TESTING FACILITY DEDICATED TO AUTONOMOUS SUBSURFACE AND MINING OPERATIONS IN PLANETARY ENVIRONMENT

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ABSTRACT

Subsurface regions are especially interesting for exploration and utilization of planetary bodies. The subsurface planetary environment is specific and hazardous due to, i.a., reduced gravity, vacuum conditions, temperature and aggressive chemistry. The design of devices oriented for operations in such environment with potential failures require design techniques focused on low TRL/low cost hardware experiments. A new facility where complex surface and subsurface operations could be validated was developed at CBK PAN. This two level facility allows for tests of surface operations such as rover navigation and motion in sandy terrain, as well as drilling from the top level into a 2.2 m long tube, filled with regolith or rock, that can be rotated to simulate reduced gravity conditions.

1. INTRODUCTION

In recent years, the interest in exploration and utilization of planetary bodies has been shifting from surface to subsurface regions. From scientific point of view, this includes remote measurements taken by spacecrafts and in-situ measurements taken by landers and rovers operating on planetary surfaces. The best examples are the results of the Moon polar regions characterization done by the Lunar Reconnaissance Orbiter [1] and comet nucleus characterization done by the instruments onboard the Philae lander [2]. From commercial perspective, this process is accompanied by a growing interest in utilization of planetary bodies: mining of the specific resources [3] or lunar base development (e.g. [4] and [5]).

In Europe, there are a few testing facilities where some mining subsystems can be tested. For example Selex and AVS companies developed testing facilities to check performance of their sampling devices. Other penetrometers were tested either in DLR Bremen [6] or in CBK PAN in Warsaw [7] to check penetrometer operations under the surface and in reduced gravity. For the Exomars mission, Selex also developed a facility to test their drilling system [8]. A melting probe was tested in Space Research Institute, Austrian Academy of Sciences in Graz [9]. In context of future Phootprint mission, Airbus Stevenage plans to perform tests of a sampling chain on air bearing table in CBK PAN [10].

In this paper, a new testing facility dedicated for autonomous subsurface and mining operations is presented. The main purpose of this facility is to test devices such as drilling and coring mechanisms, sampling devices, penetrometers, and different types of sensors in subsurface operational conditions. In addition, a test plan of an Ultralight Mobile Drilling System (UMDS) is presented.

This paper is organized as follows. In section 2, utilization of space resources is presented. Section 3 is focused on the new testing facility, and the example test campaign is described in section 4. The paper concludes with section 5, presenting its conclusions.

2. SPACE RESOURCE UTILIZATION

Based on available data, it is possible to define four categories of accessible resources in the Solar System that can be potentially extracted and sold. These are platinum group metals, water as a source of propellant, rare earth elements and structural elements for 3D printing (Al, Si, Ti). Detailed analysis of the economic values of all these resources, together with technical constraints, is provided in [4].

In most space agencies, initialized were specific activities focused on space resources utilization. However, much more effort of industrial and research community is needed to make a vision of space exploration and utilization more realistic. Three major fields play a crucial role in that process. The first field is related to new technology and testing infrastructure development. This should be done by consortia composed of space hardware specialists understanding space environment and companies developing technology for terrestrial mining industry. The latter can bring to the teams particular knowledge about how to handle with very specific processes like deep drilling or excavation, especially in the context of hardware-reliable operations. The second field is related to establishing appropriate business and policy environment for such activities. This should include: definition of technological missions, which allow testing technology in operational conditions, and establishment of a market for business activities such as selling goods obtained from the Moon or asteroids. Last but not least, interactions with public are crucial to increase the community acceptance of space activities.

3. TESTING FACILITY DEDICATED FOR SUBSURFACE OPERATIONS

Mining processes in terrestrial application are well known, because they evolved through hundreds of years from crude mining of the Bronze Age to high industrialization and computerization of the present day. On the top level, mining process can be divided into the following phases: the prospecting phase when resources are documented, the surveying and preparing phase when first operations are tested, the excavating and processing phase when full scale tasks are realized and, finally, the transportation of products. Each of these phases is connected with a different type of devices. However, most of them have a common feature: an interaction with soil, rock or regolith. Over the years, on the experimental basis, special rules to handle key issues related to such interactions were designed and developed, e.g. operational procedures to handle device failures. Unfortunately, these procedures usually involve human operations, since it is the most effective solution in terrestrial environment.

There is a principal difference between research activities connected with drilling in terrestrial and in space conditions. In the first area, the effort is focused on production optimization for maximum economic recovery. This can usually be done by increasing the penetration rate and power of the system. In space conditions, the time of drilling is not an important factor, while minimization of mass and power consumption has the highest priority. In addition, planetologists indicate the need to sufficiently secure the samples gathered by drills in terms of cross contamination in the borehole as well as influence of the heat dissipation during the drilling process. These effects are especially important for lunar conditions, where volatiles are very active and there is significant temperature gradient in vertical direction.

The surface and subsurface extraterrestrial planetary environment is very specific and hazardous, mainly due to: reduced or near zero gravity, vacuum conditions, electromagnetically charged dust, temperature and temperature gradient, and aggressive chemistry through possible appearance of volatiles. Such conditions are dangerous for any mechatronic devices that are typically needed to access subsurface regions.

The abovementioned reasons were a driver for CBK PAN to start an initiative to develop a testing facility where complex surface and subsurface operations couldbe validated. The design of the testing facility is based on two shipping containers installed one on the other to provide two levels: top and bottom.

On the top level, surface operations such as: mobile rover navigation, image acquisition, motion in sandy terrain can be validated. On the bottom level, a 2.2 m long tube installed, into which any regolith or rock can be easily stuffed. If needed, the tube can be rotated to a defined angle to achieve the desired gravity conditions. The details of design are presented in Fig. 1.

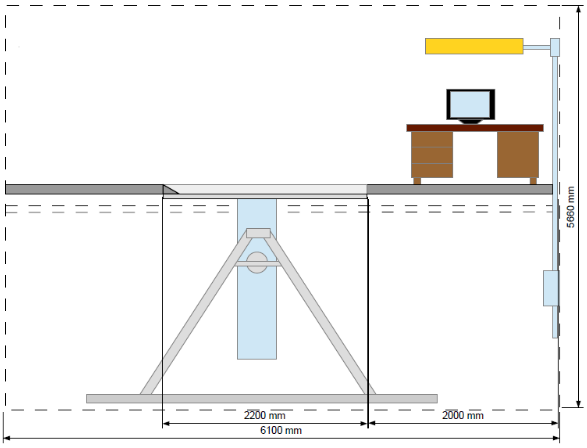


Figure 1. The design of the two level testing system.

The containers were integrated together with all equipment as shown in Fig. 2.

Figure 2. The test facility after integration.

4. MOBILE DRILL EXAMPLE

In the frame of a Polish national project, the UMDS dedicated to planetary environment was developed [10]. The system consist of three major subsystems: (i) mobile platform, (ii) support subsystem and (iii) drill head (Fig. 3).

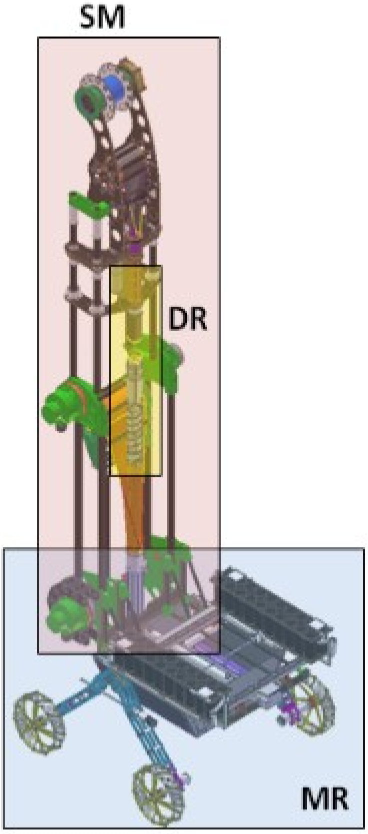


Figure 3. The mobile drilling system designed by CBK PAN and AGH University of Technology. MR – mobile robot, SM – support module, DR – drill head.

The main features of the system result from its mobility, provided by its integration with a rover, and from the special design of the support module that takes advantage of tubular booms to guide the drilling subsystem. The latter is designed to reduce the path for cuttings and to be applicable for operation in vacuum conditions. At the system level, the UMDS was designed to reduce both its mass and its power consumption in each operational phase. The system is also considered for terrestrial applications, for which it may be tested with a UAV helicopter.

As a result of the 3-years project, a prototype was designed, manufactured and assembled (Fig. 4).

The testing procedure of the mobile drilling system focuses on validation of its key functions, i.e. (i) autonomous navigation in unknown terrain towards a specified point, (ii) preparation for drilling operations including anchoring, unfolding the support module and setting appropriate drilling parameters, (iii) drilling and acquiring samples from the whole borehole, and finally (iv) transportation of samples to the initial point.

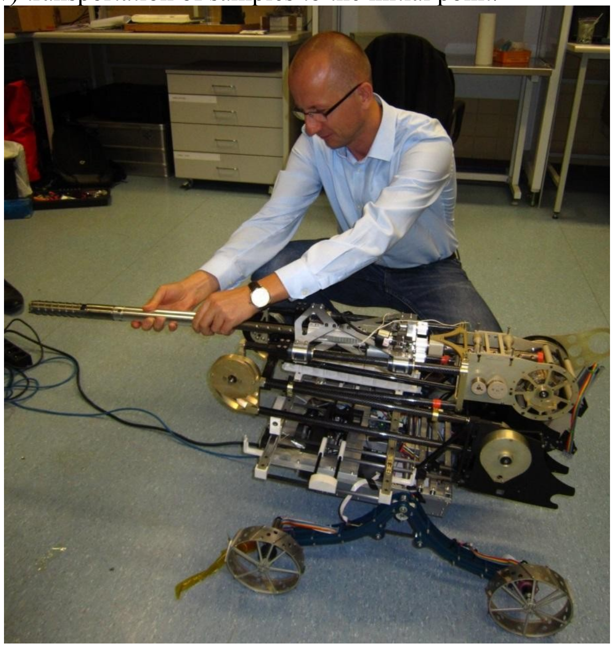


Figure 4. Integrated prototype of the mobile drilling system (UMDS).

To perform the tests, the following operations in the tests facility are planned:

- Execution of the final phase of mobile robot autonomous navigation with aim to reach desired point with accuracy of about 30 cm.
- Validation of the anchoring operation through measurement of the reaction force. Its vertical component should not be higher than the weight of the UMDS.
- Checking the support system unfolding operations with aim to measure the accuracy and reliability of the process. In addition the horizontal force component will be measured during this operation.
- Validation of drilling process, especially in context of the acquired amount of sample, core breaking, drilling parameters (applied vertical force, torque), reactions on mobile platform and failures detection.
- Collecting samples into a sampling container located on the mobile rover.
- Processes needed to end drilling actions such as: disconnections from borehole securing system and support module folding.
- Navigation to the initial point.

These operations are presented in Fig. 5 and Fig. 6 on the following page.

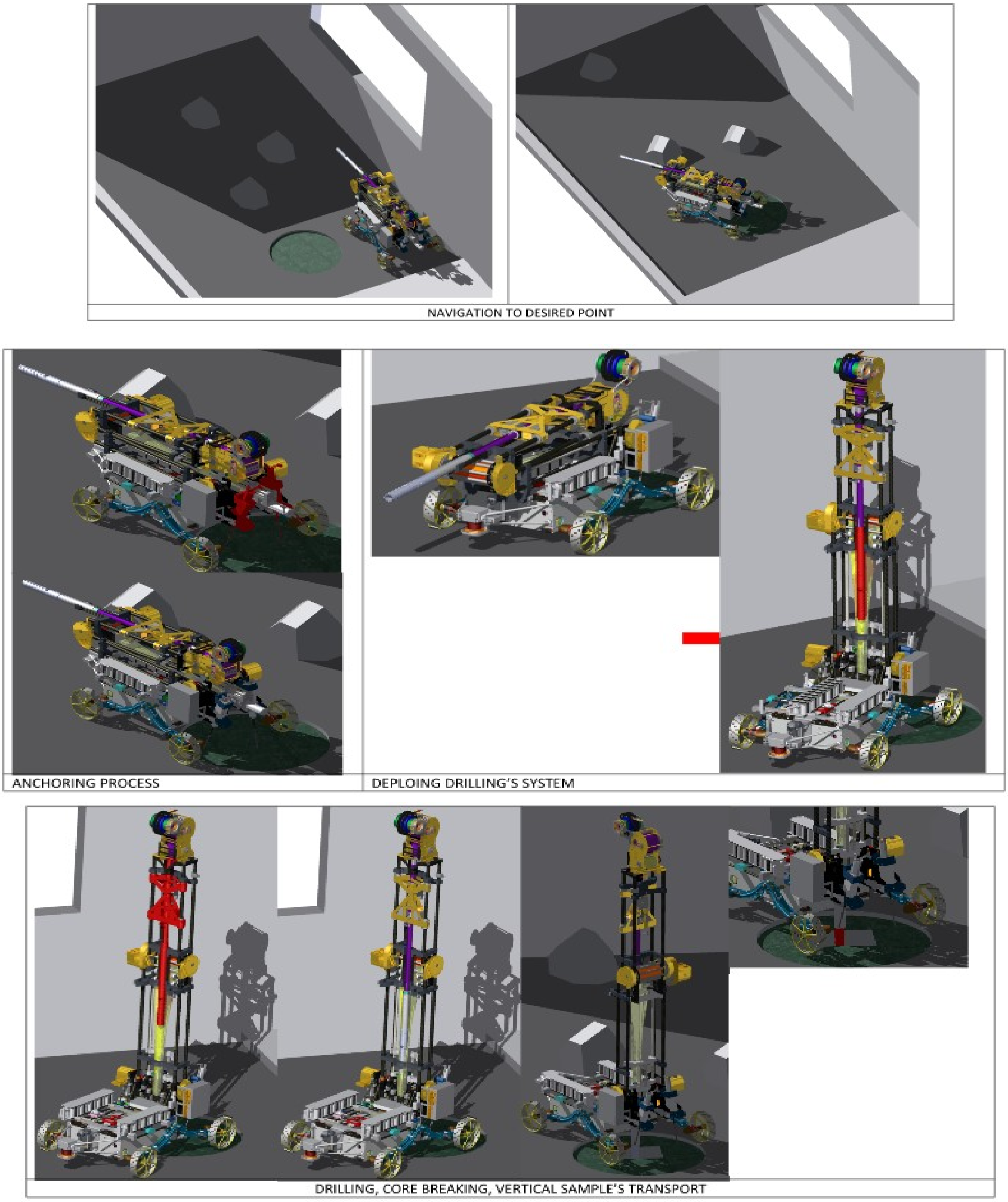
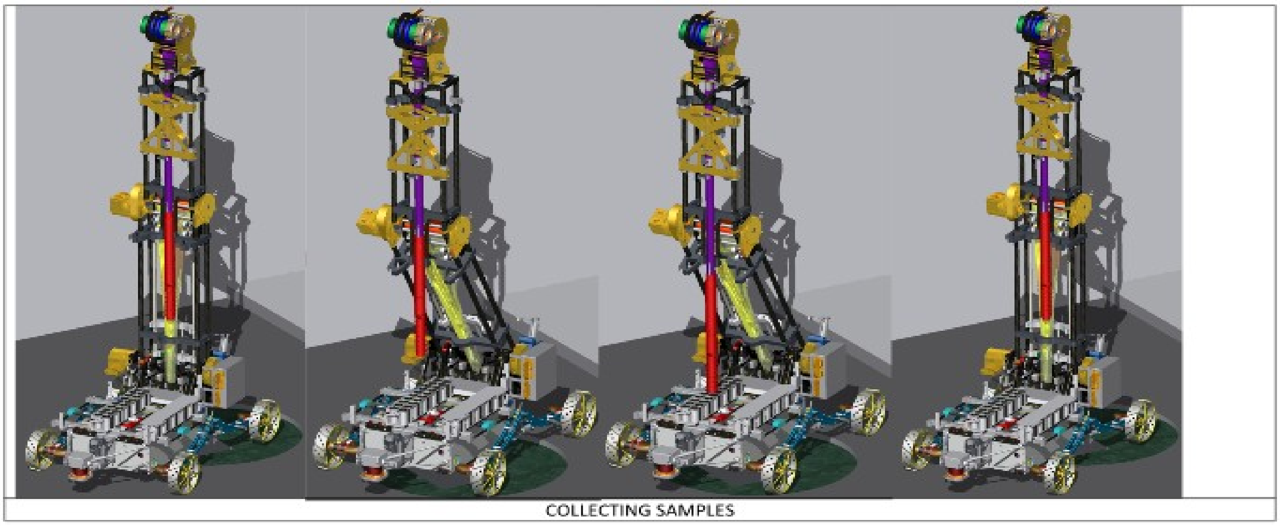


Figure 5. Processes of the UMDS, part 1


COLLECTING SAMPLES

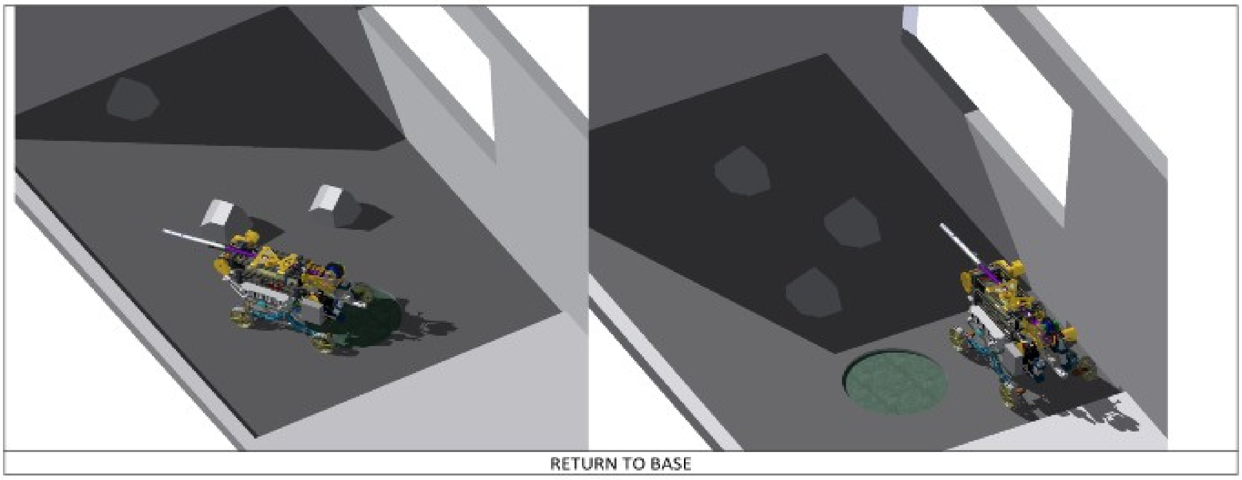

RETURN TO BASE

Figure 6. Processes of the UMDS, part 2

5. CONCLUSIONS

In this paper the new testing facility dedicated for autonomous subsurface and mining operations is presented. Its main purpose is to test devices such as drilling and coring mechanisms, sampling devices, penetrometers, different types of sensors in subsurface operational conditions. Currently, the first phase of the testing facility development has been finished. The laboratory has two floors. On the top floor, any hardware like a lander or a rover can perform surface maneuvers. In a dedicated area, the device can perform subsurface operations up to the depth of two meters. On the bottom level, the regolith/rock material sample can be set to be accessible from the top level. In addition, this sample can be monitored to measure the drilling parameters during operations. In the near future, it is planned to perform a test of the UMDS which was developed in CBK PAN and AGH University of Technology.

It is important to add that hazardous space planetary environment and design of devices oriented for operation with potential failures require special design techniques. These techniques are focused on low TRL/low cost hardware experiments and easy access to testing facilities. Their wide implementation requires reorientation of agency approach to space technology design, which on low TRL level is mainly focused on simulation. It this case, a special effort should be made to prepare appropriate design paths (ECSS norms) to underline an experimental approach.

6. ACKNOWLEDGMENT

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