserving the integrity and quality of the collected samples. This will lead to the acquisition of more precise and valuable data that can be applied across various research domains. Safeguarding samples from contamination and degradation will enable more comprehensive and accurate analyses, thereby contributing to the advancement of knowledge in disciplines such as geology, biology, and environmental chemistry. Moreover, these dedicated compartments will facilitate the secure transport of samples to specialized laboratories for further analysis.

3.3.5. Increased Versatility and Adaptability

The V2 platform is meticulously crafted for exceptional versatility and adaptability, making it suitable for a diverse array of terrain conditions and sample types. It is suitable for diverse applications, including exploration of challenging terrains, inaccessible areas, and collection of samples for complex scientific studies. Its enhanced versatility enables its use in various environments such as deserts, mountains, polar regions, and underwater, expanding its range of applications and facilitating studies and research that were previously unattainable. The platform's adaptability to different sample types also allows for multidisciplinary analyses, integrating data from various scientific fields to gain a more comprehensive understanding of the investigated environment.

4. Conclusions

The creation of the V1 platform was a crucial step in developing technology for autonomous exploration of rugged terrains. This initial prototype opened new horizons in sample collection from inaccessible or dangerous environments for humans, demonstrating that it is possible to access and collect samples without direct human intervention. Although it is an ambitious project that promises a lot, we must admit that V1 platform is limited in storage capacity, manipulator design and energy consumption.

First of all, the most evident limitation of the V1 platform was its reduced sample storage capacity. Its compact dimensions restricted the number and diversity of samples that could be collected in a single mission, affecting the scientific value of the missions. Additionally, the serial manipulator of the V1 platform proved inadequate for many complex tasks required in rugged terrains. The limited mobility and precision of the manipulator restricted the platform's ability to collect diverse samples and respond efficiently to mission requirements, thus reducing overall efficiency and prolonging mission duration.

Energy consumption was another major challenge for the V1 platform. Navigating rugged terrain required high energy consumption, reducing the platform's operational time and efficiency. The lack of an efficient energy recharge system severely limited the platform's autonomy, necessitating frequent recharging breaks and reducing overall productivity. Furthermore, the V1 platform's design did not allow for efficient sample segregation, leading to cross-contamination between collected samples and affecting the validity of the obtained data. All these limitations can be treated in much more detail and will be the starting point for the realization of the V2 platform. This V2 platform must, from the beginning, overcome these limitations and be able to satisfy the imposed requirements.

Given these limitations, the development of the V2 platform was proposed to overcome the deficiencies identified in the V1. The V2 platform will have larger dimensions, allowing for the integration of a greater number of individual collection boxes to prevent cross-contamination between samples and to enable the storage of a larger volume of samples. It will also be equipped with two tentacle-type manipulators, providing greater flexibility and mobility for precise sample collection from hard-to-reach locations.

The V2 platform will benefit from an improved energy system, including larger 36V 4400 mAh batteries and solar panels, ensuring extended autonomy and reducing the need for frequent recharging breaks. This will enhance the platform's capacity for exploration and sample collection in difficult terrains. Additionally, the platform will include dedicated compartments for liquid and solid samples, maintaining the integrity and quality of the collected samples.

In conclusion, the development of the V2 platform represents an important step in improving the capabilities of sample collection and storage in challenging terrains. By addressing and remedying the limitations of the V1 platform, the new prototype will offer greater efficiency and precision, extended energy autonomy, and better protection of sample integrity. These improvements will enable more detailed and precise studies and research, expanding the frontiers of exploration and knowledge in various scientific fields. The V2 platform will represent a robust and versatile solution for sample collection in diverse and difficult environments, significantly contributing to the advancement of knowledge and the development of new technologies and research methods.

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