MISSION CONTROL

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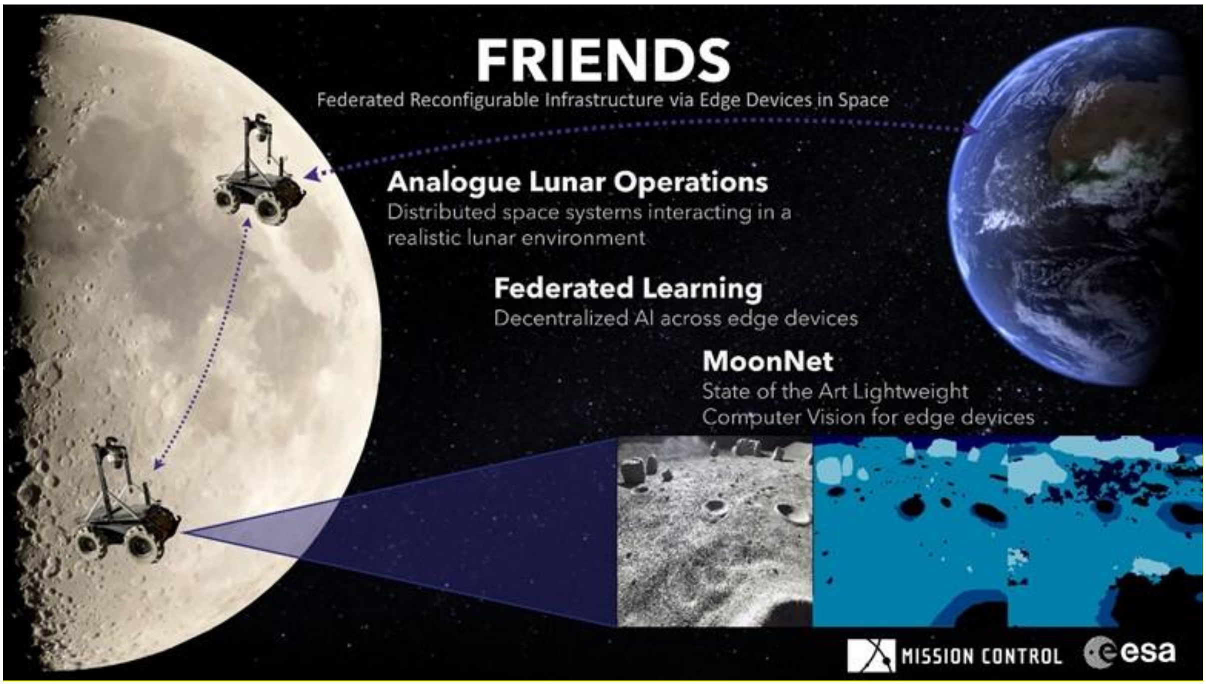

FRIENDS – Federated Reconfigurable Infrastructure via Edge Devices in Space

Executive Summary

Study

Campaign: Cognitive Cloud Computing in Space
Idea: I-2022-00378
MCSS.2105

Affiliation: Mission Control Space Services Inc.

Activity summary:
Mission Control is exploring a new distributed compute paradigm for space assets that use low-power hardware and deep learning to create a robust, versatile software framework applicable to future lunar exploration and operations scenarios. By deploying a flight-ready deep learning lunar terrain classifier, MoonNet, across a networked series a of lunar nodes, including rovers, Mission Control explores realistic operations scenarios including network dropouts, pseudo-labelling, and federated updates that keep data secure and avoid large data transfers back to ground stations back on earth.

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FRIENDS Executive Summary

Today's space missions rely on communication with facilities on Earth to achieve their objectives. As humanity moves forward with plans for the Moon and then Mars, as envisioned in the Global Exploration Roadmap [1-4], there will be both an increasing number of space and compute assets on other planetary bodies and increasingly complex needs from in-situ resource utilization to agriculture to space health. With the latest advances in intelligent agents, driven by the perception abilities of deep learning, this presents an opportunity to add greater autonomy and communication between assets, avoiding the communications bottlenecks and latencies that come with communicating directly with Earth.

Mission Control aims to build software-defined systems that can repurpose compute components and move away from single use spacecraft, towards a mission-agnostic paradigm. To achieve this goal Mission Control is combining low-power convolutional neural networks (CNNs), suitable for use on space hardware, with federated learning over a simulated lunar network, demonstrating greater data efficiency and privacy than if all raw data was routed directly to ground stations on Earth. We deploy the FRIENDS system in our analogue lunar environment, the Moonyard, to demonstrate its potential for reuse and reconfigurability in future lunar operations scenarios.

FRIENDS defines lunar nodes in a containerized software environment that uses the OpenFL [5] package to coordinate federated updates of deep learning software across distributed compute assets without exchanging raw data. We deploy MoonNet, an optimized convolutional neural network scheduled for lunar operations in 2023 [6], on the different lunar nodes and each node performs semantic segmentation of rover navigation camera imagery. Realistic training and testing imagery is gathered from Mission Control's Moonyard, a large lunar analogue environment with simulated solar illumination and rich geological features including regolith, craters, and rock outcroppings shown in Figure 1.

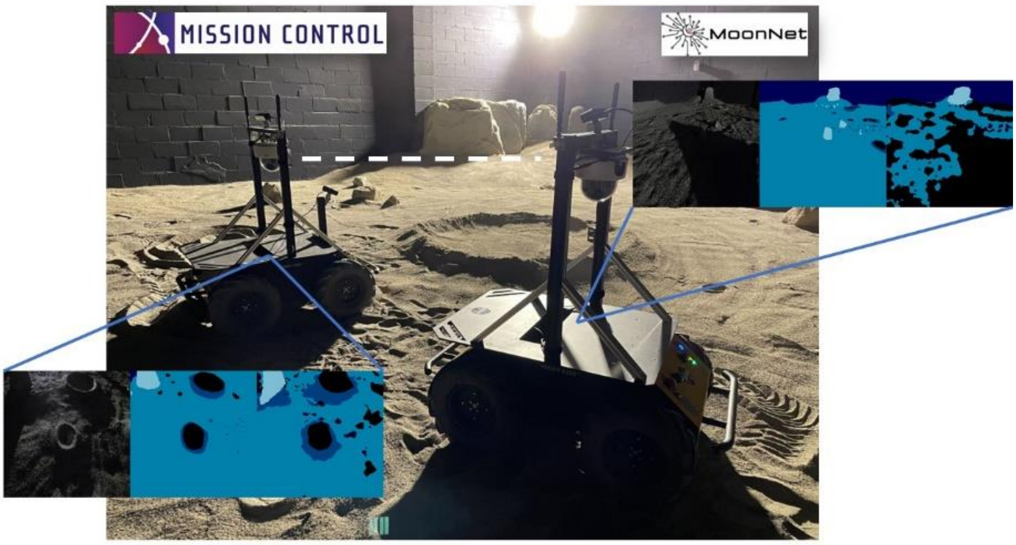

Figure 1: A training setup in the Moonyard demonstrating MoonNet terrain segmentation outputs from two rovers acting as lunar nodes and updating their models using federated learning.

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We undertake a series of Moonyard testing scenarios, integrating the FRIENDS software stack with Clearpath Husky Rover computer hardware in the Moonyard. We then test the federated deployment of MoonNet, including pseudo-labelled training updates and network delays, across different configurations of the lunar nodes. Performance metrics measured during training and across validation imagery demonstrate reproducibility on different edge hardware set-ups and the utility of the federated learning training paradigm for realistic lunar operations. Across test scenarios of a federated update of a pre-flight model, training accuracy and mean intersection over union were approximately 80-90% and 40-50%, respectively, as shown in Figure 2. A federated update from randomly initialized weights produced training accuracy of approximately 20-60% and mean intersection over union metrics of approximately 10%-20%, as visualized in Figure 2. Future work will focus on integration with robotic sensors and payloads, enabling testing of different class balances across each aggregation node.

Figure 2: Training metrics across scenarios on rover

References

[1] ISECG, The Global Exploration Roadmap, The Global Exploration Roadmap January 2018 (globalspaceexploration.org) (2018)

[2] ISECG, Global Exploration Roadmap Supplement – Lunar Surface Exploration Scenario Update, Global Exploration Roadmap Supplement – Lunar Surface Exploration Scenario Update | ISECG (globalspaceexploration.org) (2020)

[3] ISECG, Global Exploration Roadmap Supplement October 2022 – Lunar Surface Exploration Scenario Update, GER_Supplement_Update_2022.pdf (globalspaceexploration.org) (2022)

[4] ISECG, Global Exploration Roadmap Critical Technology Needs, 2019_GER_Technologies_Portfolio_ver.IR-2019.12.13.pdf (globalspaceexploration.org) (2019)

[5] G. Reina, A. Gruzdev, P. Foley, *et al.* "OpenFL: An open-source framework for Federated Learning", arXiv:2105.06413v1 [cs.LG] (2021)

[6] A. J. Macdonald, A. Budhkar, B. Bonham-Carter, *et al.*, "Enabling Autonomy with a Deep Learning Framework for Planetary Exploration" Conference Proceedings of ASCEND2022, AIAA 2022-4295 Session: Technologies for Space Robotics (2022)