Reliable Regolith Handling: A Modular, Low-Power Conveying System for Handling Abrasive Materials in Space and Lunar Environments

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About

Who
Polimak is an engineering and fabrication company that specializes in bulk solids handling technologies for various industries.

What
Main product lines are bulk solid conveying, storage, loading, discharging dosing, dust collection systems.

How
- Designing and engineering bulk material handling systems.
- Manufacturing systems and components.
- Developing software for industrial automation systems in the bulk solids handling industry.

With
Over 100 employees

Where
Turkey, USA, Germany, England, Scotland

Terrestrial: polimak.com  Celestial: polimak.space
Our Aim In Space Tech

Utilizing our extensive terrestrial expertise in processing, conveying, and storing bulk solids, we aim to contribute to space tech, enhancing resource extraction from celestial bodies.

Key technologies for Lunar, Martian, asteroid, and zero-gravity environments:

- Interconnected conveying systems for extraction, processing, and transport units.

- Advanced storage and transportation systems for space resources.

- Systems enhancing logistics for more efficient space operations.
Challenges in Regolith Handling and Logistics

Regolith Handling Challenges

**Abrasive Nature:** Abrasive regolith can quickly wear down equipment.

**Temperature Extremes:** Handling equipment must withstand drastic temperature shifts.

**Dust Emission:** Sticking regolith dust can obstruct machinery.

**Static Electricity:** Static buildup poses risks.

**Site Changes:** Frequent relocations necessitate modular, portable systems.

**Power Supply:** Supplying power to conveying machinery and robots is a major challenge.

**Conveying Routes:** Conveying regolith from excavation to processing areas poses difficulties.

**Spare Part Supply:** Space travel logistics complicate machine spare part resupply.
Common Conveying Systems for Regolith Transport

- Auger/Screw Conveyor
- Belt Conveyor
- Pipe Conveyor
- Bucket Elevator
- Chain Conveyor
- Vibrating Feeder
- Pneumatic Transport
Utilizing Robotic Rovers for Regolith Transportation

Advantages of Robotic Rovers

- Autonomous Operation
- Precise navigation in difficult terrains
- Deploying multiple rovers can enhance operational scale.
- Flexible navigation paths for relocation of excavation sites

Disadvantages of Robotic Rovers

- Limited speed limits efficiency in transportation tasks.
- Open top body could cause dust spreading during transport
- Reliability issues due to harsh environments
- Maintenance challenges
- For large-scale operations, more rovers or trips are needed.

Robotic Rover Economics

Time Consumption
- 50%: Empty, traveling back from the processing area to the excavation site for reloading.
- 5-10%: Loading and unloading activities
- 5-30%: Charging or battery replacement
- 20-40%: Payload transport

Energy Consumption
- 75%: For moving robotic rover itself
- 25%: For moving payload

* values are estimated

Credits: ICON/BIG-Bjarke Ingels Group
Modular Drum Conveyor

The conveyor system uses connectable, rotating drums with inner helical flights to transport bulk materials along a flexible path while they rotate.

With its modular, building blocks like design, the conveying system is easily adaptable to process needs, making it perfect for wide range of regolith conveying applications.
Modular Drum Conveyor

KEY FEATURES

- Modular design allows limitless configurations and simple assembly.
- 50% of the parts can be made from extraterrestrial materials.
- Reduces abrasion via rolling regolith particles instead of sliding.
- Fully-contained system prevents dust emission and component contact.
- Suitable for low or zero gravity.

Single inlet, single outlet conveying on moon surface

Double inlet, single outlet conveying on moon surface

Single inlet, single outlet conveying on asteroid surface
Comparison With Other Systems

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Modular Drum Conveyor</th>
<th>Auger</th>
<th>Robot Trucks</th>
<th>Belt Conveyor</th>
<th>Pipe Conveyor</th>
<th>Vibrating Feeder</th>
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<td>Static Electricity</td>
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*Closed-loop pneumatic conveying systems can operate in a vacuum environment.

**PS:** Table compares conveying systems for regolith handling. It gives a general overview and does not account for all possible technologies and variations. The suitability of each method may change with new developments.

**Improving Operational Efficiency**

Modular drum conveyors are suitable for short to long distance conveying and gathering from multiple extraction sites, while robotic rovers excel at short-distance transportation. Integrating both systems presents an optimum mix of efficiency and flexibility.
Current & Future Work

Current Work
- Technical designs of key components were completed.
- Patent application completed.
- Small scale prototypes produced.
- Preliminary tests were done.
- TRL 5 for terrestrial applications is reached.
- Terrestrial commercialization efforts started.
- Started preparing full scale prototype for field tests.

Future Work for Terrestrial Applications
- Full scale prototype tests (within 2 months).
- Configuration management studies for different bulk materials, capacities and conveying routes (within 8 months).
- Design improvements (within 8 months).
- Real life testing in operational environments (within 8 months).
- Technical documentation and certification (within 12 months).
- Reaching TRL9 (within 12 months).

Future Work for Celestial Applications
- Procurement of space grade motor & gearbox (within 4 months).
- Testing with regolith simulants (within 8 months).
- Primary design improvements (within 12 months).
- Collaboration with space agencies, companies and institutes (within 12 months).
- 3D printing of parts with molten regolith (? depends on availability).
- Zero gravity testing (?).
- Testing on moon (?).
- Secondary design improvements after tests (?).
Thank You

Questions?
Thank You

Questions ?
What You Need to Know About Lunar Communications

June 2023

Sarah Withee and Danielle Mortensen
Extreme Access Focus Group
JHU Applied Physics Laboratory

Sarah.Withee@jhuapl.edu Danielle.Mortensen@jhuapl.edu
Terrestrial vs Lunar Comms
Availability, Accessibility, and Duration

**Terrestrial**

Call anyone with a phone number, anywhere, at any time without reservations or blackouts and talk for however long you wish.

**Lunar**

Set up contact schedule with your provider, most likely for limited duration communications (minutes to hours at a time). At present, you can only contact your service provider. There is no network to connect you to other users.
Choose a cellphone provider

Choose pre-built hardware (iPhone, Android, etc) that works with the network

Sign contract with provider and pay fees

Call anyone with a phone number, anywhere, at any time without reservations or blackouts, even if they have a different service provider. Pay a flat rate for voice comms and a certain amount of data.
Lunar Comms: Current Process

1. Analyze radio propagation characteristics and communications availability of your operating location.
2. Select a ground station service provider.
4. Develop link budget & Apply to spectrum licensing for transmit (1-2 yrs min.).
5. Launch & communicate with your provider during scheduled time periods (no 24/7 comms).
6. RF compatibility testing with your service provider.
7. Sign contract with provider and pay fees.
8. Integrate hardware.
Blackouts of Comms Services at Various Locations on the Moon

South Pole Direct to Earth (DTE)
- 8-14 day comms blackouts depending on location at the Pole

South Pole relay
- ESA Lunar Pathfinder best case 10 hours on 2 hours off for South Pole (starting in 2026)
- Parsec No blackouts as long as you have a view of the sky (starting in 2025, according to LSIC comms subgroup presentation 5-17-2023)

Far Side – no DTE, relay only

Availability and duration of relay services will depend on provider

In all locations, local topography will also affect comms availability
Factors Limiting Availability of Lunar Comms

**Direct to Earth (DTE) Comms**

- Location on the Moon
  - Do you have a view of Earth?
  - Does lunar topography permit communication (i.e. no mountain blocking your signal)?

- Is your Earth ground station in view?
  - Just because you can see the Earth doesn’t mean you can see your ground station

- Is it your allotted time to communicate with your provider?
  - Ground station service providers generally utilize a time-division model for comms

- Radio frequency interference
  - We’ve seen this already at Mars, and that was with only ~13 missions operating

**Relay Comms**

- Are there relays that service your location on the Moon?
  - Initial services are focused on South Pole

- Is the relay satellite in view?

- Relay services will provide comms to multiple clients
  - This may limit time available to any one client for comms

- Radio frequency interference
  - We’ve seen this already at Mars, and that was with only ~13 missions operating

At present there is no “roaming” from one provider to another. This may change, but for now, your mission can only communicate with your comms provider and no one else.
Delays

Delays will be part of the system, so plan for them!
Includes light time delays and travel time from ground stations to mission ops centers.

Earth-to-Moon
~2.6 seconds round trip light time
Surface-to-Surface Comms

- Currently limited to line of sight (~2 km or less depending on topography)
  - Due to lack of atmosphere for bouncing signal
- Network infrastructure is in very early stages of development
  - Tech demo from Nokia of LTE/4G tech happening in sometime in 2023
  - Mission will gather data needed on RF propagation and regolith properties to help validate models used to design cell networks
Implications for Mission Planning and CONOPS

- DTE comms blackout and lunar night do NOT always occur at the same time.
  - If you are using DTE and you are solar powered/need light to operate, you may not be able to communicate during light periods.

- Delays of 2.6 seconds are substantial for teleoperation.
  - Delays of greater than 0.4 to 0.5 seconds significantly degrade the performance of human operators.
  - Need to account for the performance hit due to time delay.

- Rover missions will have different (and more complicated) comms issues than stationary installations.
- Comms availability depends on your location and whether you are doing DTE or relay.
Questions to Ask Your Comms Service Provider

• Recommend reviewing the Lunar Pathfinder Services Guide to get an idea of what questions to ask:
  • [https://www.sstl.co.uk/getmedia/ea388951-1330-4746-b641-72b7cd65f05a/Lunar-Pathfinder-Services-Service-Guide-V2-3.pdf](https://www.sstl.co.uk/getmedia/ea388951-1330-4746-b641-72b7cd65f05a/Lunar-Pathfinder-Services-Service-Guide-V2-3.pdf)

• What is your pricing model?
  • Per bit? Per minute? Something else?

• Do you provide…
  • A comms terminal? Or is the mission responsible for providing radio hardware?
  • Spectrum licensing? Or will the mission be responsible for filing the paperwork for a transmit license?
### Upcoming Lunar Relays (Subject to Change)

<table>
<thead>
<tr>
<th>Lunar Pathfinder (ESA)</th>
<th>Khon2 (Intuitive Machines)</th>
<th>COMMSTAR-1 (CommStar Space)</th>
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</thead>
<tbody>
<tr>
<td>• Anticipated in-orbit services by 2026</td>
<td>• Operations planned to start in ~2023</td>
<td>• COMMSTAR-1 anticipated to arrive by 2023</td>
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<tr>
<td>• ESA commercial relay satellite</td>
<td>• Relay services for spacecraft in cislunar space and on the Lunar surface</td>
<td>• Optical and radio frequency relay services</td>
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<tr>
<td>• Transmission to Pathfinder over X-band</td>
<td>• Plan to have 5 data relay satellites in a variety of orbits</td>
<td>• “For commercial and government users on and around the Moon”</td>
</tr>
<tr>
<td>• Intended to support Lunar robotic missions</td>
<td>• Khon satellites developed by York Space Systems, but owned and operated by IM</td>
<td>• Working with industry to “permit ‘On-Net’ access to an existing, privately-financed,</td>
</tr>
<tr>
<td>- Moonlight is an SSTL follow-on intended for human missions</td>
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<td>multi-billion-dollar, diverse global infrastructure – space, ground, fiber, cloud</td>
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<td></td>
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<td>storage, hardware, and software”</td>
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</table>

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=IM-3-NOVA
https://www.intuitivemachines.com/lunar-data-services
https://www.esa.int/ESA_Multimedia/Images/2021/09/Lunar_Pathfinder
Upcoming Lunar Relays (Subject to Change) Cont’d

**Parsec (Lockheed Martin)**
- Services missions on the Far Side and Lunar South Pole
- Two commsats in place by 2025
- Low and high data rate options
- Real time and store-and-forward options
- Also provides Doppler and two way ranging for positioning

**Near Space Network**
- Run by NASA, but NASA purchases services from commercial providers
- “The network will act as a one-stop-shop for mission teams, helping with planning and design, spectrum management, launch, operations in orbit, and more.”

**Lunar Gateway**
- Supporting human crewed missions to lunar South Pole
- Can support up to 3 simultaneous lunar surface users

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https://www.nasa.gov/russia/2023/nasa-seeks-commercial-near-space-network-services


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23 June 2023