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Sample collection and containment system for a compact planetary exploration rover

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Abstract: The purpose of this research is to develop an exploration rover to use in Earth and Martian-like environments, which requires the development of a sample collection system for soil, rock and atmosphere. Along with that system, a corresponding sample containment method has to be developed, in order to preserve the materials which are being brought back.

A rover with a drilling module with a compartment container part, holding the total capacity of 5 isolated samples, was designed and implemented. A weighing module for immediate post-collection sample test was added, as well as pH, temperature and humidity sensors for the soil. For atmosphere examination, sensors of pressure, temperature, humidity and CO_2 concentration were employed, with plans of future development and new sensory modules addition.

Keywords: space, exploration, rover, sample collection, drilling

1. INTRODUCTION

In light of a growing interest in interplanetary exploration and conquest, the number of projects researching and developing probing rovers and sondes is at its height. Sample-based research of foreign environments is the objective of, among others, NASA's 2020 Perseverance rover mission [1] and ESA's ExoMars programme, begun in 2016 [2]. A future perspective of construction of such space vehicles is space colonization, based in carefully and suitably chosen areas for scientific and utilitarian bases, which will be made possible due to appropriate environmental examination.

The project of the rover under development presents an advantageous approach to further use, since it is a low-cost (under 2000 EUR), low-mass (under 18 kg) solution for an exploratory rover design. Its dimensions are under 600x500x500mm. The mentioned simplicity allows for the control of multiple similar vehicles at once and makes them more reliable than complex missions, which can be doomed by a single-point failure. This approach focuses on enabling free exploration of vast terrain by multiple smaller rovers.

A concept of such a mission could involve a main non-mobile lander—a science laboratory which could be even more advanced than NASA's Perseverance, with a fleet of tens of rovers and drones of various sizes preparing and bringing samples to the main laboratory.

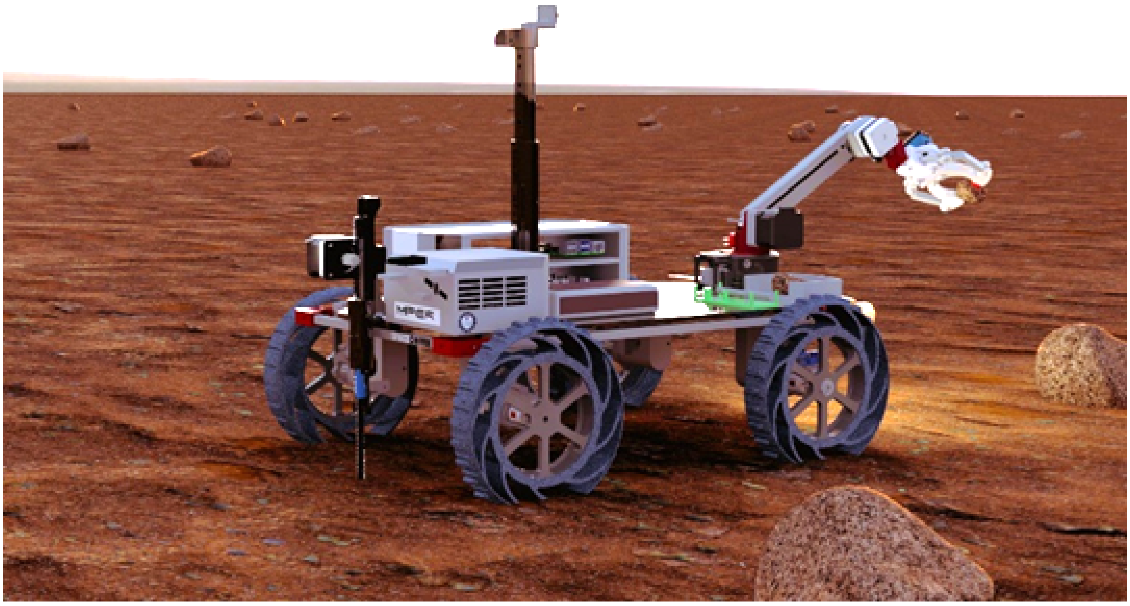

Figure 1. MPER rover render on Mars, including the modules: Drill (leftmost), Manipulator (rightmost) and Chassis. Movable camera and antenna module is visible in the middle.

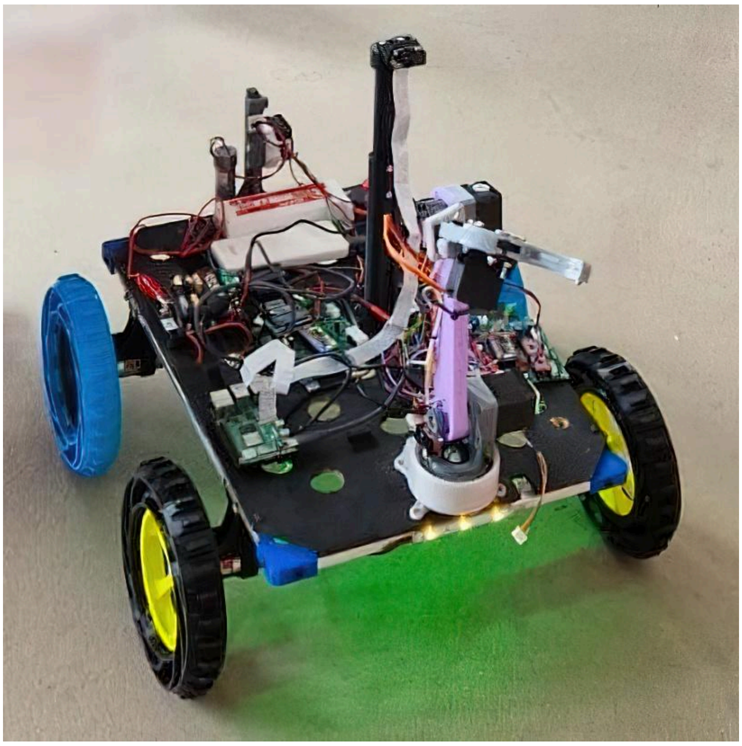

Figure 2. MPER rover prototype during testing of remote control and video transmission

2. COMPONENTS AND FUNCTIONALITY OF THE DRILLING SYSTEM

The prototype of an exploration rover is equipped with a three-part system of sample collection through drilling and gripper manipulation. It is an effective and secure tool for conducting research on gathered resources, allowing for instant preservation and containment of a sample, after an initial study of its parameters. The complexity of the task is conquered by the Manipulator, Drill and Sample Containment modules. On top of the more basically needed parts, the rover is accommodated to uneven and rugged planetary surface areas thanks to its 4-wheel drive with a shock absorption system, which grants it an accessory agility of movement to gather specimens in hard-to-reach or obstructed places.

2.1 Manipulator

The rover arm, with its manipulator and gripper, were designed and constructed with the goal of optimal sample collection. The 4-degrees-of-freedom, 5-articulated manipulator enables the rover to pick up materials from surfaces around it, and carry them over to its platform, which is equipped with a weight for a primary determination of a sample's parameters.

The Robotic Arm, of which the manipulator constitutes the main part, is lightweight, with 4DOF, utilizing 3 stepper and 2 servo motors for precise movement navigation. Its maximal pickup capacity stands at 0.5 kg, with a planned expansion to 1 kg.

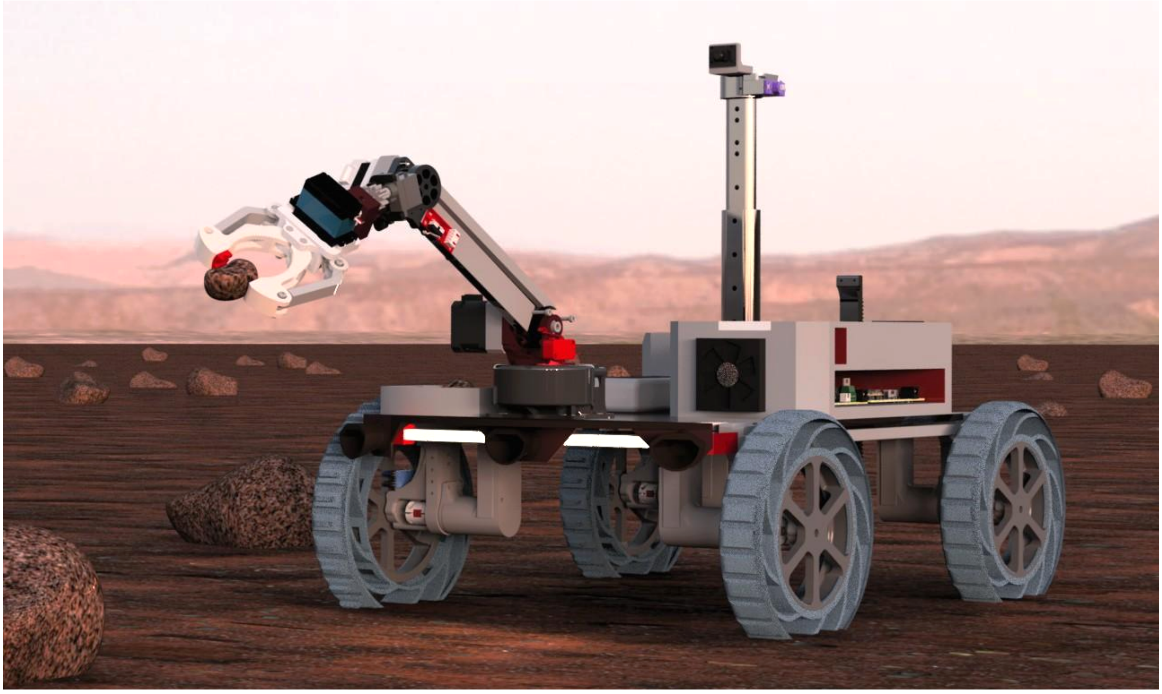

Figure 3. Close-up of the Manipulator module holding a Martian rock on the rover's render.

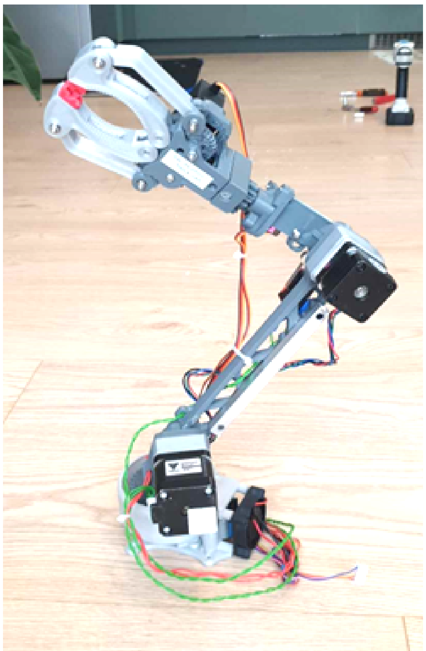

Figure 4. Rover arm prototype, made with COTS electronic components and custom 3D printed mechanical parts.

Part of the manipulator made with special devotion in the ongoing project are the gears, designed to increase the torque of motors, using a combination of 2 gear types—planetary and cycloidal reduction gears, which seem to be the standard solution. The created element is a stepped-planetary gear (not to be confused with compound). It allows a large reduction of 40:1 in a 40x40x20mm package. The gear is fully printed and has been successfully tested up to 23 Nm of torque when printed in PETG material. We expect this value to increase even further when printed in Nylon.

The manipulator prototype has been assembled and finished for use, as the most important component. The prepared version relies on stepper motors and servomechanisms. To be implemented remain current consumption sensors, which would enable diagnostics gathering for gripper and joint forces, and the sample drill's movement.

2.2 Drilling and Sampling system

The Drill is a module responsible for soil-samples collection. The design depth of a drill is up to 20cm under the surface. The newest design of the system includes a stepper motor moving a carriage across a V-slot rail, with an endstop at the top. The stepper motor's torque is increased using the custom-made stepped-planetary gearbox described above.

The drill has a diameter of 16mm and a length of 320mm, and rotates in a drill guide, allowing the sample to be carried upwards toward the sample container system. The guide is split in two parts - fixed and moving. The fixed part provides mechanical support and acts as a linear bearing, while the moving part is attached to the carriage and has a tight fit with the drill bit, allowing the soil samples to travel upwards, as shown on Fig. 6..

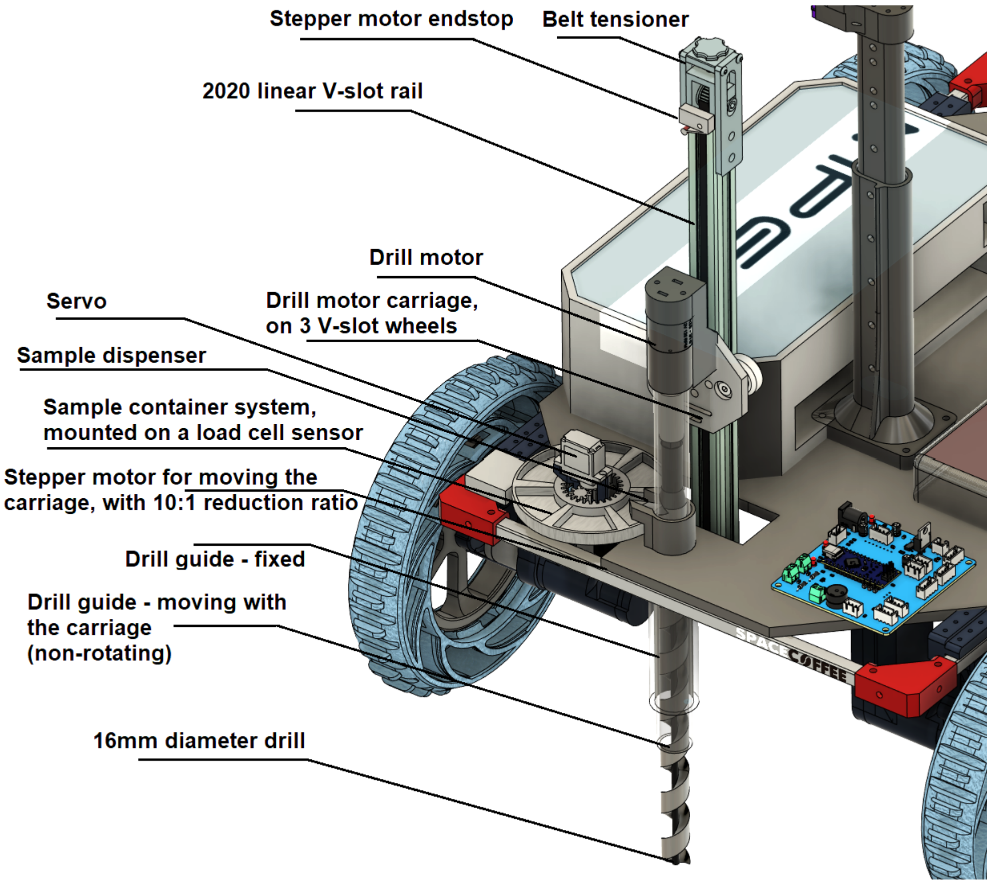

Figure 5. Current drilling and sampling system design, with major components highlighted.

One of the design goals was to minimize the number of motors and mechanical joints needed for the whole system. One stepper motor, one DC motor for drill rotation and one small servo for sample container rotation bring the complexity to absolute minimum, while maintaining good capability.

Assembly and tests of the new design, shown on Fig. 5 and Fig. 6., in simulated foreign planetary conditions are the next step of the Drilling Module's development.

Figure 6. Renders of the drilling system in the stowed (left) and deployed position (right). Note the guide, one part of it extending with the motor (attached to the gantry). This allows travel of the drilled sample upwards.

2.3 Sample Containment

Sample containment is conducted through a combination of three elements in total: the Manipulator and two Containers—first located in the front part of the platform, second in the rear. Using the manipulator, specimens can be transported and preserved in the prepared containers, with a regard to their particular fragility and assuring previous sterilization of the containment.

The rear container has five compartments for soil samples from the drill bit. It is capable of weighing the samples with +- 0.5 g precision using a single load cell sensor. The individual samples can be weighed by measuring the change in total weight of the module. The samples can be emptied and filled remotely as necessary, and the revolver-style container system is controlled by a single servo motor. Front cargo compartment, within the reach of the robot arm, also includes an ionizing radiation sensor and a weight sensor. It's suitable for storing rocks or other items picked up by the rover, including basic tools that can be used by the Manipulator.

2.4 System operation and control

All compounds of the system for sample collection and storage are driven by an independent microcontroller, only receiving and sending data to the main controller (Raspberry Pi). The data is sent in custom CAN-like frames, but over a UART bus. These frames contain control sums and are transmitted every 100 ms. The control isn't achieved by sending single commands, but rather a set of flags, indicating the desired state of the rover. This way, missing single or multiple frames won't impact the rover extensively, only delaying the sent command. Acknowledgement flags are also used, and transmitted in every frame until the command is executed and the request stops. The user interface can be accessed by browser on any PC or mobile device, allowing intuitive control of the vehicle.

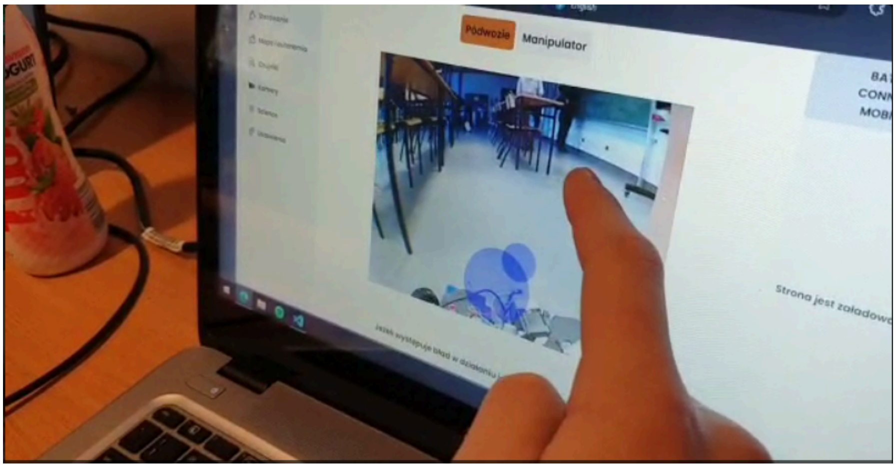

Figure 7. User Interface of MPER rover - can be accessed in a browser and provides virtual joystick control of all functions of the rover.

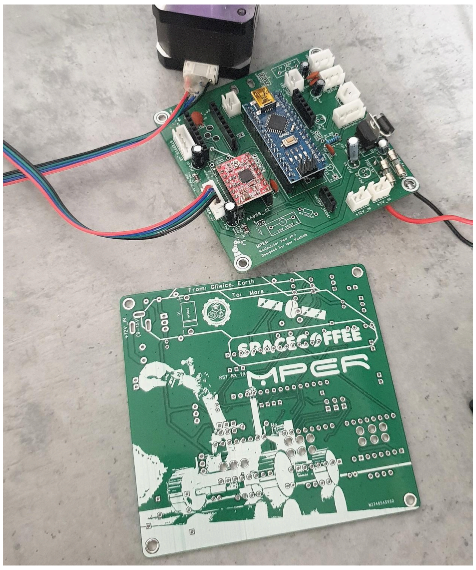

Figure 8. One of four custom PCBs designed for rover's electronic components.

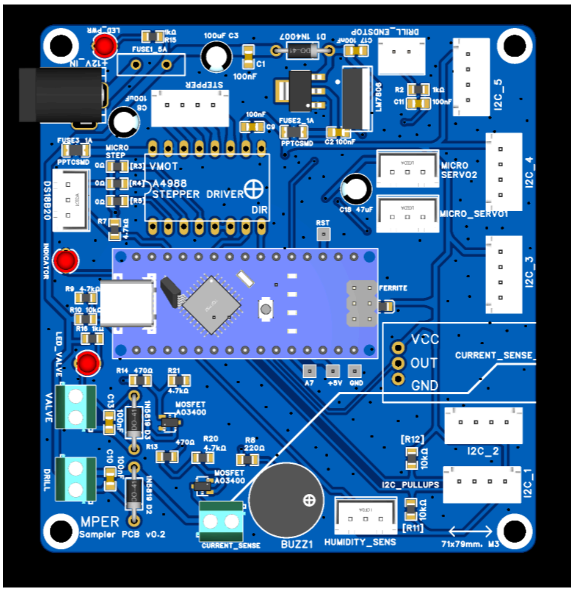

Figure 9. Render of the PCB for the Sampling system.

2.4 Environmental sensors

Used for the research of environmental conditions prevailing on planets other than Earth were the collection of sensors meant for separate examinations of the atmosphere and the soil.

For the aim of analyzing the atmospheric factors, an Arduino Nano-based system of pressure, temperature, humidity and CO_2 sensors was completed. An NC DN15 electrovalve collects the general sample, which is tested by the set of components: a BME688 humidity, temperature and pressure sensor, a DFRobot SEN0377 gas recognition sensor (CO_2), a Geiger counter, and an ionizing radiation sensor, which, mounted next to the front cargo compartment, can be used to measure background radiation and solar storms, and also detect radioactivity of objects picked up by the rover. The examination of factors related to soil conditions will be possible due to use of humidity and temperature probes, consecutively: MTK339 and DFRobotKIT 0021.

All of the listed above devices are needed among the modules devoted to assessing the elements of a planet's nature, evaluating its habitability and, for example, crop harvest ability. Measurements prepared during the study of the sample are transmitted from the sensory modules through an UART bus to the Raspberry Pi 5-based main computer. The noted values are then sent to the ground base for the conduct of further research.

3. FUTURE DEVELOPMENTS

Work is being done on improving the rover in all aspects - for the Manipulator, there is a need for enhancement of the range and torque capability of this module so that it can easily perform various tasks. To achieve more dexterity, there is a plan on adding one more degree of freedom - wrist angle. This will allow the manipulator to be equipped with an inverse kinematics algorithm and absolute positioning. When the design is finalized, there's a plan to release the manipulator's documentation as an open-source project. The arm can serve for a wide range of interactions with the environment, functioning as a low-cost educational Cobot.

Under consideration are also upgrades and developments of the sample retrieval system, with the objective of optimization of specimen gathering methods for more secure storage and isolation of samples [9, 10]. A larger, stationary version of the developed drill module is also considered, which can be used for Earth research or fitted on a larger rover. A depth of up to 1 meter is expected to be achievable. An important addition in the works is a UV radiation sensor, as part of the environmental sampling module.

A highly promising solution is the use of solar panels as part of the Power supply module, an approach adopted by various already-existing exploration rover projects [12, 13, 14]. However, the idea is not as straightforward in execution as in vehicles and devices operating on Earth—the distance and position of other planets in regards to the Sun, proper solar cell selection and consideration of an energy storage system for contingency or highest demand situations. A design of a collapsible solar array, for preserving the rover's mobility and stability when not charging, is possible.

4. CONCLUSIONS

In this paper, the main capabilities of a proposed Sample Collection and Containment System have been summarized. This proposal is a simple and effective solution to the challenge of surface sample retrieval and transport.

The testing performed so far provides a confirmation of the effectiveness of drilling and sample collection down to 20 cm when mounted on the designed small-scale rover. The design of the sampling and drilling system can be scaled up appropriately for larger rovers.

Further tests are now planned to enhance the rover's system capabilities of detecting substances and materials of higher interest, in view of the space colonization objective, as well as Earth surface research.

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