SPACE RESOURCES HANDLING SYSTEMS FOR LUNAR, MARTIAN AND SPACE MISSIONS

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Introduction: This abstract presents the development of ISRU technologies designed for the effective handling, conveyance, and transportation of space resources, including: (1) Conveying regolith from excavation zone to processing facilities on Lunar / Martian surface, (2) Continuous feeding regolith to analyzers and processing devices on lunar landers and rovers, (3) Conveying large volumes of regolith for lunar construction works, (4) Stockpiling and contained storage of raw materials, (5) Filling flexible or inflatable fabric materials to build structural elements for lunar architecture, (6) Transporting raw materials between celestial bodies, vehicles, space shuttles, storage vessels etc., (7) Handling and mechanical processing regolith (crushing, sieving, mixing, sifting etc.).

There will be a rising need for efficient, adaptable technologies for handling larger regolith quantities for a wide range of ISRU applications. Some of the challenges in regolith handling are abrasive nature of regolith, temperature extremes, dust emission, static electricity, site/conveying route changes, limited power supply, launch weight limitations, and low gravity.

Technology Development: Within this project's scope, Polimak has developed a range of systems and technologies tailored to address specific challenges in space resource handling. These systems are designed to provide solutions for the following tasks, with a combination of these tasks tailored to meet the specific needs of various missions:

Conveying: A special type of conveyor was developed to convey regolith through modular, motor-driven rotating drums with internal flights, adaptable for varying distances and routes. Regolith is transported within these drums, minimizing abrasion and contact with moving parts. Additionally, it includes processing features like sieving and mixing. Its simple design is conducive to 3D printing of main components, potentially using available regolith. The modular conveyor design significantly enhances energy efficiency and utilization by at least 50% compared to lunar rovers, which spend a substantial portion of their operational time returning empty to the loading area. By strategically deploying a system where 90% of the conveying route is managed by this modular setup, and only relying on rovers or excavators for the critical remaining 10%, an exceptionally efficient method of regolith handling can be achieved.

Transportation on Lunar/Martian Surface: Modular drum conveyor can be mounted on lunar rovers for secure regolith transportation and easy transloading. The modular drum concept makes it possible to excavate loose regolith from the surface, store it inside the rover body and discharge it to another system such as processing machinery.

Space Transportation: A bespoke bulk material container has been engineered for efficient operation in zero-gravity, featuring an adaptable structure with movable sidewalls that facilitate the easy loading and unloading of materials.

Storage: Lunar regolith stockpiling offers a simple storage solution, advantaged by the lack of side winds that might disperse fine powders. For the Martian environment, an enclosed storage solution is advantageous. Modular drum conveyors and rovers work together to efficiently collect and store regolith. The choice between open stockpiling and enclosed storage influences the design of subsequent systems.

Dust Containment: The modular drum concept provides a contained conveying solution for powdered materials. Additionally, a lunar-grade telescopic chute system was designed to prevent dust emission during stockpiling.

Figure 1: Modular drum conveyor featuring horizontal and inclined routing.

Recent Developments: The project is structured to provide comprehensive solutions for space resource handling, advancing through stages of technology development, testing phases, and the identification of collaboration opportunities in a sequential manner, as follows:

Modular Drum Conveyor: Several prototypes of modular drum conveyors, both small and large scale, have been successfully produced and tested. The design allows for the conveyance of bulk material over long distances, including horizontal and inclined routes in various directions.

Excavation and Transport Rover: A rover with an integrated drum conveyor was developed, capable of excavating loose regolith from the surface, transporting it over longer distances, and transferring it to another device. Additionally, a compact modular drum conveyor with an inlet hopper has been designed to receive regolith from the rover, enabling both horizontal and inclined conveying for feeding regolith into subsequent processing systems.

Lunar Testbed Trials: The rover and conveyor are currently undergoing tests in the lunar testbed of PTS Space, Germany, to demonstrate a real use case involving excavation, transport, conveying, and processing of regolith. This could be among the first demonstrations globally to showcase an end-to-end handling of space resources with interconnected systems.

Collaborations: Discussions with companies specializing in moon base construction, landing pads, payload delivery, and rover services are underway to foster collaboration and integrate into the ISRU value chain.

Figure 2: Testing of excavation, transport, and conveyance of fine powders using rover and conveyor.

Further Technology Demonstrations: To cover wide range of space exploration needs, further scenarios will be demonstrated as follows: (1) Demonstrating the excavation and transportation of loose regolith using a rover's built-in modular drum conveyor, followed by transfer to a stationary modular drum conveyor for conveyance and stockpiling, aimed at lunar construction applications. A lunar-grade telescopic chute system to prevent dust emissions during stockpiling is under development and will be utilized in this demonstration. (2) Regolith processing and analysis devices on lunar landers or rovers require external feeding mechanisms, like a scooping robotic arm. The modular drum conveyor offers a solution for continuous and simultaneous feeding of multiple devices. A demonstration showcasing this conveyor's ability to collect and distribute regolith to devices on landers or rovers will be conducted on a lunar testbed. (3) The design and demonstration of storage and transport containers suitable for low/zero gravity environments, showcasing filling, transportation, and discharging operations of these containers. (4) Demonstration of packing regolith into tubular or uniquely shaped flexible fabrics and inflatable structures, involving the development of techniques to efficiently fill these structures with regolith and securely seal them to prevent spillage. (5) The utilization of swarm rovers equipped with modular drum conveyors to create a continuous conveyor system adaptable to any distance and route. (6) The demonstration of sieving and mixing regolith simulants using a modular drum design. (7) The production of the primary components of the modular drum conveyor through 3D printing using regolith simulants.

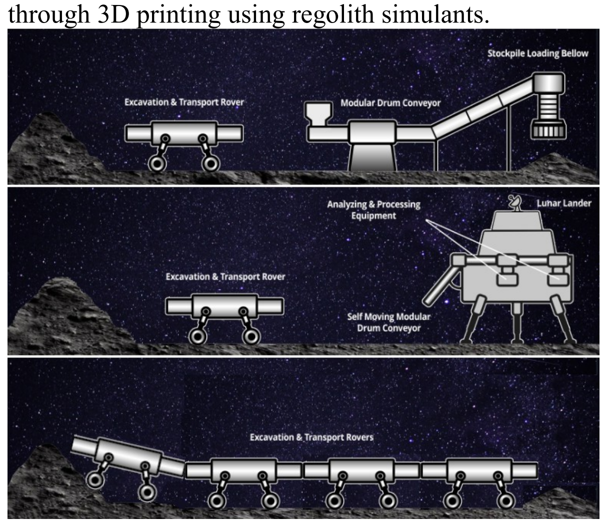

Figure 3: Lunar mission scenarios showing regolith excavation and stockpiling (top),continuous feeding of regolith analyzers on lunar lander (middle), conveying regolith with swarm rovers (bottom)

Upcoming Phases: In the upcoming phases of the project, the focus will be on enhancing the technology through continuous testing and demonstrations. Efforts will also be directed towards developing lunar-grade versions of the systems, which will undergo further testing on lunar testbeds and during parabolic flights. A significant aspect of this stage involves collaborating with companies and agencies within the space industry to utilize services like payload delivery, rovers, and lunar landers. This collaboration aims to integrate our systems into their operations, facilitating regolith processing, landing pad construction, and more. Additionally, the project will advance to conducting real lunar missions, marking a critical step in applying these technologies in actual space environments.