SnT

Interdisciplinary Centre for Security, Reliability and Trust

SpaceR

Space Robotics Research Group

REALMS 2 - Resilient Exploration And Lunar Mapping System 2

UNIVERSITY OF LUXEMBOURG

Agenda

1. Introduction
2. Related Work
3. Methods and Materials
    - Rover Setup
    - Lunar Lander
    - User Interface
4. Experiments
    - Range
    - Map Merging
5. ESA-ESRIC Challenge
6. Results
7. Conclusion

1. Introduction

ESA-ESRIC Space Resources Challenge – 1st Field Test

Figure 1 – Logo of ESA-ESRIC Challenge

Source: /https://www.spaceresourceschallenge.esa.int/

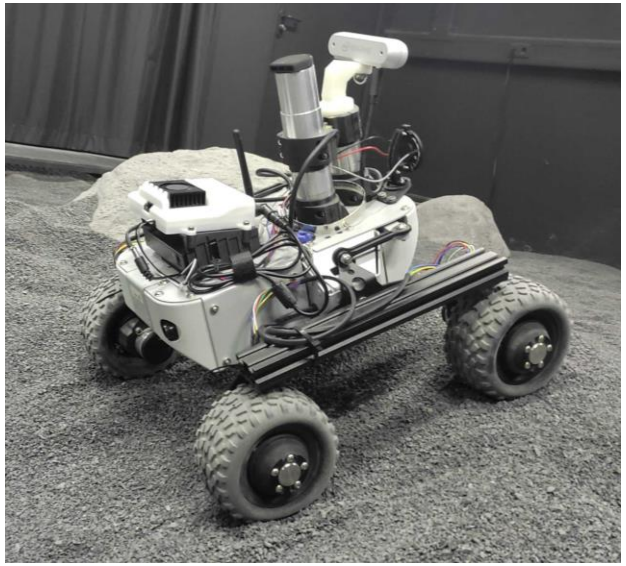


Figure 2 – Picture of the Leo Rover for REALMS

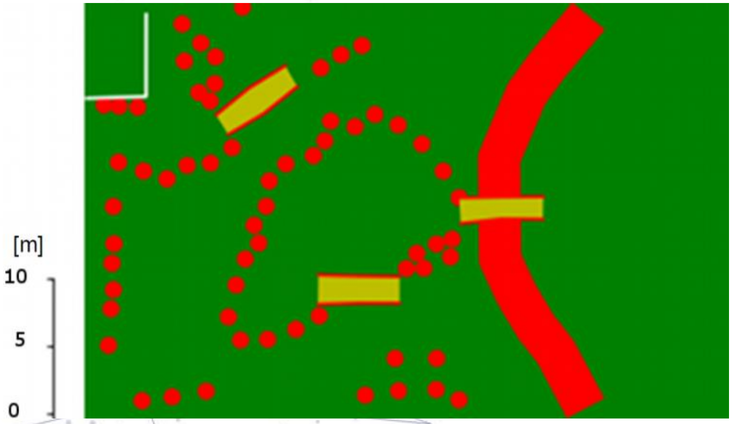


Figure 3 – Map of the first field test, given by ESA

Source: ESA Estec

Figure 4 – Picture of the first field test of the ESA-ESRIC Challenge

Source: LinkedIn - ESA

ESA-ESRIC Space Resources Challenge – 1st Field Test

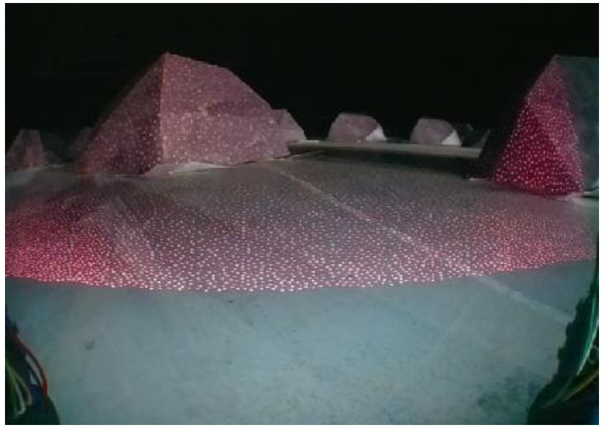


Figure 5 – Operator view of the traverse area in the first field test

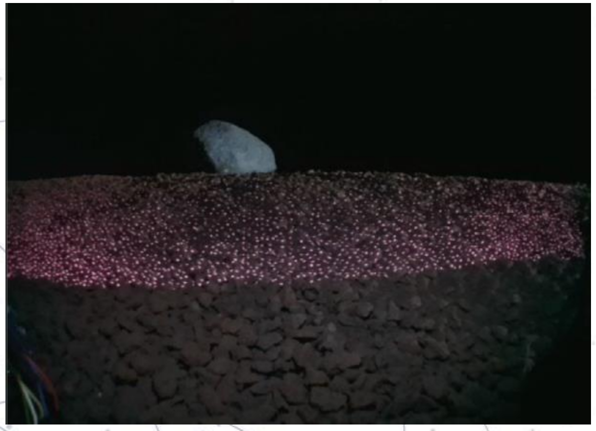


Figure 6 – Operator view of the region of interest in the first field test

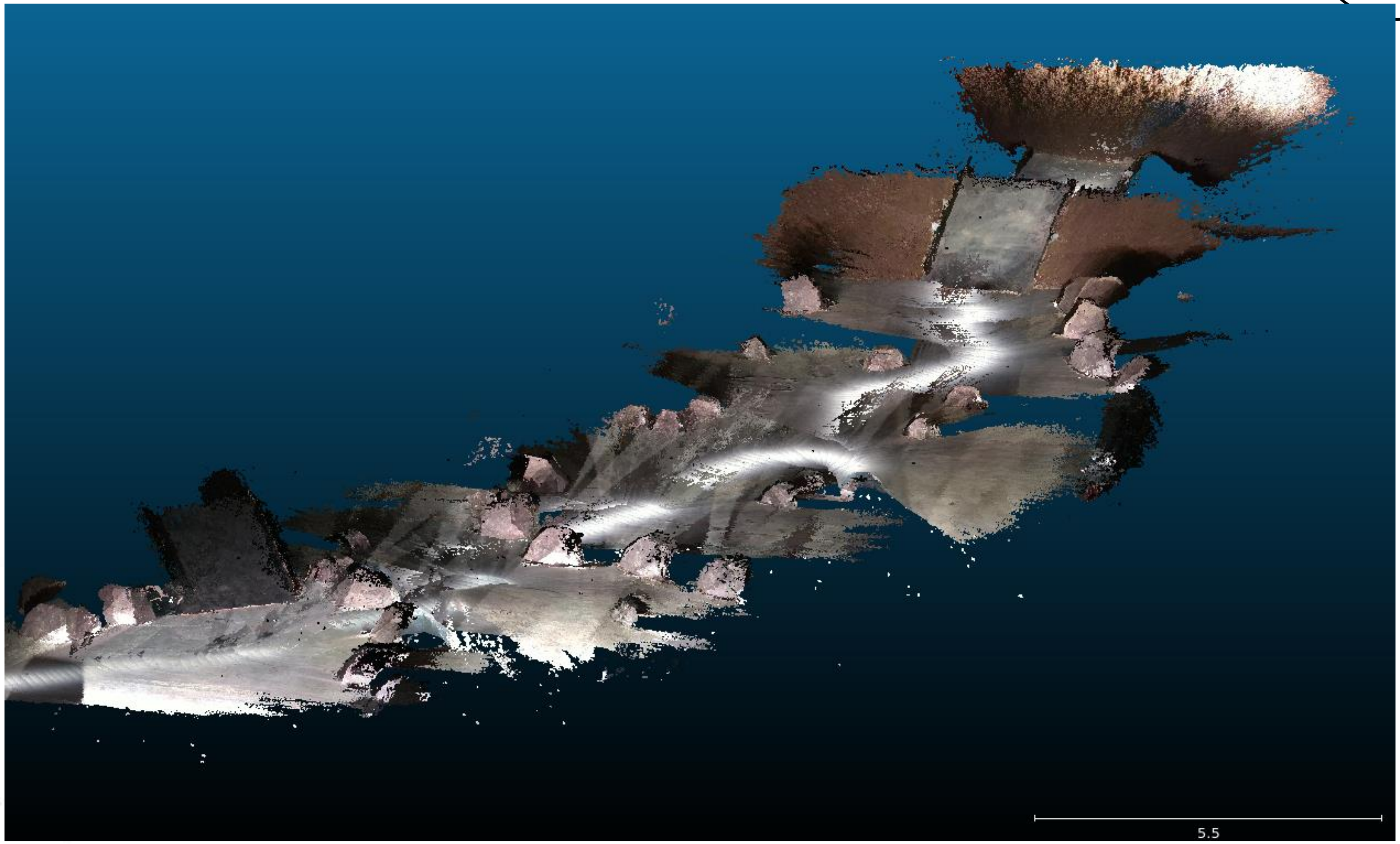


Figure 7 – Final 3D map of the first field test of the ESA-ESRIC Challenge

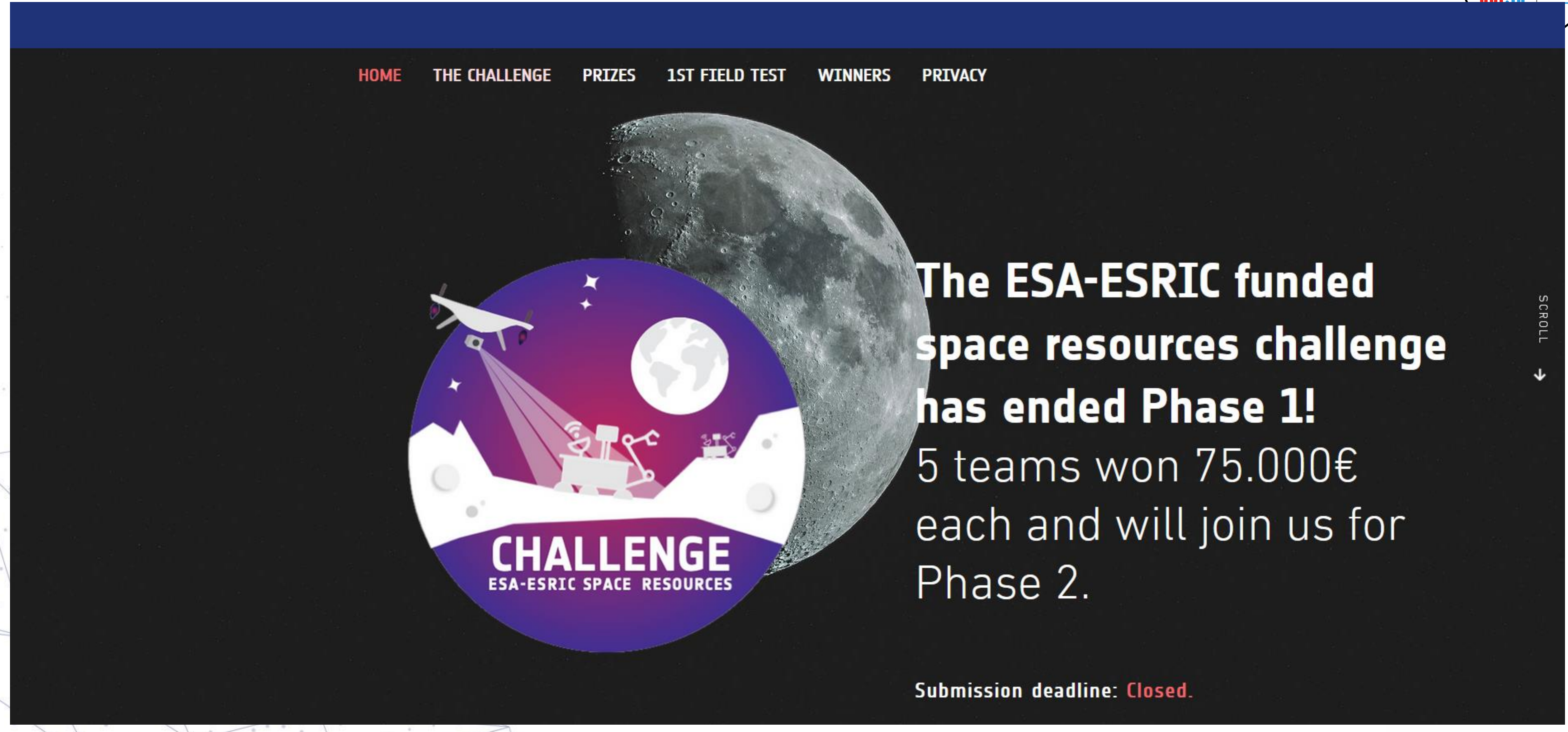
1st Field Test – Take-aways

REALMS:

- System architecture for centralized multi-robot system
- Centralised network architecture
- Limited scalability

Reference: D. van der Meer, L. Chovet, A. Bera, A. Richard, P. J. Sánchez Cuevas, J. R. Sánchez-Ibáñez, and M. Olivares-Mendez. Realms: Resilient exploration and lunar mapping system. Frontiers in Robotics and AI, 10, 2023.

ESA-ESRIC Space Resources Challenge – 2nd Field Test



Source: /https://www.spaceresourceschallenge.esa.int/, Accessed on 2023-02-05

ESA-ESRIC Space Resources Challenge – 2nd Field Test

Figure 8 – Environment of the second field test of the ESA-ESRIC Challenge

2nd Field Test – Improvements

SpaceR
Space Robotics Research Group

REALMS 2:

- System architecture for centralized multi-robot system
  - Use ROS 2 instead

- Centralised network architecture
  - Set up mesh network

- Limited scalability
  - Single-user GUI to monitor and control multiple robots

2. Related Work

Multi-robot Systems (MRS)

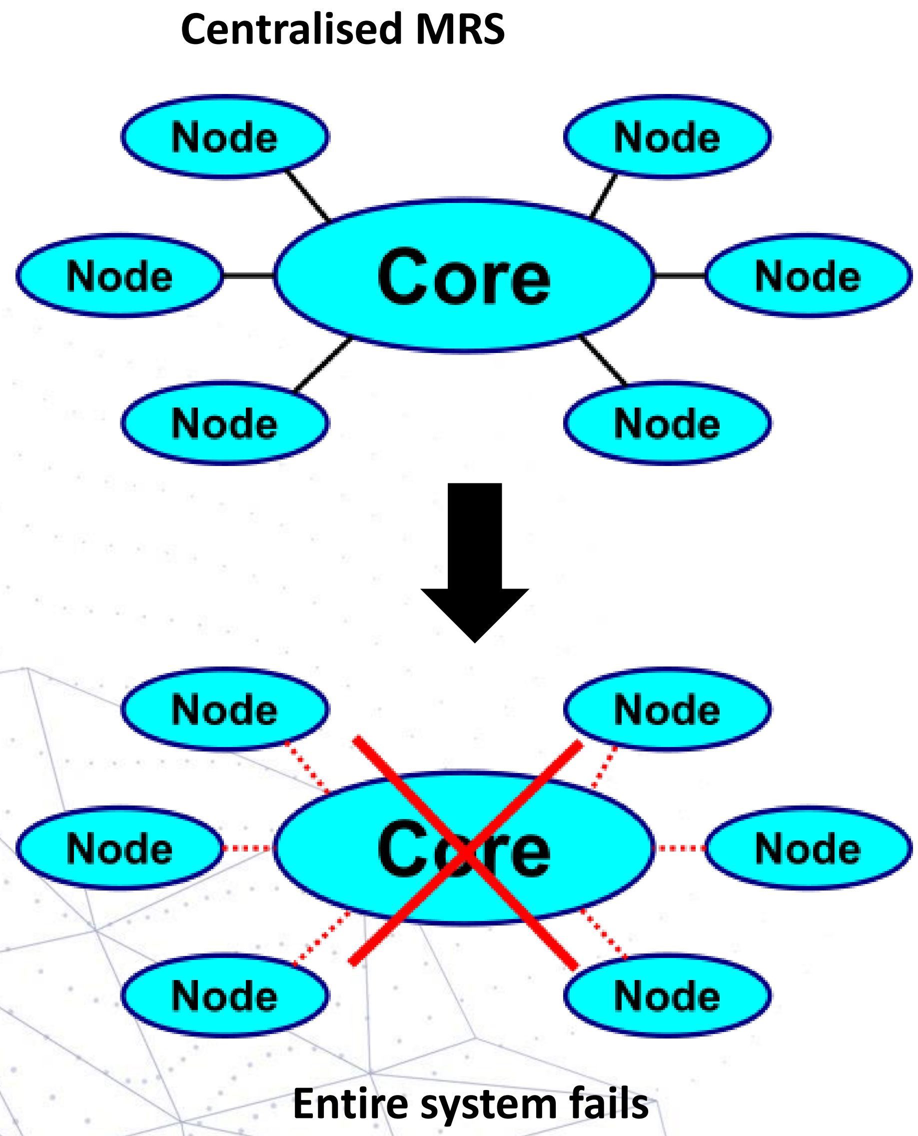


Figure 9 – Schematic of central multi-robot system with crucial failure

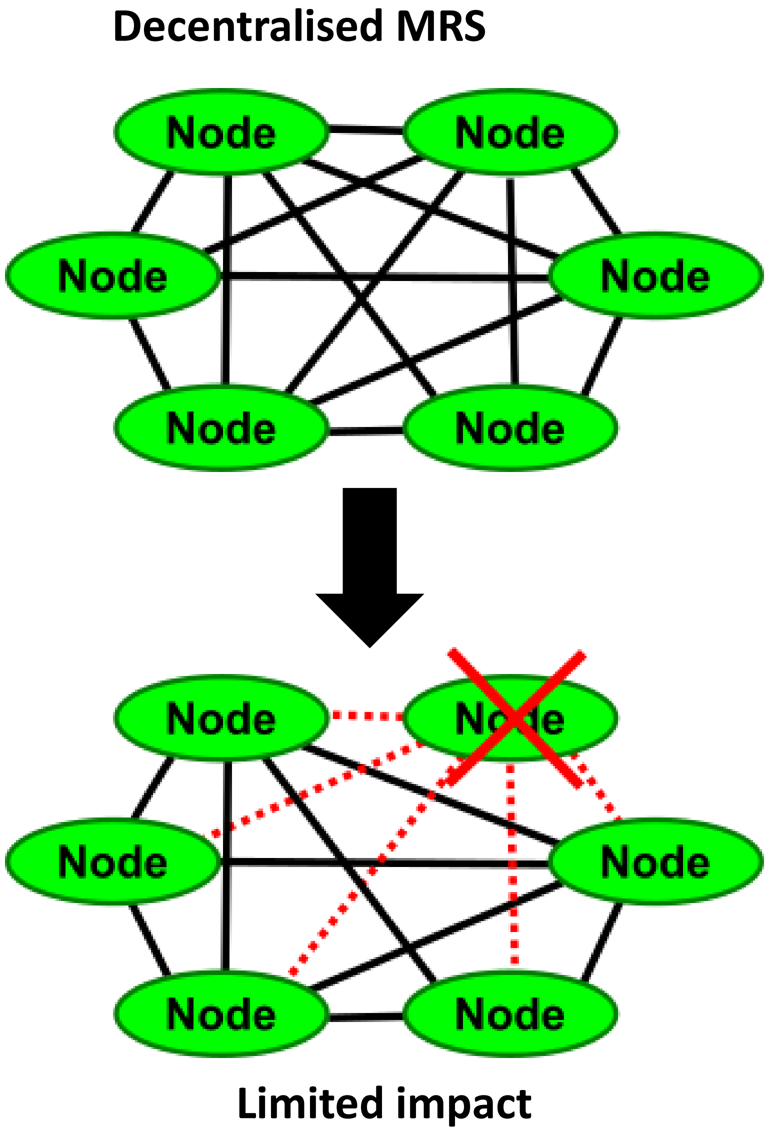


Figure 10 – Schematic of distributed multi-robot system with single node failure

Mesh networking

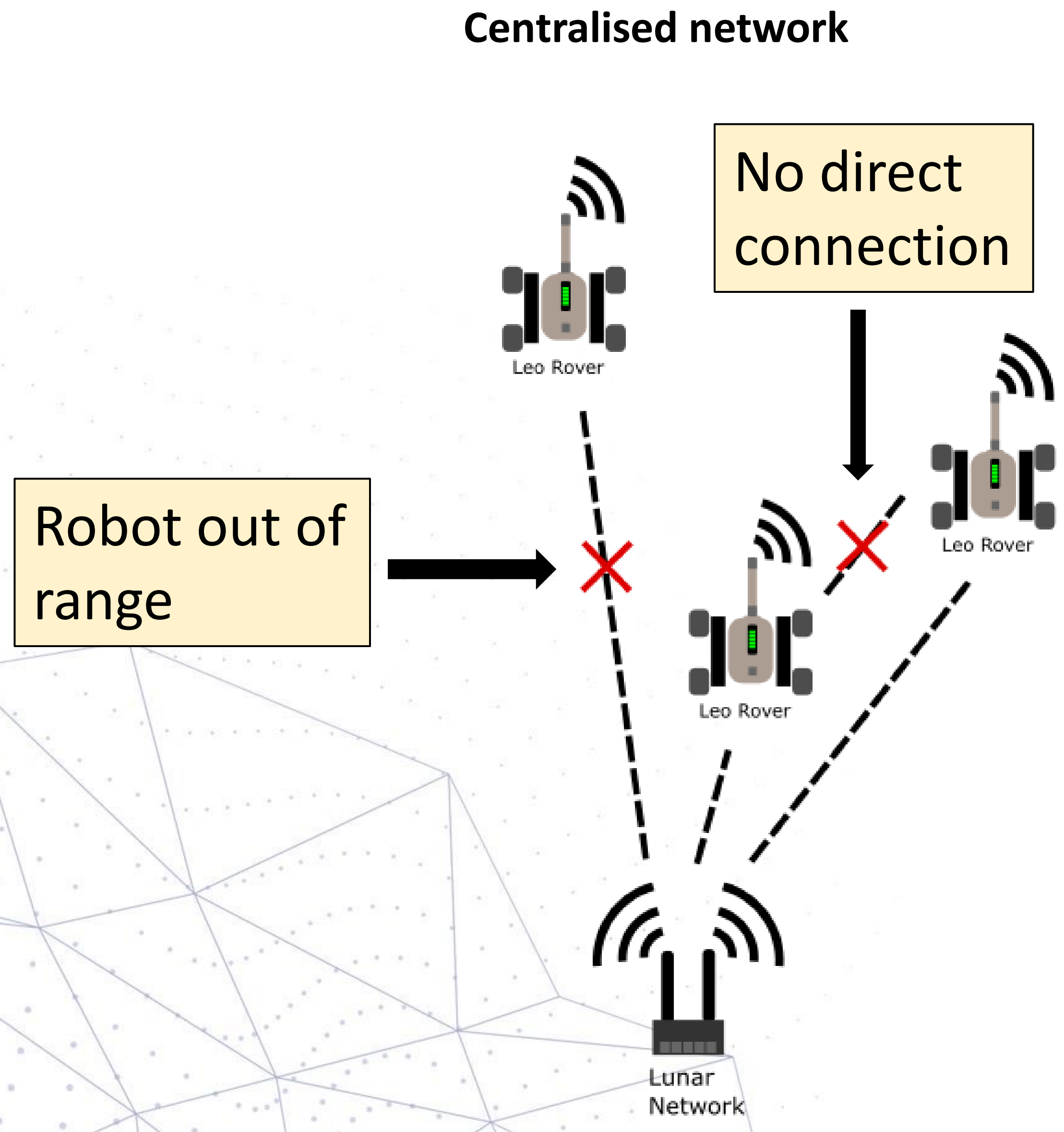


Figure 11 – Schematic of a single access point to connect all robots separately

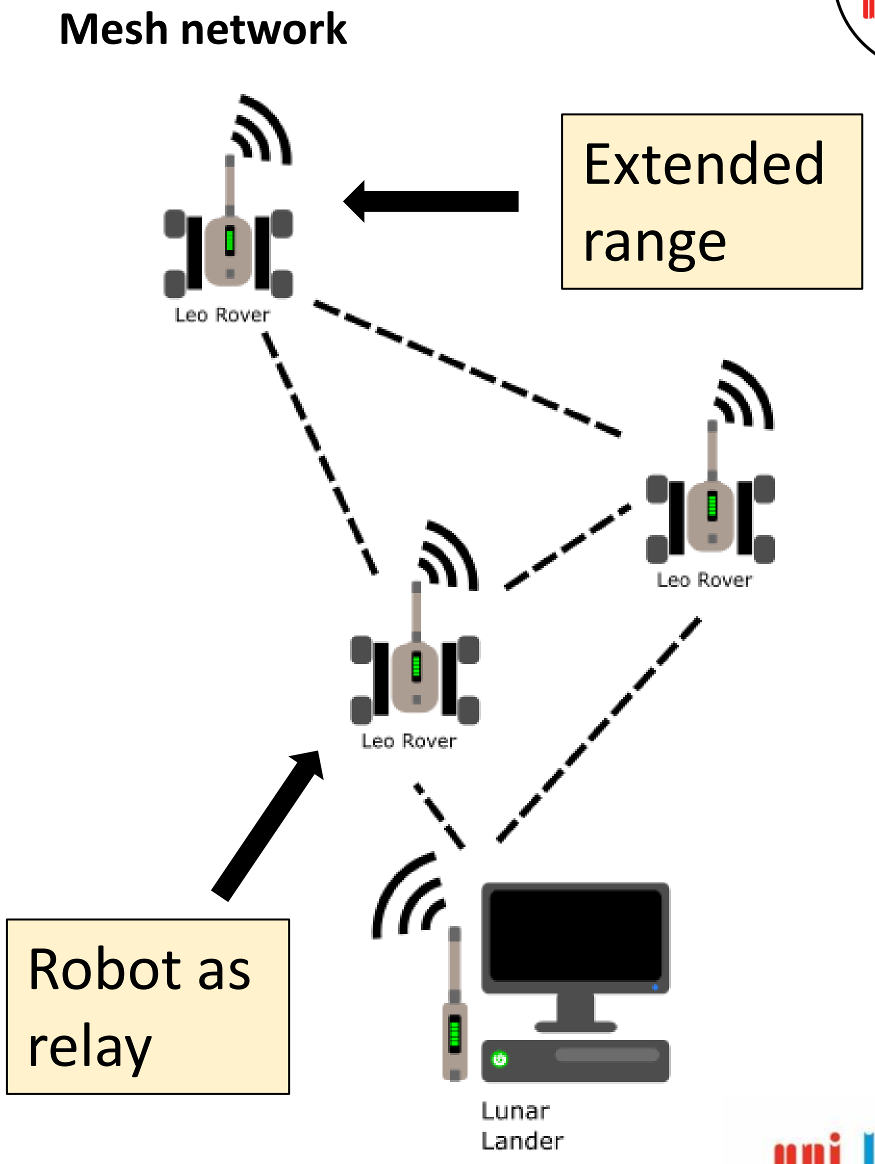


Figure 12 – Schematic of a mesh network inter-connecting all robots

ROS 2

- Communication system based on Data Distribution System (DDS)
- Developed with multi-robot systems in mind
- No need for a single ROS master
- Improved for non-ideal networks, i.e. wireless networks

Source: T. A. Yuya Maruyama, Shinpei Kato. Exploring the performance of ros2. Frontiers in Robotics and AI, 10, 2016.

3. Methods and Materials

Robot Setup: System

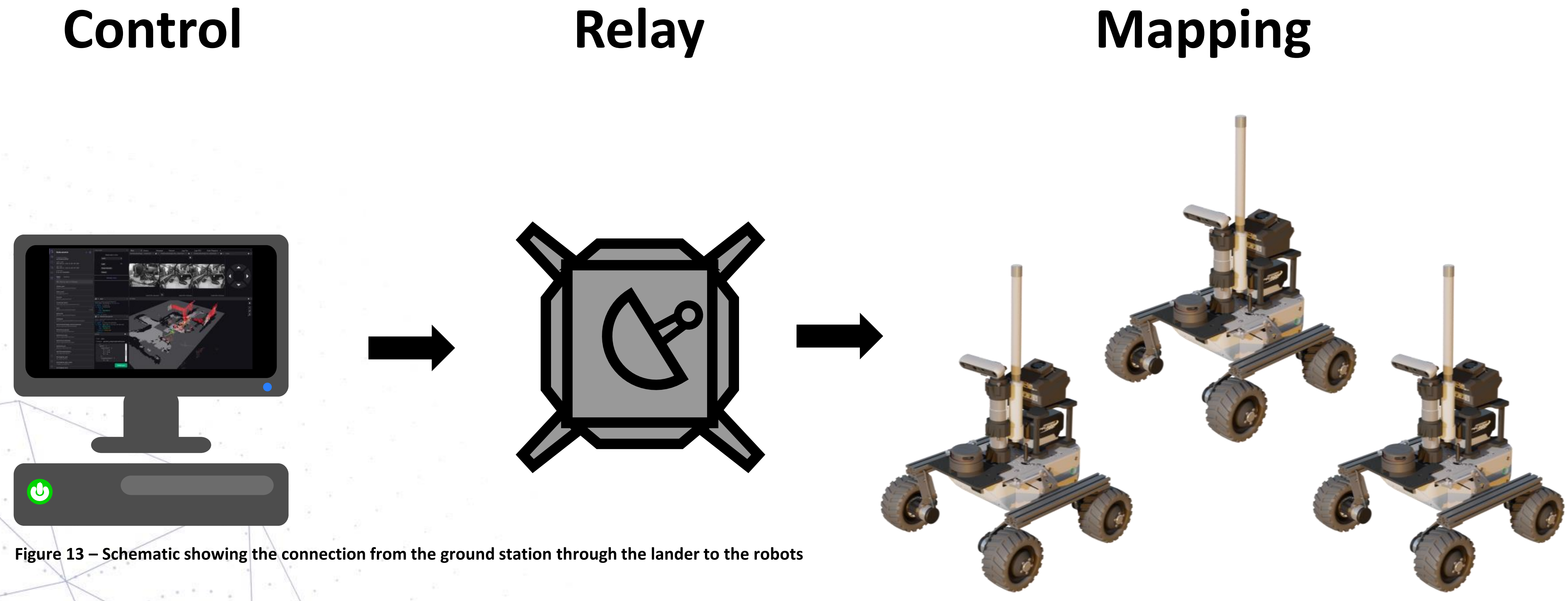


Figure 13 – Schematic showing the connection from the ground station through the lander to the robots

Robot Setup: Leo Rover Base

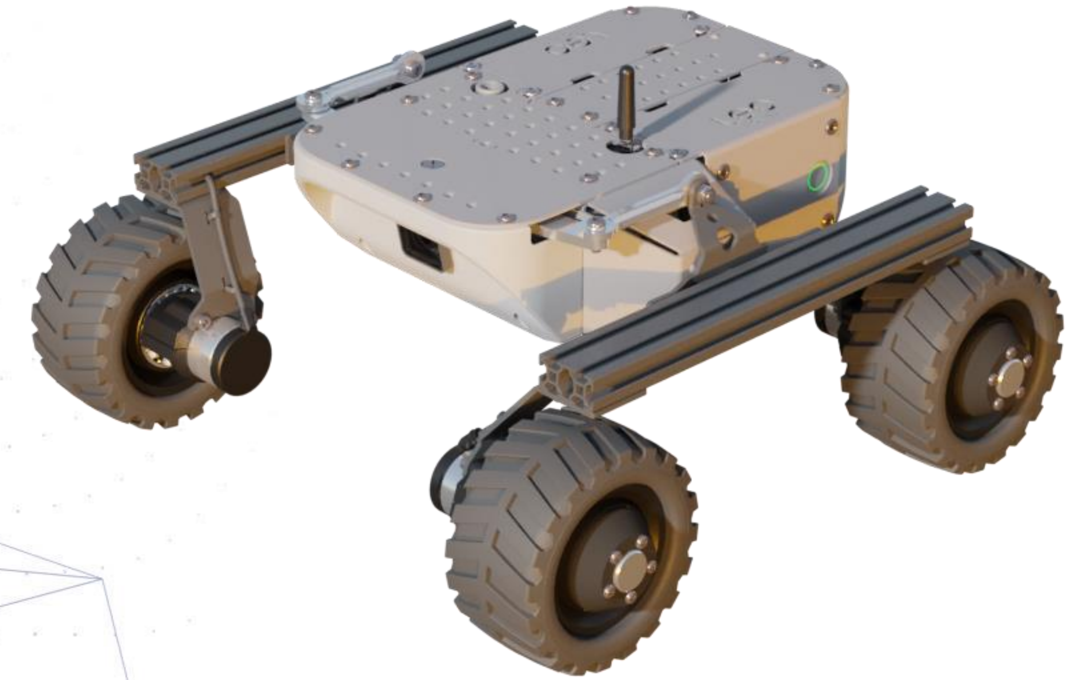


Figure 14 – Leo Rover base model

Robot Setup: Leo Rover for REALMS

SpaceR
Space Robotics Research Group

Figure 15 – Leo Rover model for REALMS

Robot Setup: Leo Rover for REALMS 2

Figure 16 – Leo Rover model for REALMS 2

Robot Setup: Leo Rover for REALMS 2

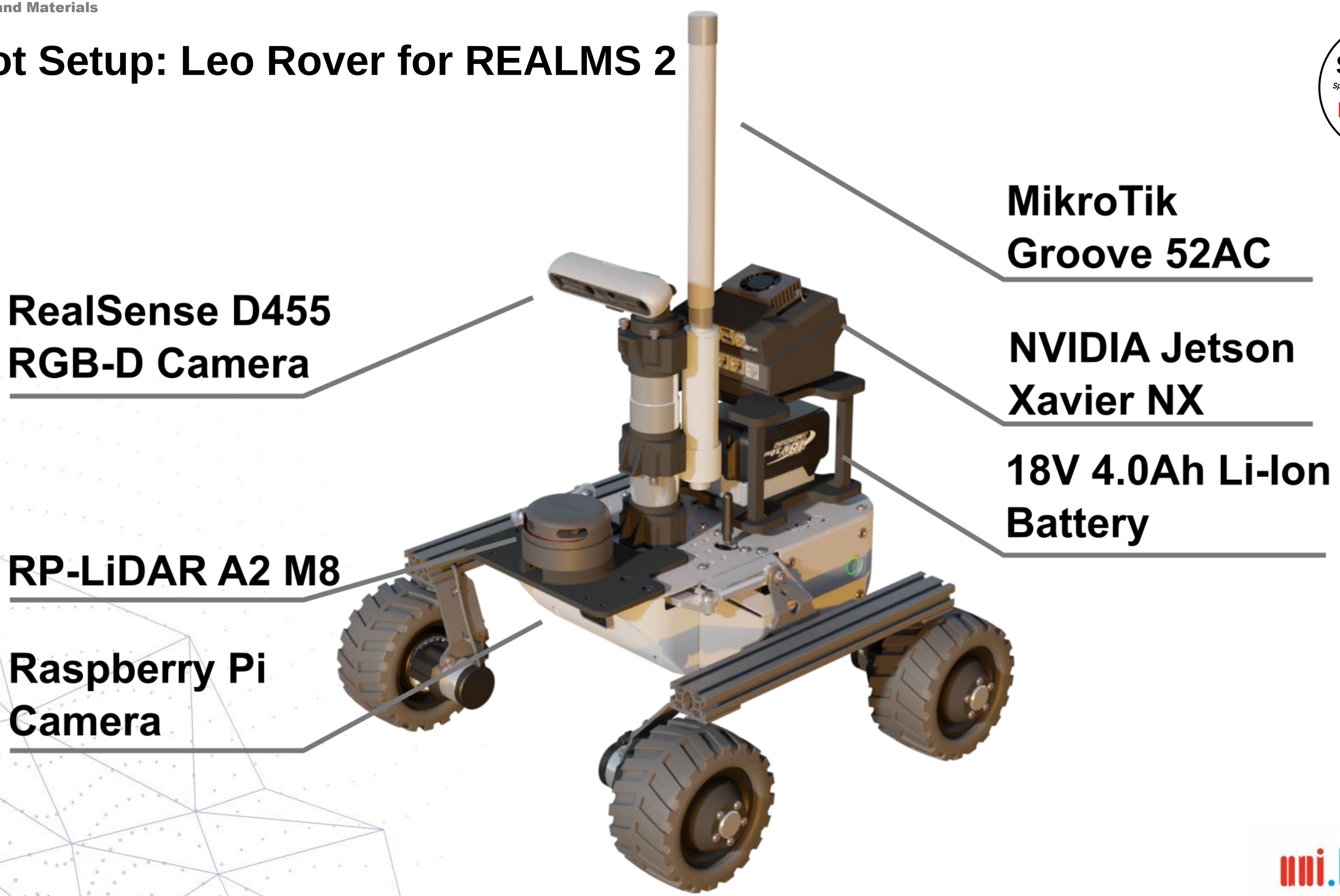


Figure 17 – Leo Rover model for REALMS 2 annotated

Robot Setup: Software

Figure 18 – Docker logo
Source: https://www.docker.com/

Figure 19 –ROS 2 Humble Hawksbill logo
Source: https://www.openrobotics.org/blog/2022/5/24/ros-2-humble-hawksbill-release

Robot Setup: Software

RTAB-Map: Real-time appearance based Mapping

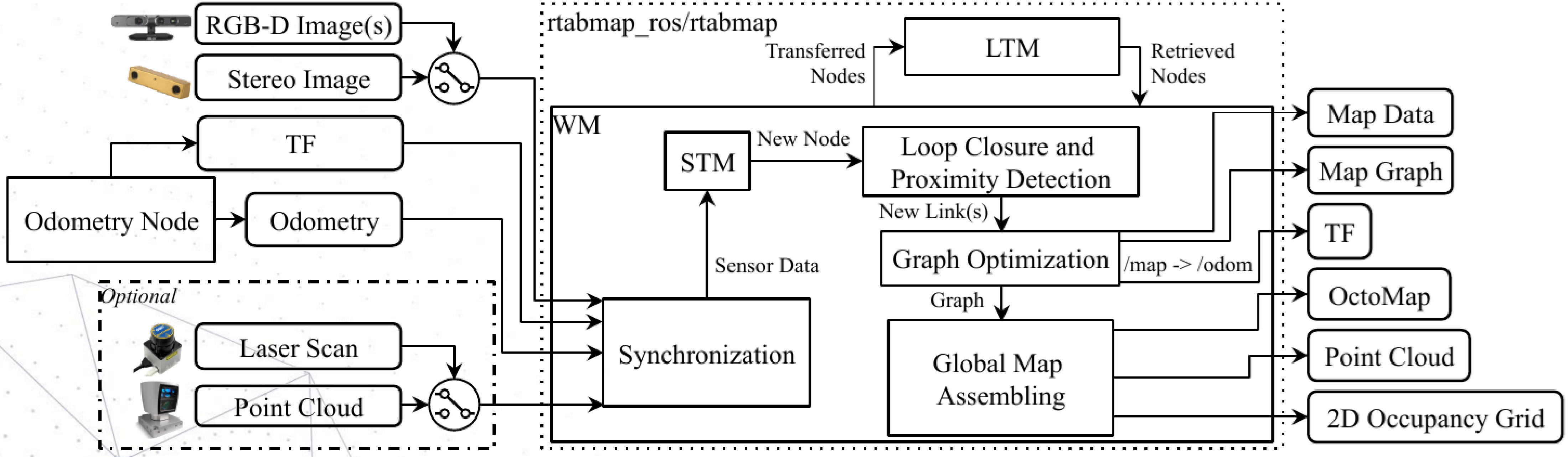


Figure 20 – Diagram of the software architecture of RTAB-Map

Source: Mathieu Labbe and Francois Michaud. "RTAB-Map as an open-source lidar and visual simultaneous localization and mapping library for large-scale and long-term online operation". (2019)

Robot Setup: Software

- Map Merging

- Navigation: Nav2 Stack in ROS 2

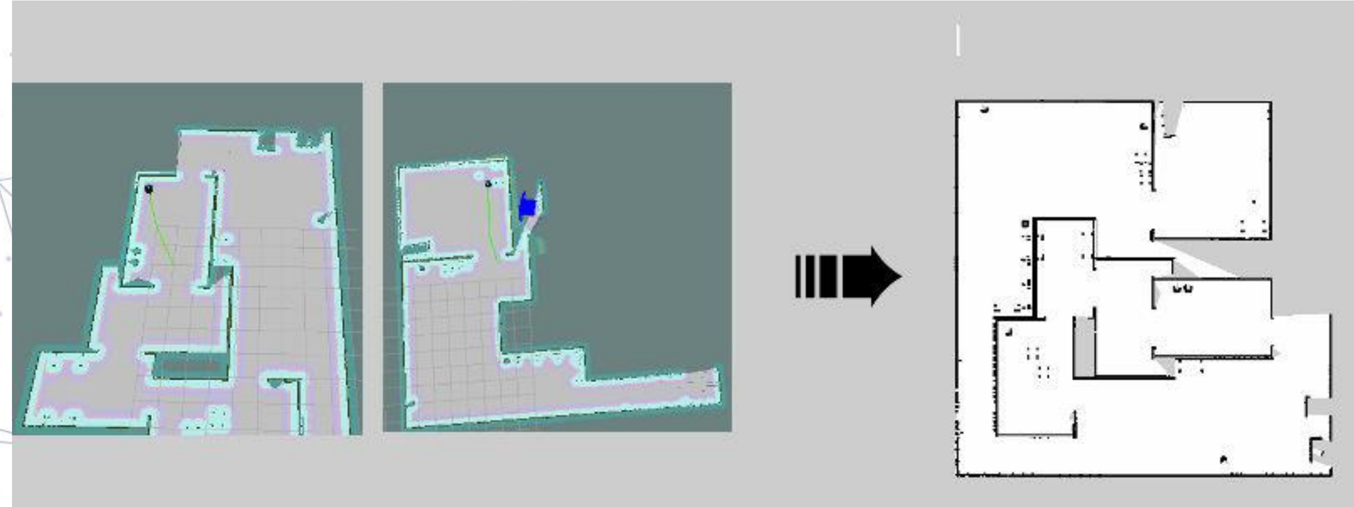


Figure 21 – Map merging software combining two maps

Source: http://wiki.ros.org/multirobot_map_merge, Accessed on 2023-09-13

Figure 22 – ROS 2 default navigation stack (Nav2) logo

Source: https://navigation.ros.org/index.html

Lunar Lander

- Relay from ground station to lunar test field
- Camera and LiDAR to observe the surroundings
- Offload computing tasks from the rovers
  - Intel NUC
  - Core-i7 CPU
  - 32 GB RAM

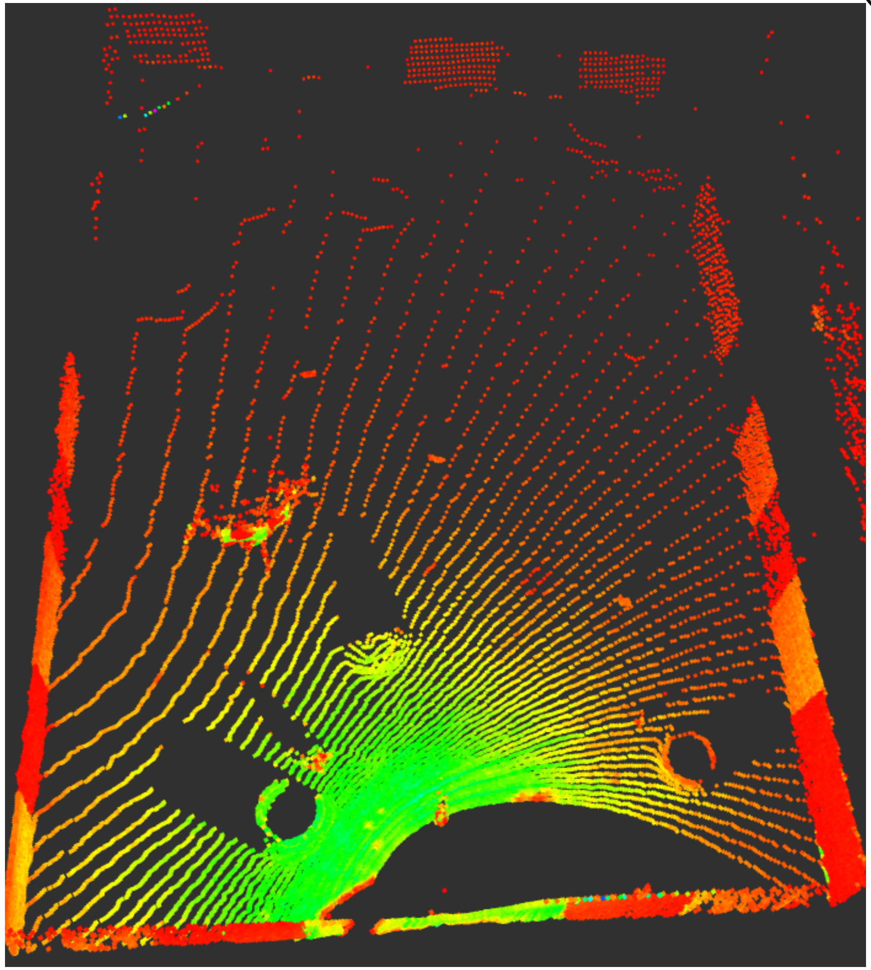


Figure 23 – LiDAR scan from the lander during the second field test of the ESA-ESRIC Challenge

Robot Setup: User Interface

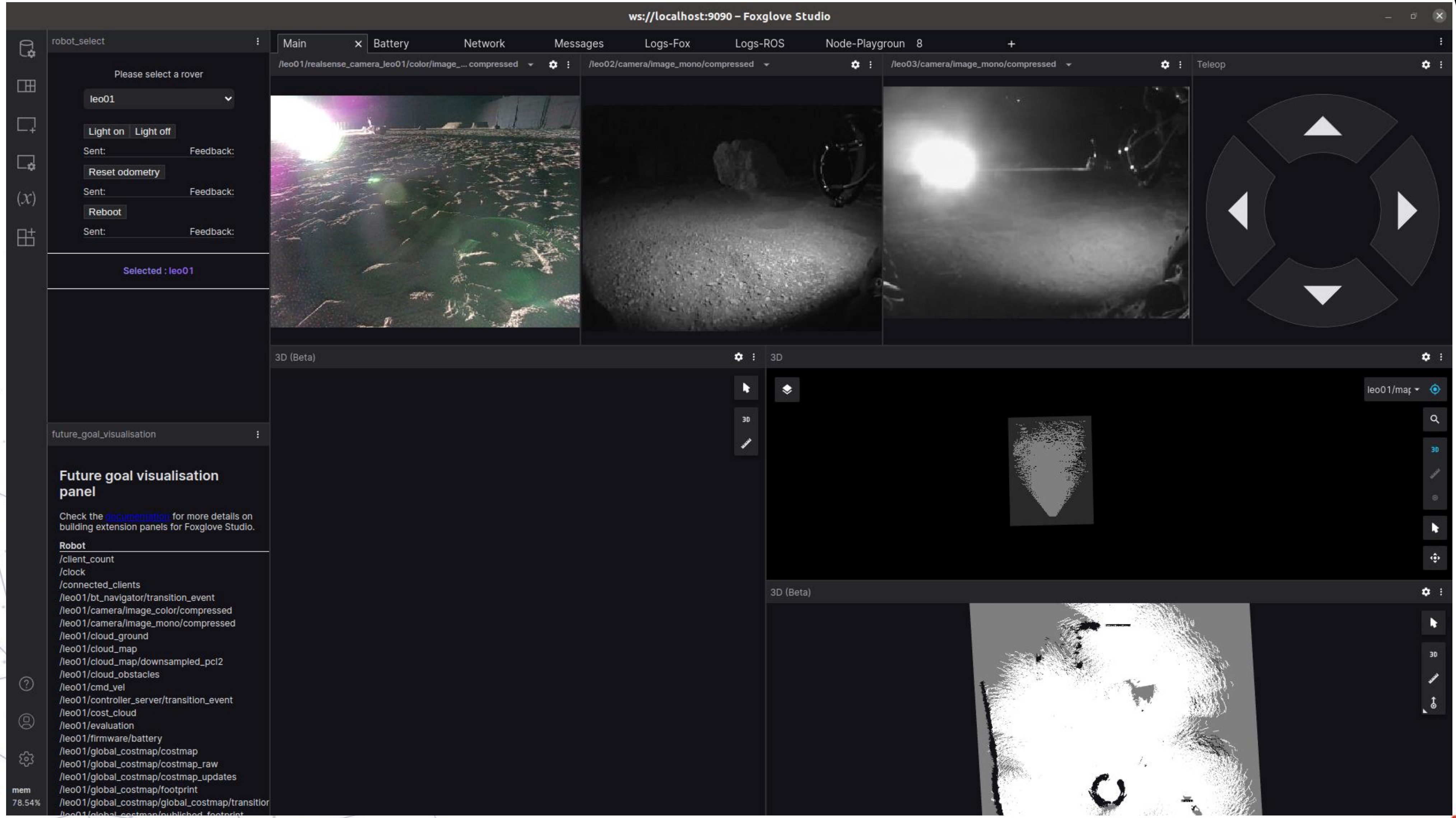


Figure 24 – REALMS 2 operator view during the second field test of the ESA-ESRIC Challenge

Robot Setup: User Interface

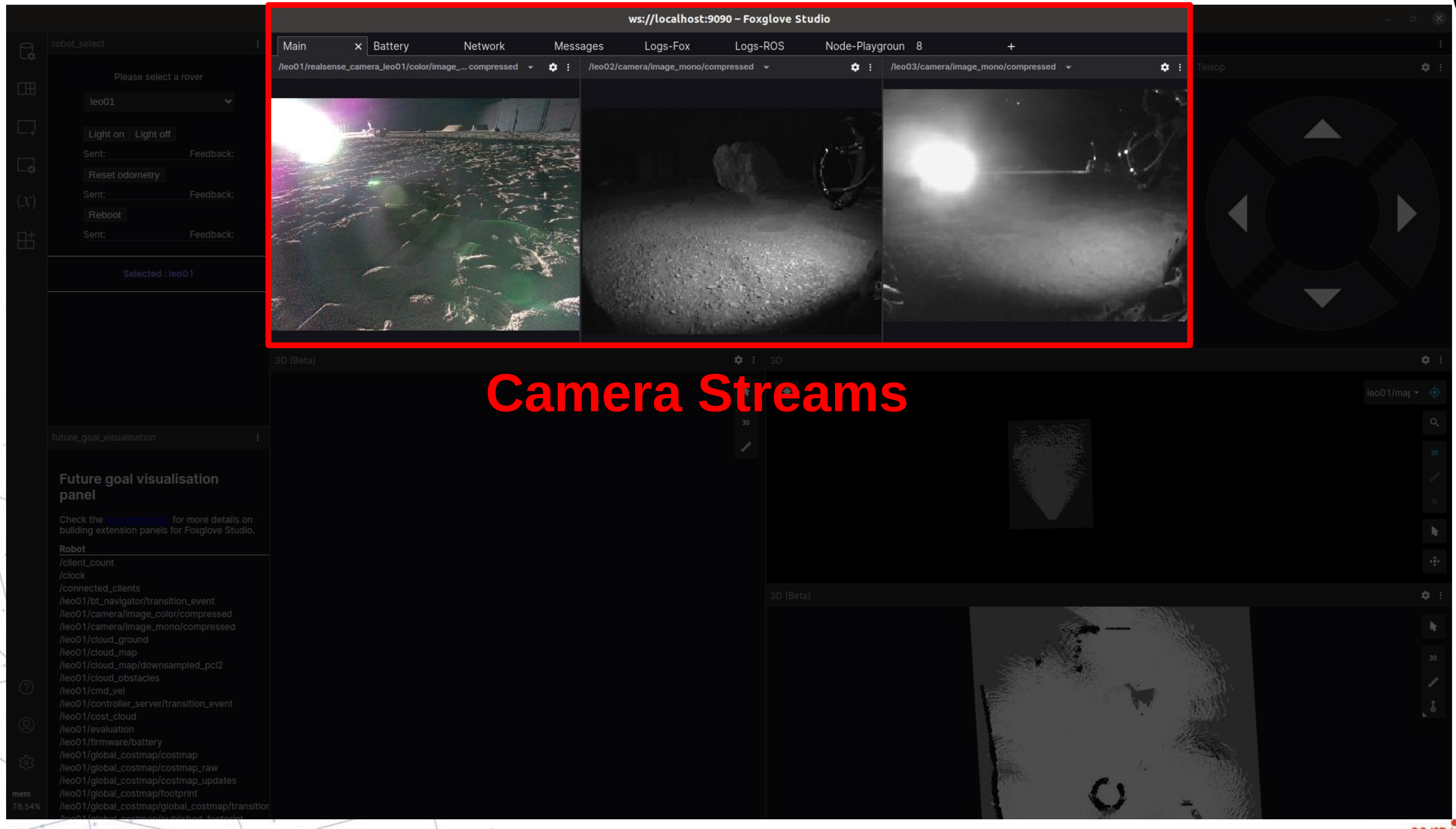


Figure 25 – REALMS 2 operator view during the second field test of the ESA-ESRIC Challenge: Camera streams

Robot Setup: User Interface

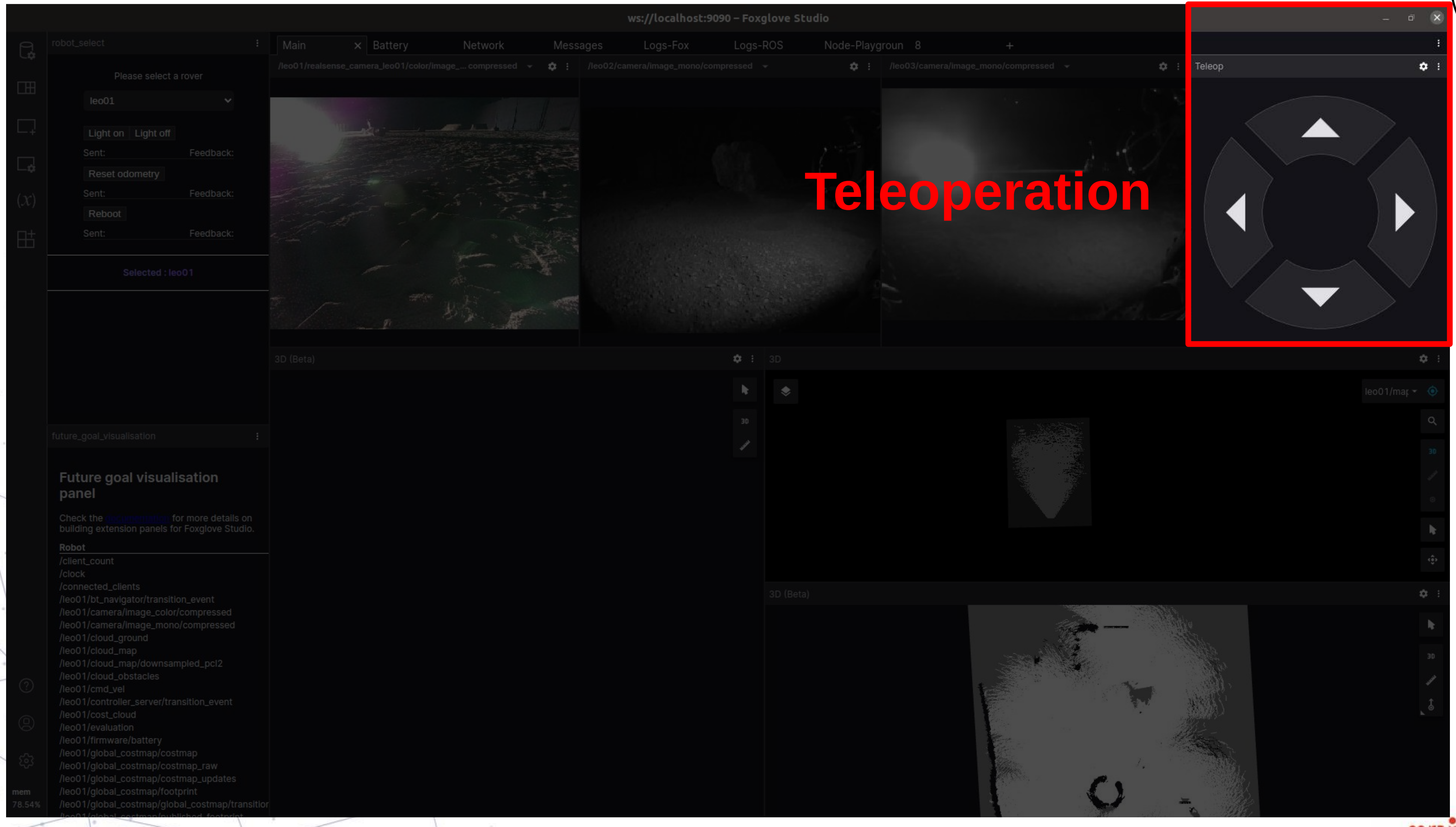


Figure 26 – REALMS 2 operator view during the second field test of the ESA-ESRIC Challenge: Teleoperation panel

Robot Setup: User Interface

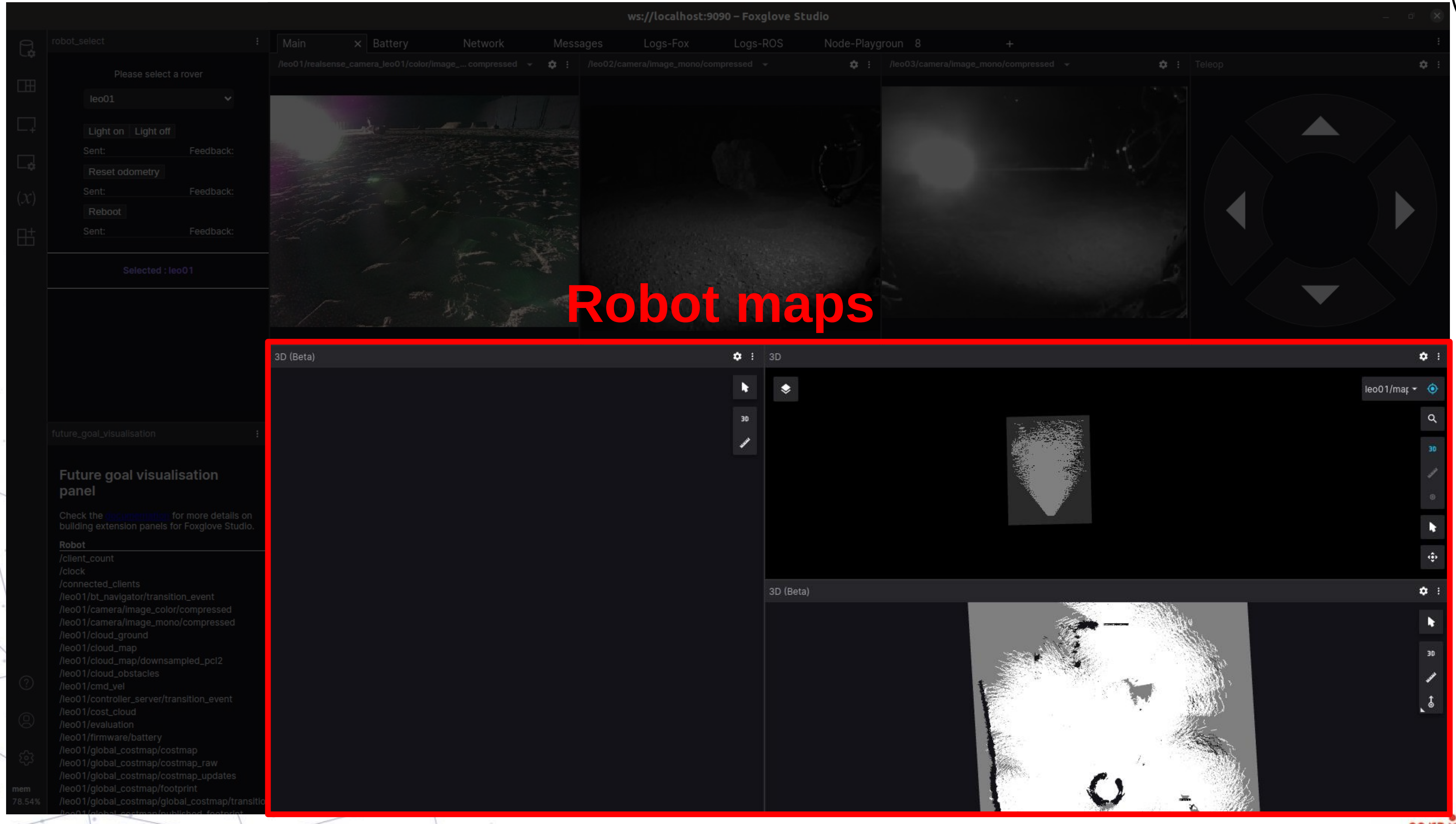


Figure 27 – REALMS 2 operator view during the second field test of the ESA-ESRIC Challenge: Robot maps

Robot Setup: User Interface

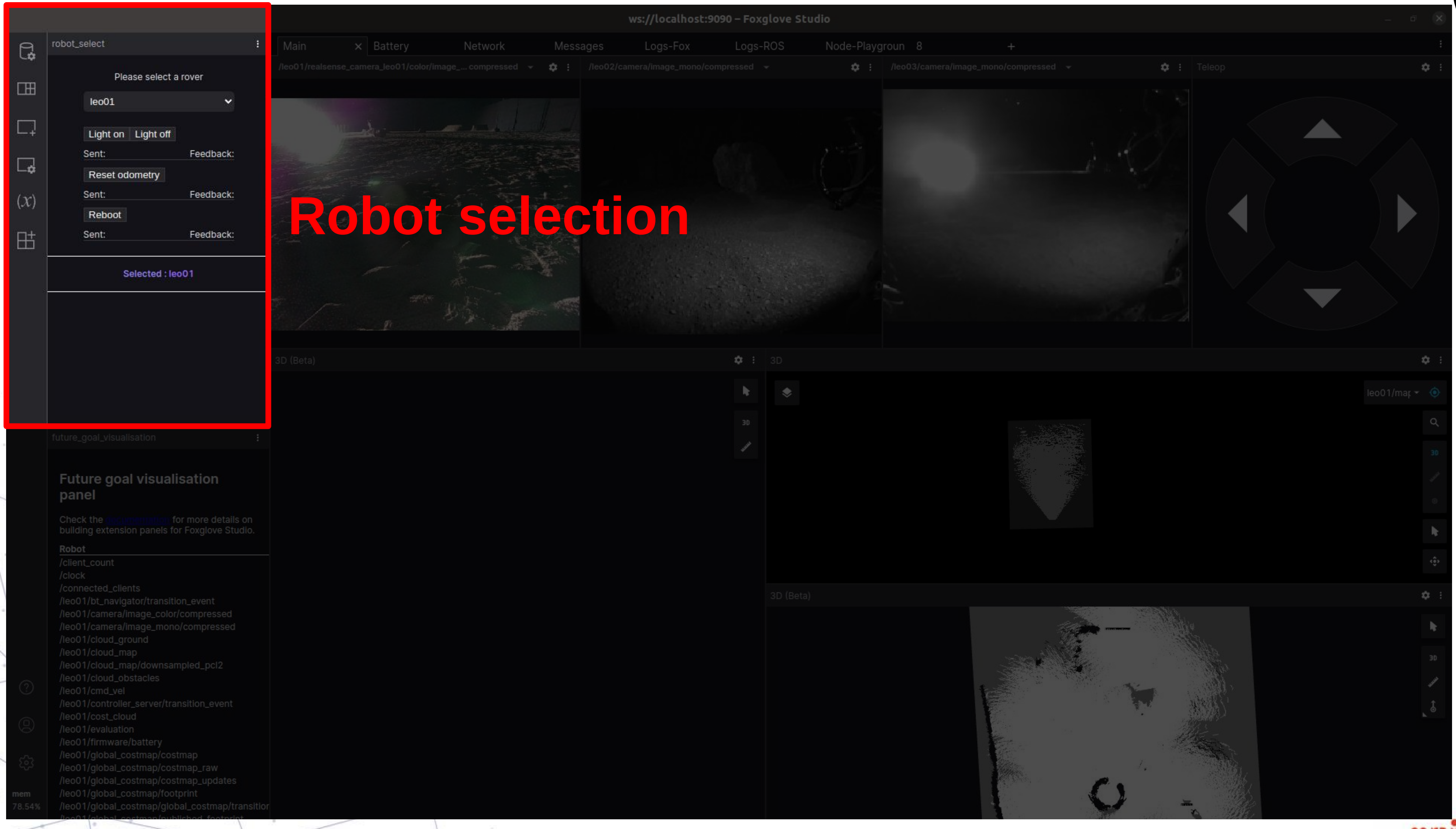


Figure 28 – REALMS 2 operator view during the second field test of the ESA-ESRIC Challenge: Robot selection panel

Robot Setup: User Interface

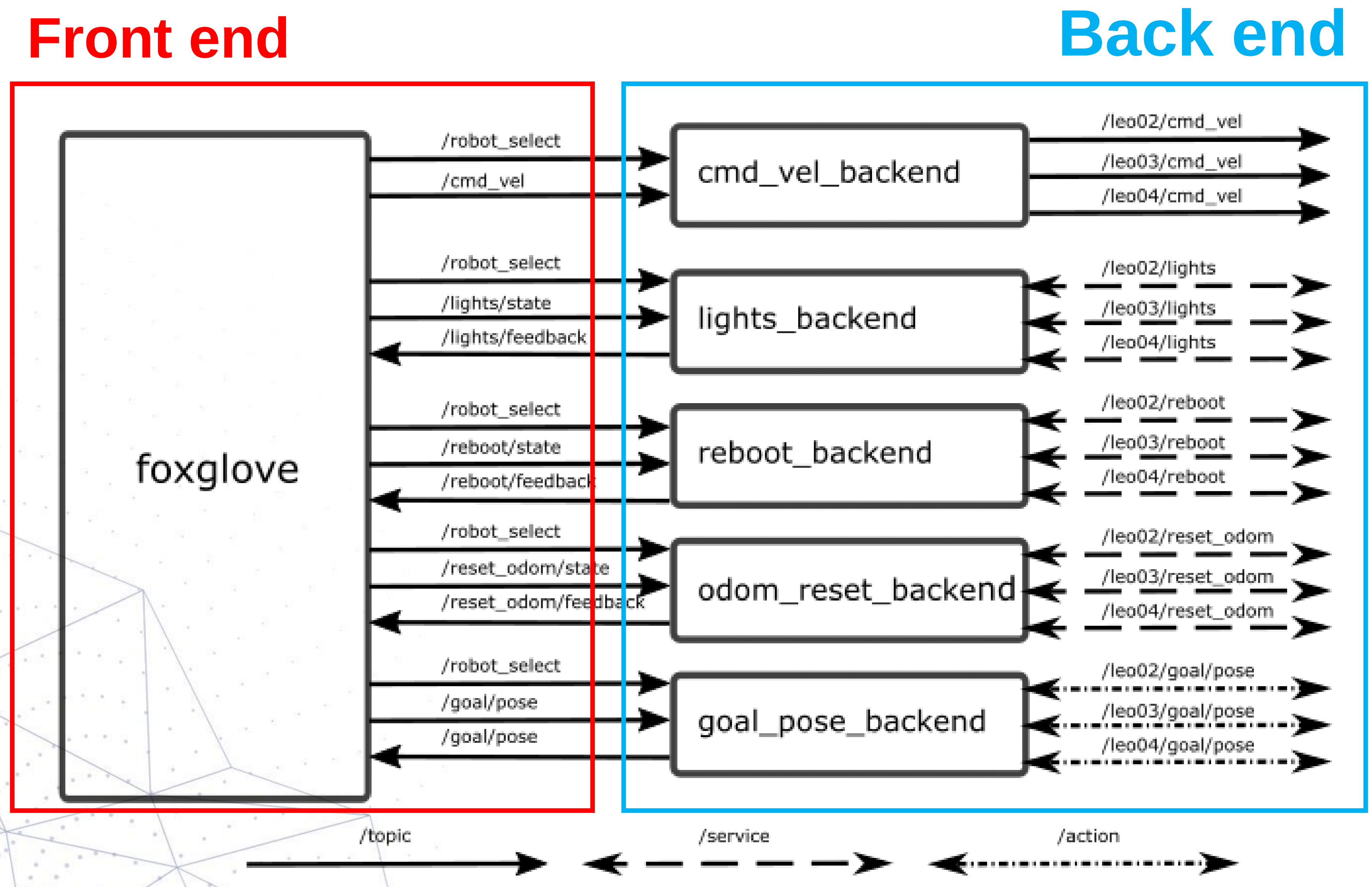


Figure 29 – REALMS 2 front end and back end system

4. Experiments

Experiments: Range

- Direct signal:
  - Ping possible
  - No video stream

- Signal through relay:
  - Video stream available
  - Bandwidth doubled

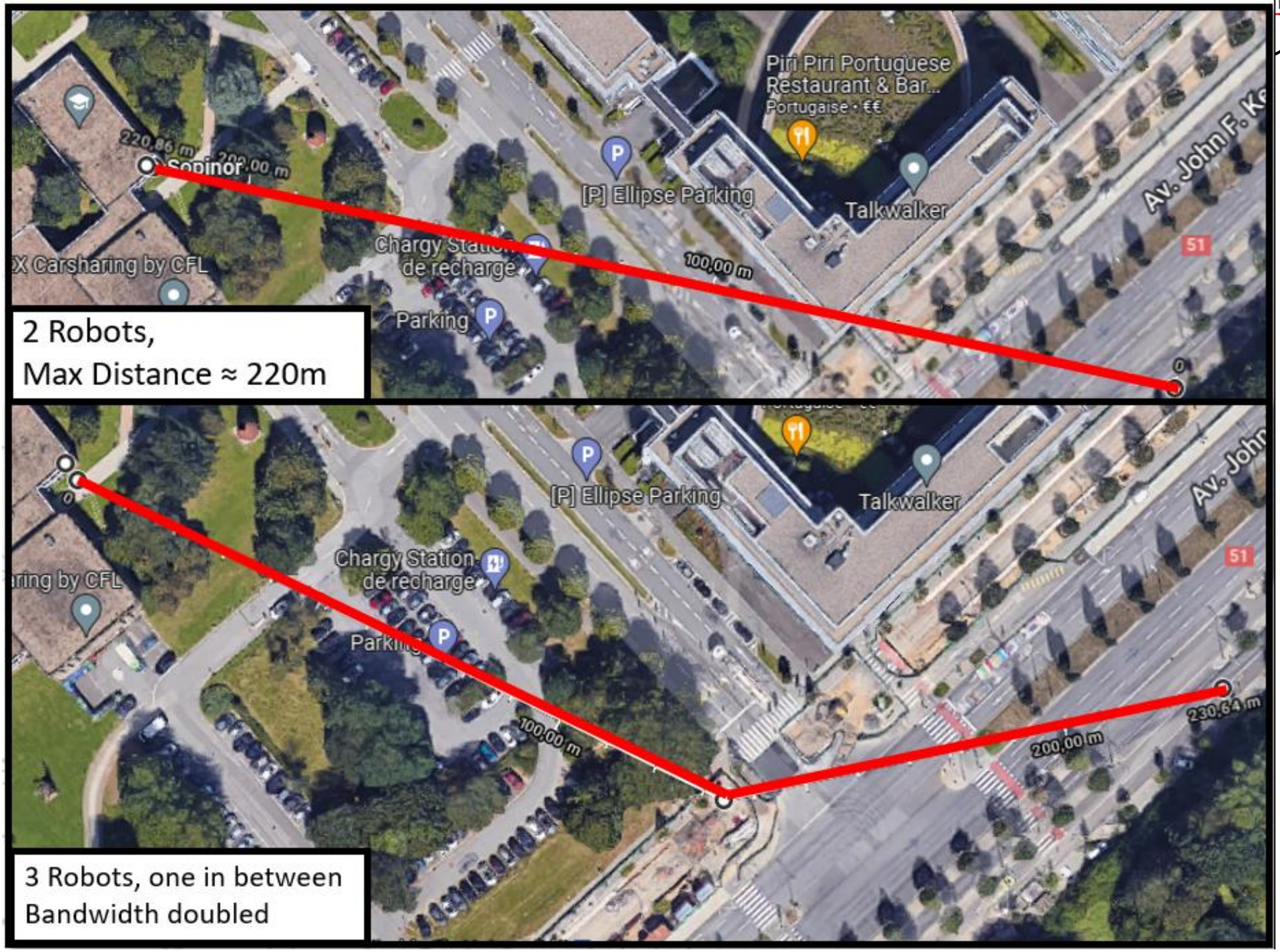


Figure 30 – Experiments to measure the maximum range of the mesh network

Experiments: Map merging

- Outdoor mapping with 2 different rovers
- 2D map shows sufficient overlap
- Map merging combines both maps

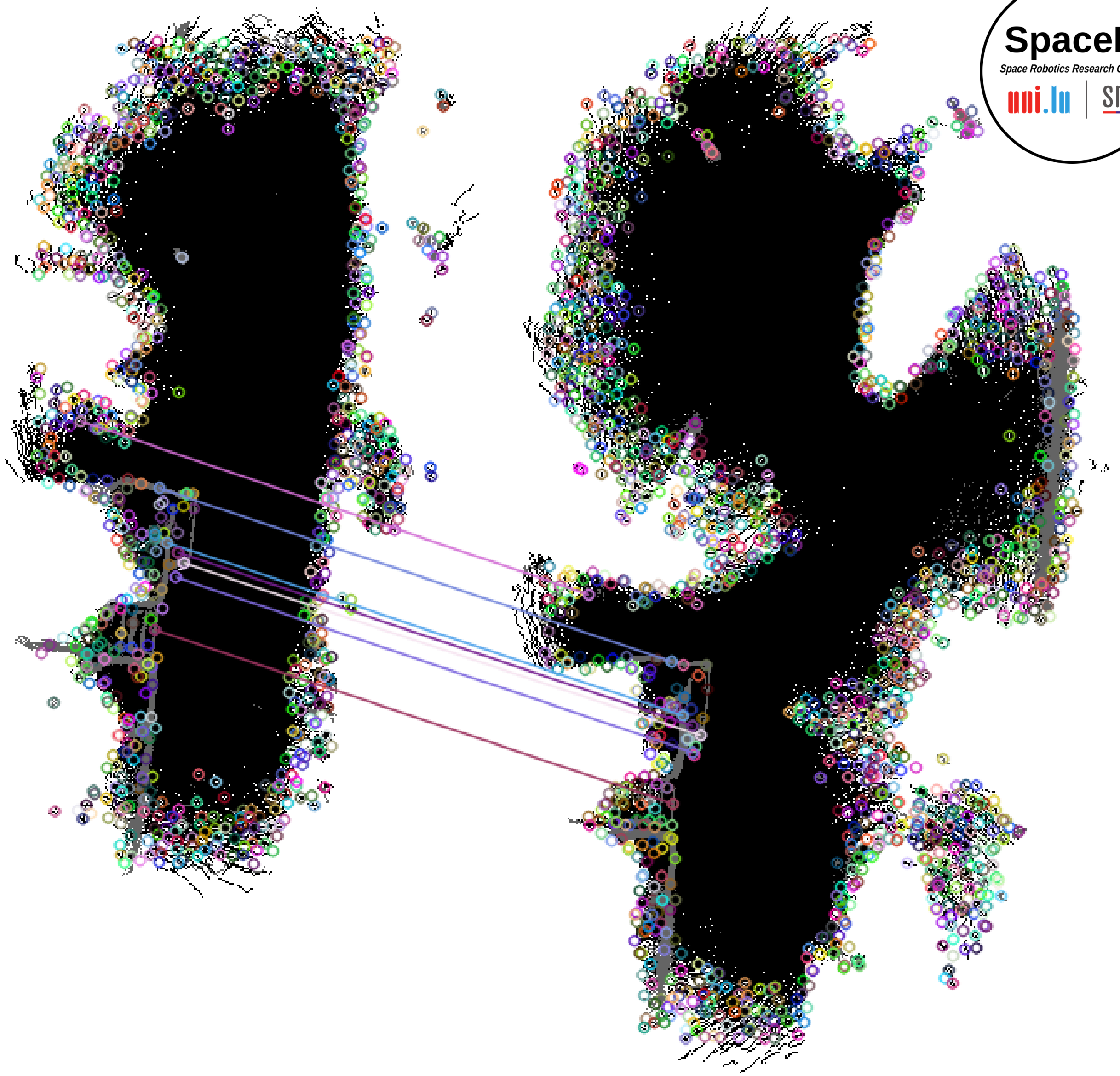


Figure 31 – Experiments to verify map merging capabilities

5. ESA-ESRIC Challenge

ESA-ESRIC Space Resources Challenge

Operator View

Figure 32 – Operator view during the second field test of the ESA-ESRIC Challenge

RTAB-Map Input

Figure 33 – Visual odometry input during the second field test of the ESA-ESRIC Challenge

ESA-ESRIC Space Resources Challenge

- Video from Leo-02
- Based on key frames from RTAB-Map

Video 1 – Visual odometry key frames registered by RTAB-Map during the second field test of the ESA-ESRIC Challenge

6. Results

Results: Mapping result – about 60% coverage

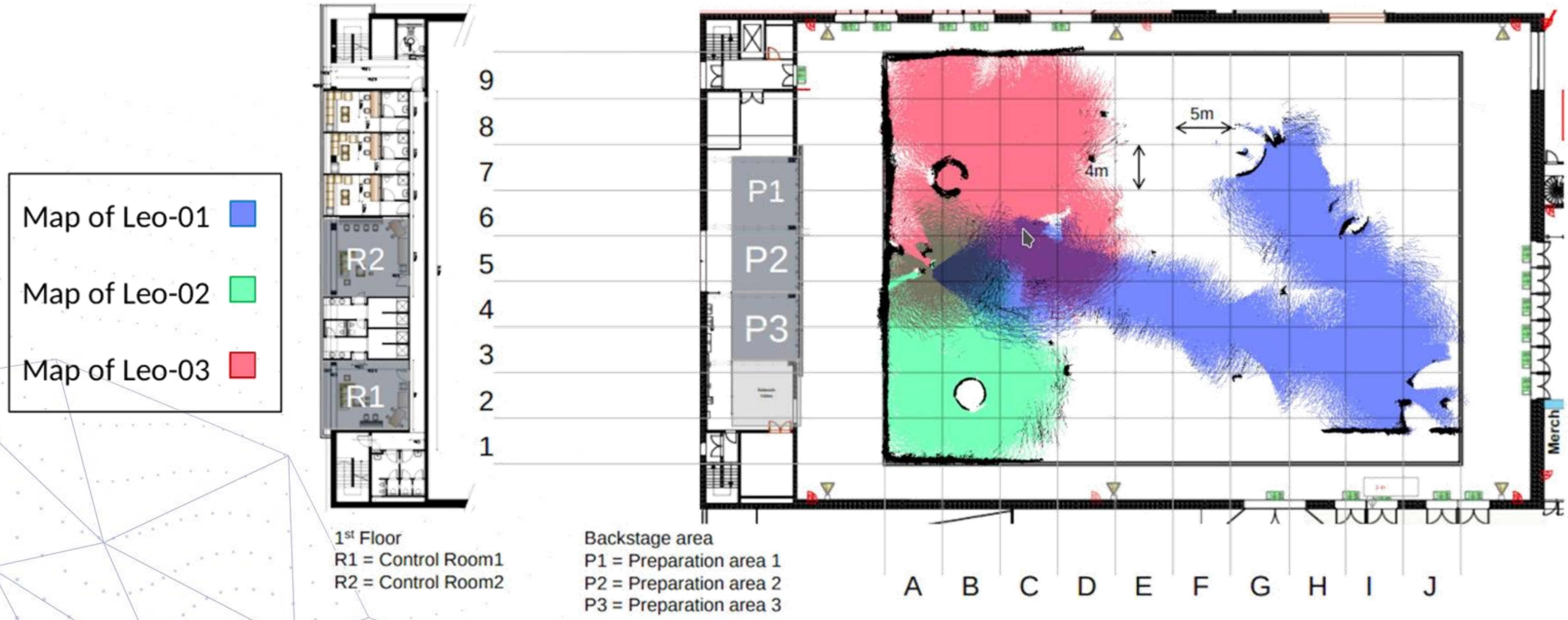


Figure 34 – Mapped area during the second field test of the ESA-ESRIC Challenge showing the contribution of each robot

Results: Sementic map (post-processing)

Map of Leo-01
Map of Leo-02
Map of Leo-03
Luvmi-X detected
Leo Rover detected
Crater
Boulder

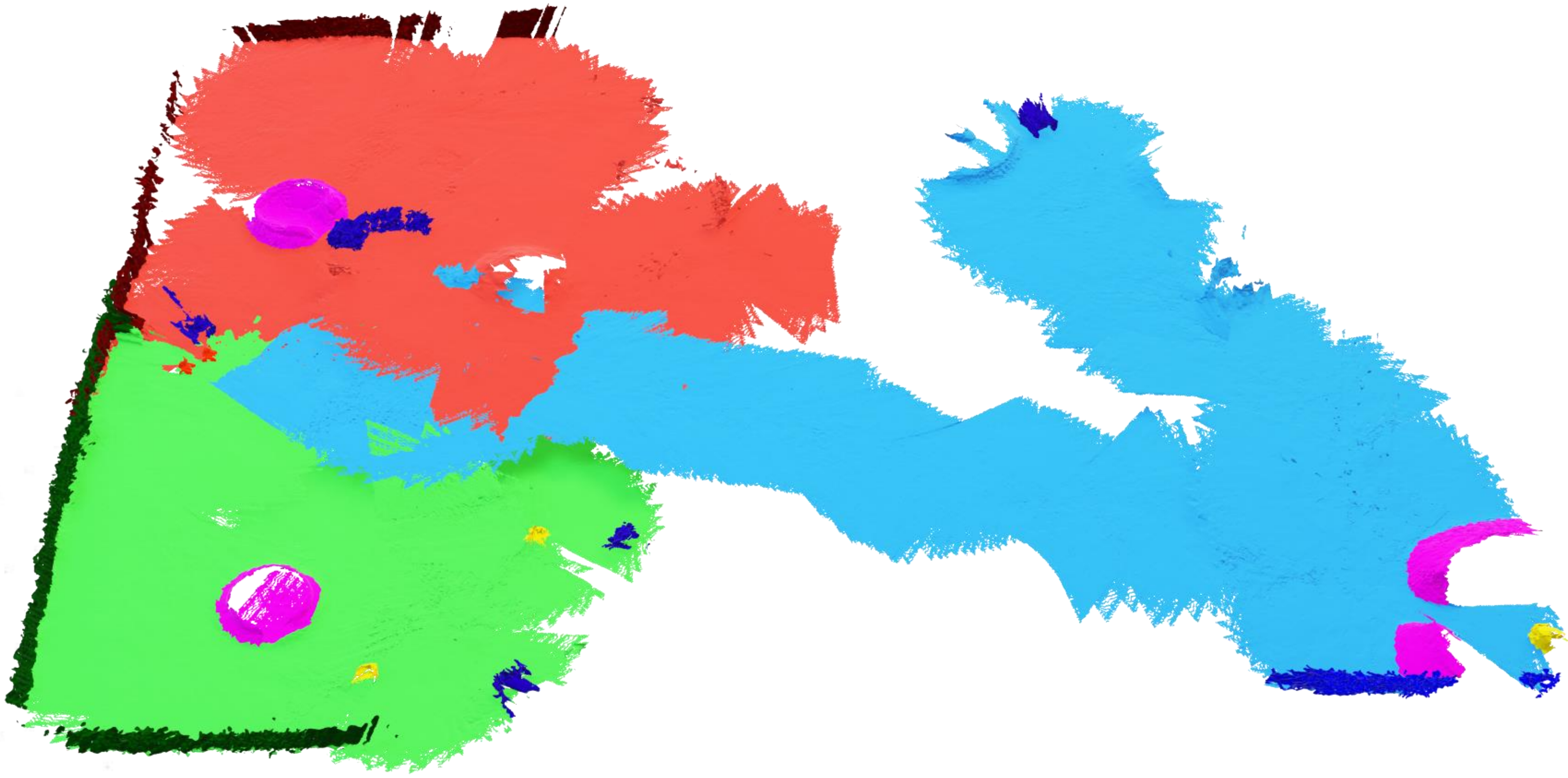


Figure 35 – Mapped area during the second field test of the ESA-ESRIC Challenge as 3D model segmented in manual post processing

7. Conclusion

Conclusion: Lessons learned

SpaceR
Space Robotics Research Group

- Map merging does not work on very sparse environments
- Lost odometry must be detected immediately
- Autonomous navigation needs to be robust

Conclusion: Benefits of REALMS 2

SpaceR
Space Robotics Research Group
uni.lu | SnT

- ROS 2 for distributed Multi-Robot System
- ROS 2 for resilience against single point of failure (ROS Master)
- Mesh network for relaying and avoid single point of failure
- Docker for scalability and modularity
- GUI to control multiple rovers for scalability and usability

References

References

[1] T. Clephas, J. Galvis, and C. A. Alvarez. m-explore ros2 port. https://github.com/robo-friends/m-explore-ros2, 2021. Accessed on 2023-09-13.
[2] eProsima. eProsima Fast DDS Performance. https://www.eprosima.com/index.php/resources-all/performance/eprosima-fast-dds-performance , 2023. Accessed on 2023-07-03.
[3] ESA - European Space Agency. 1st field test - esa-esric challenge. https://www.spaceresourceschallenge.esa.int/general-3, 2023. Accessed on 2023-06-28.
[4] ESA - European Space Agency. 2nd field test - esa-esric challenge. https://www.spaceresourceschallenge.esa.int/copy-of-1st-field-test, 2023. Accessed on 2023-06-28.
[5] Foxglove. Foxglove studio. https://github.com/foxglove/studio, 2021. Accessed on 2023-09-13.
[6] G. R. Hiertz, D. Denteneer, S. Max, R. Taori, J. Cardona, L. Berlemann, and B. Walke. IEEE 802.11s: The WLAN Mesh Standard. IEEE Wireless Communications, 17(1):104–111, Feb. 2010. Conference Name: IEEE Wireless Communications.
[7] K. Ideas. Leo Rover - build and program your own robot. https://www.leorover.tech/, 2023. Accessed on 2023-07-31.
[8] IEEE - Standards Association. 802.11s-2011 - ieee standard for information technology–telecommunications and information exchange between systems–local and metropolitan area networks–specific requirements part 11: Wireless lan medium access control (mac) and physical layer (phy) specifications amendment 10: Mesh networking, 2011.

References

[9] M. Labbe and F. Michaud. RTAB-Map as an opensource lidar and visual simultaneous localization and mapping library for large-scale and long-term online operation. Journal of Field Robotics, 36(2), 2019.

[10] S. Macenski, T. Foote, B. Gerkey, C. Lalancette, andW.Woodall. Robot operating system 2: Design, architecture, and uses in the wild. Science Robotics, 7(66):eabm6074, 05 2022.

[11] Y. Maruyama, S. Kato, and T. Azumi. Exploring the performance of ros2. In Proceedings of the 13th International Conference on Embedded Software, page 1–10, Pittsburgh Pennsylvania, 2016. ACM.

[12] L. Parker. Alliance: an architecture for fault tolerant multirobot cooperation. IEEE Transactions on Robotics and Automation, 14(2), 1998.

[13] L. E. Parker. Multiple Mobile Robot Systems, page 921–941. Springer Berlin Heidelberg, 2008.

[14] D. van der Meer, L. Chovet, A. Bera, A. Richard, P. J. Sánchez Cuevas, J. R. Sánchez-Ibáñez, and M. Olivares-Mendez. Realms: Resilient exploration and lunar mapping system. Frontiers in Robotics and AI, 10, 2023.

[15] L. Yang and S.-H. Chung. HWMP+: An Improved Traffic Load Sheme for Wireless Mesh Networks. In 2012 IEEE 14th International Conference on High Performance Computing and Communication & 2012 IEEE 9th International Conference on Embedded Software and Systems, pages 722–727, June 2012.

[16] T. A. Yuya Maruyama, Shinpei Kato. Exploring the performance of ros2. Frontiers in Robotics and AI, 10, 2016.

iSpaRo 2024 LUXEMBOURG

LUXEMBOURG
International Conference on Space Robotics
24 - 27 June 2024

isparo.space

- Proceedings in IEEEXplorer
- Single track: Everybody hears what everybody wants to tell
- 10 minutes presentations
- With an exhibition hall for showcasing (Industry and Academy)
- In the process of getting the support of IEEE RAS TC on Space Robotics to make it one of the leading conference of this TC
- 4 keynotes
- 1 Workshop on Lunar Autonomy
- Poster-Video sessions for the latest findings
- Topics on orbital robotics, planetary, extreme environments and from Earth to Space and vice versa

uni.lu | SnT

SpaceR
Space Robotics Research Group
uni.lu | SnT

University of Luxembourg

Interdisciplinary Centre for Security, Reliability and Trust

Contact:

Dave van der Meer
Doctoral Candidate
dave.vandermeer@uni.lu

More information and videos are available https://www.spacer.lu/

Stay tuned

@SnT_uni_lu
@davesroboshack

- SnT, Interdisciplinary Centre for Security, Reliability and Trust
- Dave van der Meer

iSpaRo 2024
June 24-27, Luxembourg
SAVE the DATE

isparo.space