SOFTSERVE'S MULTI-ROBOT ON THE MOON: EXPLORATION AND MINING

Enabling sustainable space missions through advanced robotics

softserve

The discovery of ice at the Moon's poles, inferred by several different instruments on lunar orbiters and by an impactor experiment, has unlocked a transformative potential for space exploration. This ice, located in permanently shadowed craters and beneath the lunar surface, can be converted into critical resources such as water, oxygen, and hydrogen-based rocket fuel.

These resources are essential for supporting life and powering future missions, significantly lowering the cost of long-term space exploration. Using lunar ice, the Moon could become a strategic hub for deeper space missions, including Moon-to-Mars expeditions. Resource extraction is vital to making space travel more sustainable and economically viable.

STUDY FOCUS

This white paper explores **SoftServe's multi-robot ecosystem** designed to simulate and optimize the extraction and processing of lunar resources efficiently. This simulation-first approach provides the ability to design adaptability and scalability into future lunar operations:

Simulation-First Development: Utilizing NVIDIA Omniverse™ and Isaac Sim™ for high-fidelity lunar environment simulations.

Multi-Robot Ecosystem: Enables collaboration between excavators, haulers, and thruster-driven drones powered by AI-driven navigation and decision-making, which can be extended to other types of vehicles, robots, and structures.

Sustainability Focus: Reduces reliance on Earth-based supplies by creating scalable, efficient solutions.

By integrating advanced simulation technologies and robust robotics, the system addresses challenges such as energy efficiency, extreme environmental conditions, and autonomous collaboration.

LUNAR RESOURCE POTENTIAL

The current cost of sending cargo to the surface of the Moon is a staggering **$1.5 million per kilogram**. However, these costs could be significantly reduced by utilizing lunar ice to produce rocket propellants, making lunar missions more **economically viable**. Extracting resources directly from the Moon also promotes sustainability by reducing the reliance on Earth-based supplies, enabling longer, more self-sufficient space missions.

The Moon could become a vital depot for fueling future expeditions and supporting the aerospace, mining, and construction industries. NASA's lunar outpost plans and the growing commercial space sector would contribute to a future where lunar resources drive space exploration beyond Earth. This infrastructure would make deep-space missions more feasible and open the door for robotic exploration and resource utilization on other planets, such as Mars.

REDEFINING RESOURCE EXTRACTION APPROACH

Lunar resource extraction presents unique challenges, including harsh terrain, extreme temperatures, and communication outages. These factors make traditional single-robot operations inefficient and high-risk. Multi-robot fleets are essential because they enable autonomous collaboration, provide risk-reducing redundancy, and allow for scalability. That ensures continuous operations even if individual robots fail. Unlike single units, coordinated fleets can simultaneously map, excavate, transport, process resources, and construct various structures — significantly improving efficiency.

Current methods that rely on Earth-controlled rovers or limited automation cannot scale to meet the demands of sustained lunar missions. **SoftServe's mission orchestrator** addresses these challenges by seamlessly integrating diverse robotic teams, optimizing task execution, and ensuring real-time adaptability. This makes large-scale lunar operations feasible and sustainable. This solution is critical for any organization looking to deploy robotics beyond Earth.

ROBOTICS AND SIMULATION TECHNOLOGIES

1. **Simulation Platforms**: SoftServe's partnership with NVIDIA enhances simulation capabilities in space system development. Using NVIDIA Omniverse™ and Isaac Sim™, SoftServe adopts a simulation-first approach, replicating many aspects of harsh lunar conditions with high fidelity.

2. **AI Integration**: Powered by ROS2 and SLAM algorithms, SoftServe's robots autonomously map, navigate, and interact with lunar environments.

3. **Terramechanics Modeling**: Advanced terramechanics ensures precise simulations of lunar soil interactions, allowing to optimize excavation techniques by design and autonomously during operations.

ROBOTICS DESIGN

In the multi-robot simulation ecosystem, SoftServe applies **Physical AI** which involves AI-driven physics modeling and optimization, crucial for precise simulation, control, and decision-making in challenging environments. This technology is integrated with multi-robot SLAM, enabling real-time mapping and navigation for autonomous robots. The use of Physical AI ensures that robots can make informed decisions based on real-time data, enhancing their ability to perform complex tasks in unpredictable environments.

The robotic fleet is powered by a **mission orchestrator**, enabling autonomous decision-making and collaboration. In the context of lunar exploration, the mission orchestrator enables the robots to perform tasks such as navigation, resource extraction, and communication with other robots. SoftServe's multi-robot ecosystem, validated through simulation, includes:

EXCAVATORS

Drive efficient resource extraction

HAULERS

Transport resources to lunar outposts

DRONES

Designed for mapping and reconnaissance

Additionally, we apply **terramechanics** to create precise modeling of the behavior of the Moon's regolith-dominated surface, enabling robots to adapt to the unique challenges posed by lunar terrain while moving or excavating. Combined with sophisticated **robotic perception technologies**, SoftServe's multi-robot system offers superior navigation and manipulation capabilities, which are essential for the unpredictable nature of lunar missions. By performing **heterogeneous robotics fleet simulation**, SoftServe ensures that different types of robots can collaborate seamlessly to achieve a common goal. This ability to simulate the collective mission of a diverse fleet is critical for optimizing task efficiency and minimizing operational risks.

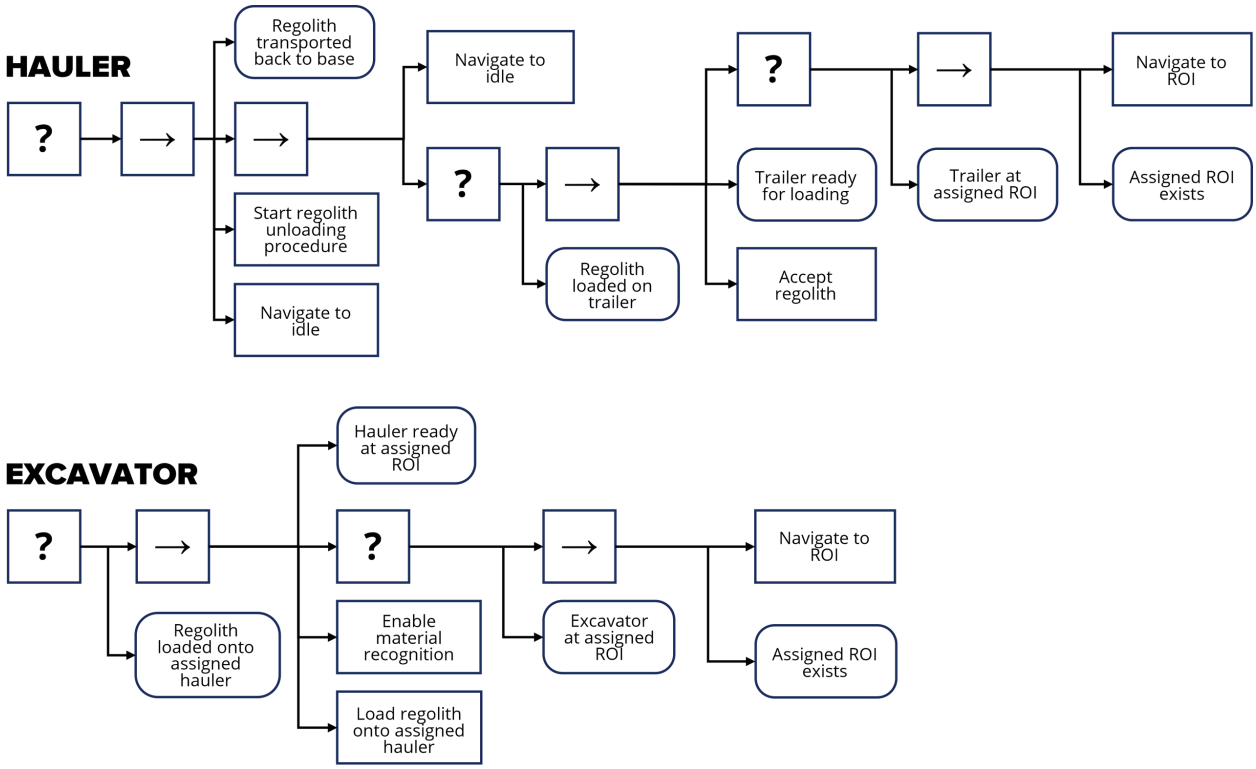


Figure 1: Snippet of the L-REX Excavator and Hauler behavior tree diagram.

The mission orchestrator coordinates the simulated robots' actions. For example, the **L-REX** excavator uses the mission orchestrator to sequence its actions. First, it navigates to a designated mining site identified from lunar drone mapping, then it checks the soil conditions, and finally, it begins the excavation process. If any step fails, the mission orchestrator can trigger fallback mechanisms to handle the failure, such as reattempting the navigation or switching to an alternative task.

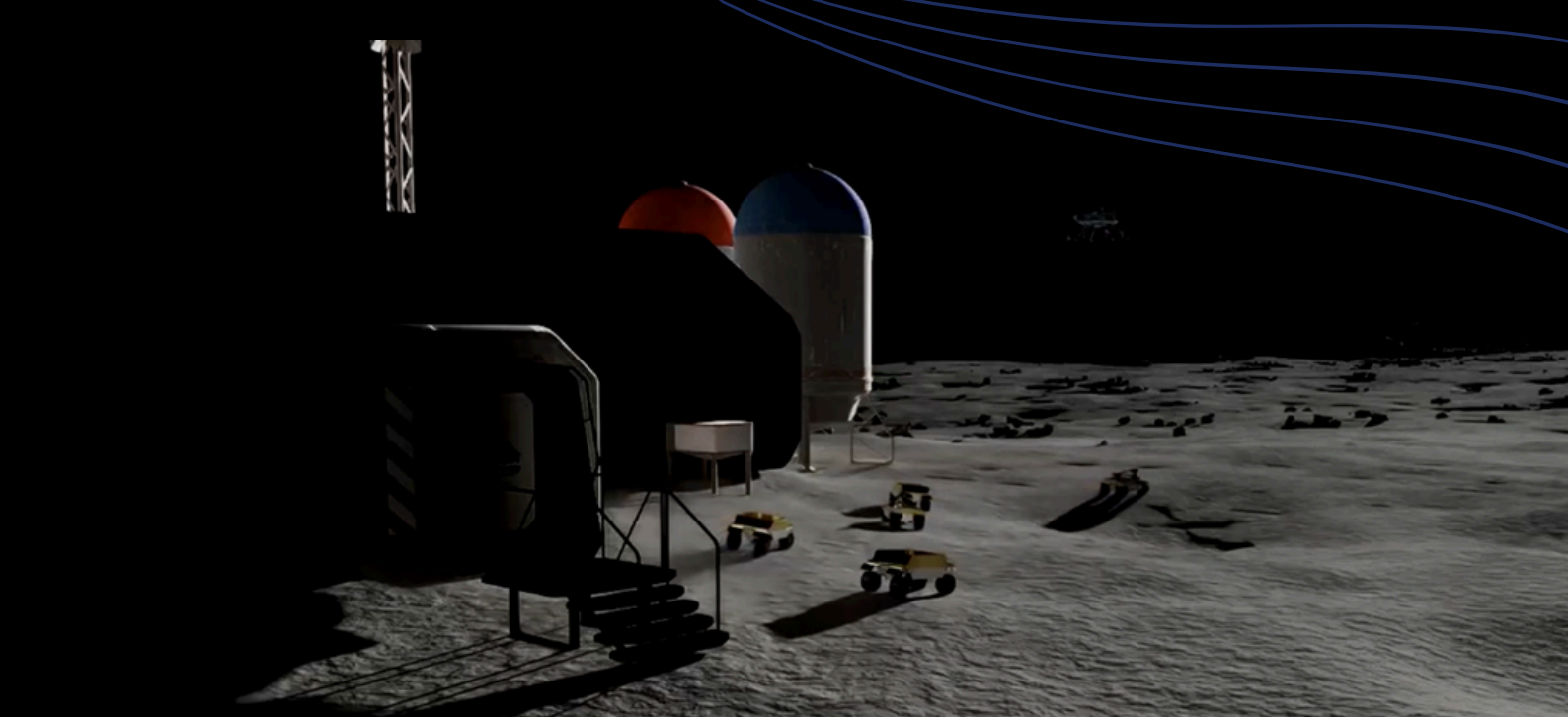


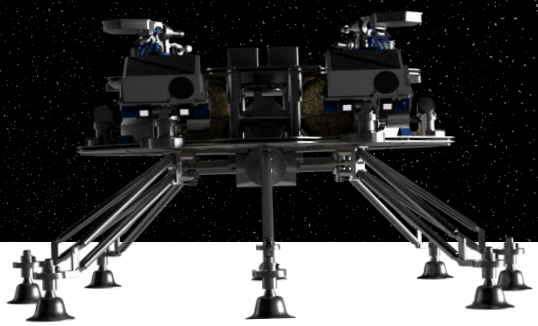
Figure 2: Multi-robot mission approaching the lunar outpost.

In highly unusual or extreme conditions, the mission orchestrator is particularly effective. For instance, if a **hauler** experiences a mobility failure due to terrain issues, the mission orchestrator can command the drone (propelled by thrusters) to conduct an external assessment, and it can assign another one of the haulers to take over the task of the incapacitated one.

SIMULATION ENVIRONMENT USING NVIDIA OMNIVERSE

SoftServe's partnership with NVIDIA enhances simulation capabilities in space system development. This collaboration delivers a highly adaptable and cost-effective solution as SoftServe uses **NVIDIA Omniverse™** and **Isaac Sim™** to adopt a simulation-first approach for lunar exploration. It is complemented by SoftServe's Moon-like environment, which provides a realistic and comprehensive platform for testing multi-robot systems in complex lunar terrain and lighting conditions.

By leveraging **co-simulation (FMI/FMU)** and tools such as **Modelica**, **MATLAB**, and **ANSYS** to create high-fidelity simulations of multiple physical interactions, SoftServe reduces the risks and costs of real-world missions and accelerates development cycles. The environment also features advanced terramechanics modeling for simulating soil interactions and optimizing excavation techniques, enabling robots to adapt effectively to lunar challenges and enhance performance.



SoftServe's Moon-like environment visualizes the lunar terrain, enabling utilization of co-simulation and **synthetic data generation** (SDG) for creation of diverse datasets that mimic the Moon's unique conditions. This environment replicates realistic textures, lighting, and environmental variables, preparing the robotic systems for the challenges of lunar exploration.

These platforms enable co-simulation of robotic operations and physics scenarios, allowing for validation and optimization of resource prospecting and extraction processes — like soil interaction and path planning — before deployment.

EXPLORING PRACTICAL APPLICATION SCENARIOS

SoftServe's simulation offers diverse **mission use cases** that showcase the practical applications of its **multi-robot ecosystem**. In one use case, the autonomous multi-robot fleet works together to mine lunar ice deposits, guided by detailed 3D maps generated by the exploration drone during lunar surface surveys. These maps help the **L-REX excavators** identify optimal sites for digging, ensuring the most efficient extraction process. Once the ice is mined, it is transported by **haulers** back to the lunar outpost, where it is processed into oxygen and hydrogen — essential for producing breathable air, drinking water, and rocket fuel, reducing dependence on Earth for supplies.

A second use case emphasizes **energy-efficient excavation**. By utilizing **co-simulation with terramechanics**, the L-REX excavator simulation allows to optimize their digging techniques to conserve energy, a vital consideration given the power-limited environment common with most space systems. This allows for long-term sustainable operations, adapting dynamically to the Moon's diverse terrain challenges.

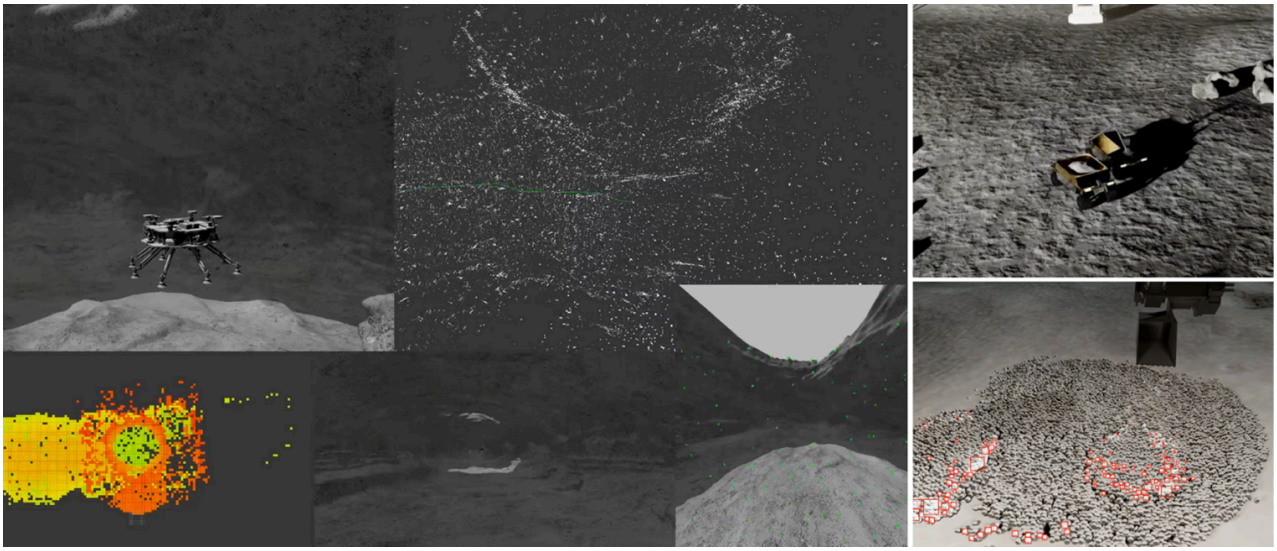


Figure 3: Multi-robot collaboration in action—locating, extracting, and delivering resources to the outpost.

The simulation also permits **redundancy plans** to be addressed to account for potential robot failures. For instance, if the lunar exploration drone fails, lower-grade satellite data from targeted observations could be used to help with resource prospecting. Haulers can be redistributed among the excavators, ensuring continued mission success. The simulation supports an **unlimited number of robots**, meaning mission scalability is limited only by computational resources. This flexibility makes SoftServe's ecosystem adaptable for lunar operations and future missions to Mars or other celestial bodies.

This also means that the multi-robot fleet can be deployed here on Earth, offering powerful solutions for industries like mining, construction, and agriculture. These sectors can benefit from autonomous collaboration, resource extraction, and improved efficiency.

- **Robots enhance safety and productivity in mining by handling hazardous tasks and optimizing resource extraction.**
- **In construction, robotic fleets streamline operations, from site surveying to material transport, reducing labor costs and increasing efficiency.**
- **Agriculture can utilize these technologies for automated planting, harvesting, and soil analysis, promoting sustainable practices.**

These scenarios demonstrate SoftServe's ability to **simulate real-world contingencies** and edge cases and ensure the robotic fleet's resilience and mission safety. By tackling mission-critical challenges like resource optimization, energy efficiency, and redundancy, SoftServe's advanced multi-robot system simulation represents a new frontier in space exploration, offering innovative solutions that can be scaled for larger, more complex extraterrestrial operations.

BRINGING LUNAR MISSIONS WITHIN REACH

SoftServe's advanced multi-robot system redefines lunar resource extraction through cutting-edge simulation and robotics. Leveraging NVIDIA Omniverse™ and Isaac Sim™, the system ensures efficient navigation, resource optimization, and resilience against operational risks. Scalable and adaptable, it supports future Mars missions and offers transformative applications in industries like mining, construction, and agriculture. SoftServe's innovative approach invites collaboration to drive sustainable space missions and groundbreaking terrestrial advancements.

SoftServe' robotics practice invites space agencies and commercial companies to collaborate in advancing technologies for lunar resource prospecting and extraction. With our proven expertise in robotic simulations and comprehensive end-to-end solutions, along with more than 20 years of overall team experience in space projects, we are uniquely positioned to help shape the future of space exploration.

We encourage businesses to leverage our innovative technologies to optimize their lunar and space missions. If you are interested in collaborating on ambitious lunar projects, don't hesitate to reach out.

SUMMARY

SoftServe's advanced multi-robot system redefines lunar resource extraction through cutting-edge simulation and robotics. Leveraging NVIDIA Omniverse™ and Isaac Sim™, the system ensures efficient navigation, resource optimization, and resilience against operational risks. Scalable and adaptable, it supports future Mars missions and offers transformative applications in industries like mining, construction, and agriculture. SoftServe's innovative approach invites collaboration to drive sustainable space missions and groundbreaking terrestrial advancements.

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Lutz Richter, Space Projects Expert at SoftServe, brings over 25 years of experience in space robotics, contributing to missions for ESA, NASA, and JAXA, including the ESA ROSETTA and NASA's Mars Exploration Rovers. He has developed planetary rover mobility systems, sample handling tools, and instruments for lunar exploration, while also serving as the President of ISTVS, advancing terramechanics for Earth and space.

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ABOUT US

SoftServe is a premier IT consulting and digital services provider. We expand the horizon of new technologies to solve today's complex business challenges and achieve meaningful outcomes for our clients. Our boundless curiosity drives us to explore and reimagine the art of the possible. Clients confidently rely on SoftServe to architect and execute mature and innovative capabilities, such as digital engineering, data and analytics, cloud, and AI/ML.

Our global reputation is gained from more than 30 years of experience delivering superior digital solutions at exceptional speed by top-tier engineering talent to enterprise industries, including high tech, financial services, healthcare, life sciences, retail, energy, and manufacturing. Visit our website, blog, LinkedIn, Facebook, and X (Twitter) pages for more information.

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