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Virtual Reality-Driven Design of Augmented Reality Technologies for Extravehicular Activities

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Lunar EVA Challenges

Future Lunar EVAs are associated with a variety of challenges:

- Difficult **lighting conditions** on the lunar surface (e.g. pitch black shadows, strong light reflections)
- High **physical + psychological workload** / loss of **situational awareness**
- High degree of **astronaut autonomy** required due to latency and bandwith issues
- Extensive use of checklists and manuals as during the Apollo missions ardous

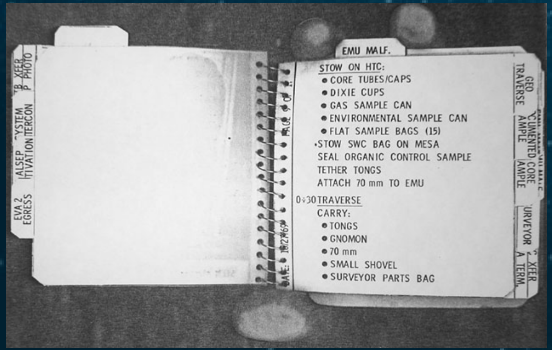

Figure 1. Apollo cuff – checklist (Credit: NASA)

Figure 2. Rendering of a (possible) future lunar EVA

Augmented Reality for Lunar EVAs

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Solution: **Augmented Reality (AR) technology!**

- Use of AR Head- Up Displays particularly advantageous, as the operator is not required to shift his gaze since 3D information is projected directly onto the field of view
- Used in numerous domains, such as **by enhancing perception and situational awareness** of soldiers, or by aiding engineers during complex maintenance and repair

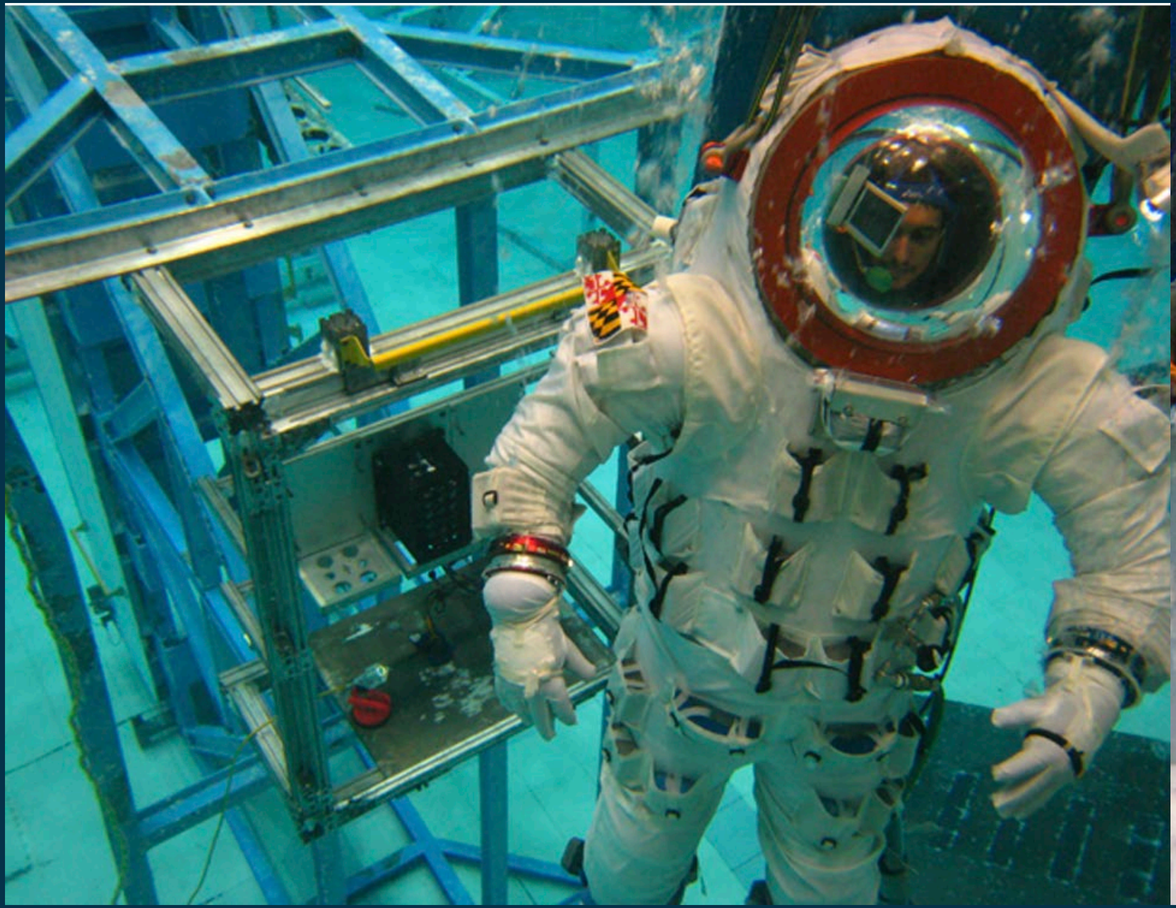
Issue:

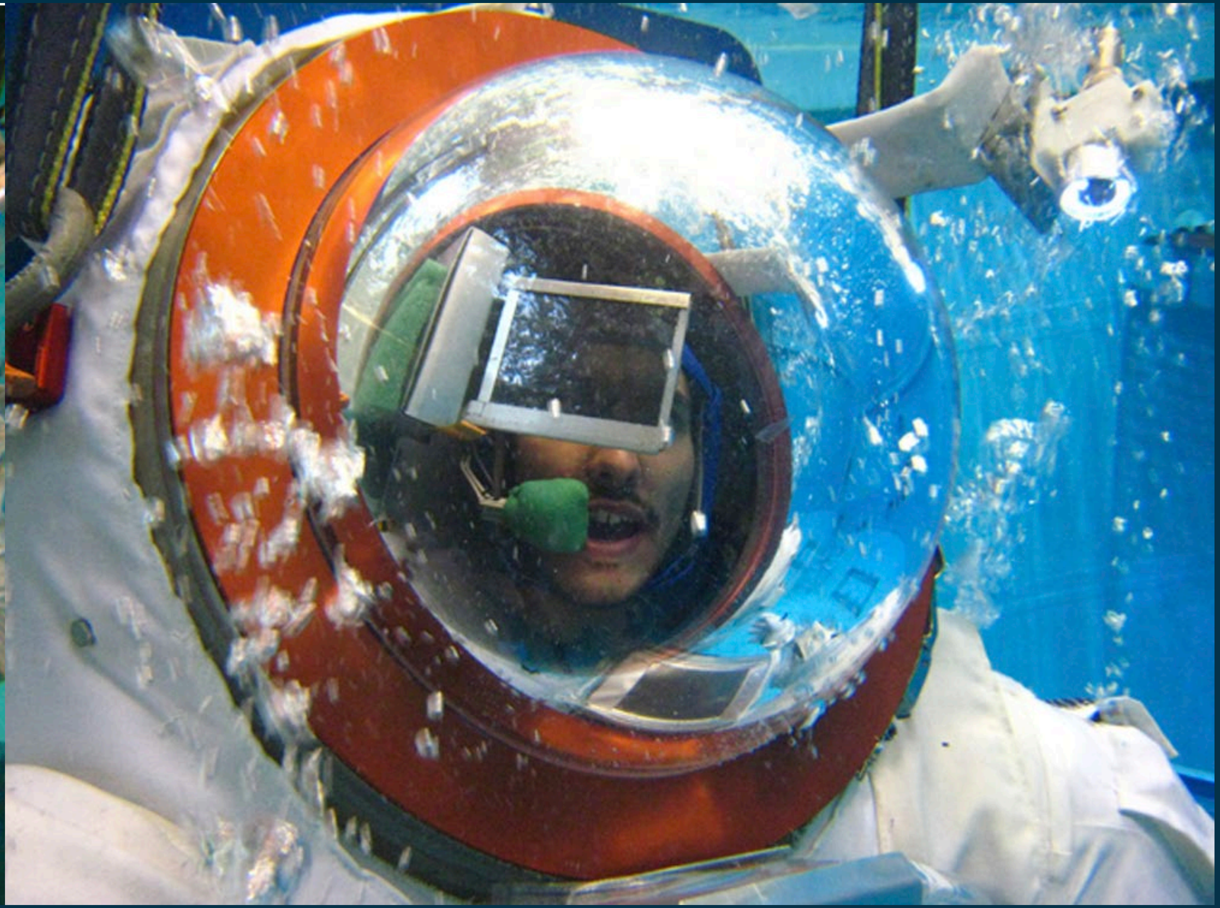
The potential use of AR in the context of lunar surface operations is still largely unexplored!

- Absence of empirical research stems from the **difficulties simulating a representative lunar environment** for the purpose of experimental deployments
- Analog testbeds to simulate reduced gravity → slow, logistically demanding, and oftentimes prohibitively expensive


MARS SOCIETY DESERT RESEARCH STATION

Traditional Design of EVA HUDs – Neutral Buoyancy Facilities





Stolen, M. F., Dillow, B., Jacobs, S. E., & Akin, D. L. (2008). *Interface for eva human-machine interaction* (No. 2008-01-1986). SAE Technical Paper.

Traditional Design of EVA HUDs – Analog Environments

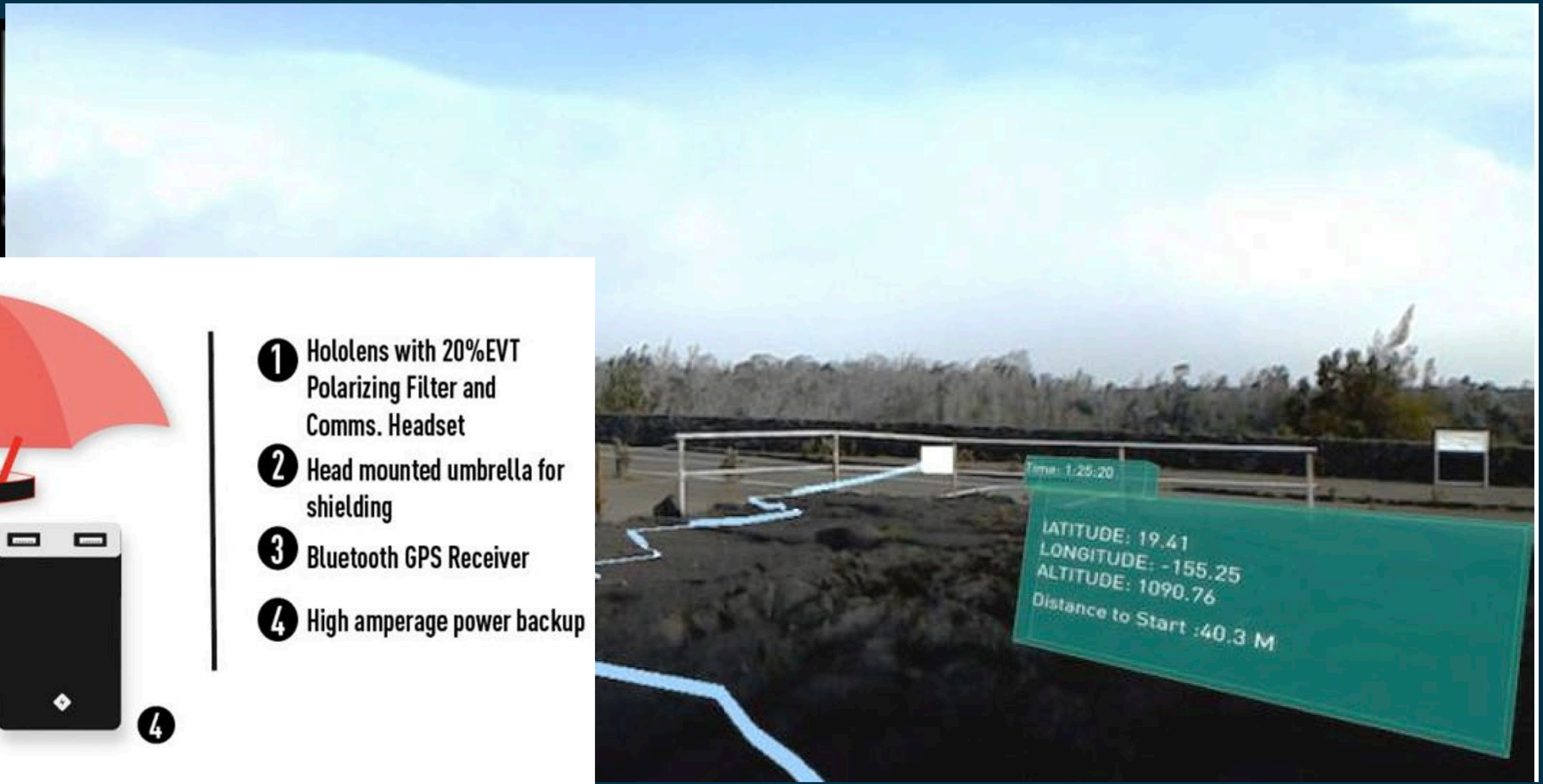


Figure 5. Holo-SEXTANT hardware

Anandapadmanaban, E., Tannady, J., Norheim, J., Newman, D., & Hoffman, J. (2018, July). Holo-SEXTANT: an augmented reality planetary EVA navigation interface. 48th International Conference on Environmental Systems.

Classical design approaches

Problems:

High cost and complexity

Limitations of current technologies

Low frequency of deployments

Few participants

Virtual Lunar Testbed

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Virtual Lunar Testbed

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Benefits:

Flexibility

Accurate Lighting

Location Independent

Lunar Terrain

Development Time

Limited Costs

Findings – Use Cases

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Astronaut Safety

Navigation

- Arrows
- Points of interests
- Azimuth information
- Distances

Collision Prevention

- Moving equipment (e.g. unloading cargo containers)
- Terrain (e.g. rocks)

Instructions and Information

Real – time repair instructions

Collaboration between astronauts and mission / ground control

Geological surveys

Suit / EVA information (e.g. oxygen, EVA time, suit pressure)

Checklists

Findings – Design Challenges

Contextual Relevancy

- Risk of overwhelming users field of view
- Relevancy to a given context needs to be ensured
- Clear advantage to already existing technologies needs to be ensured (e.g. tablet)

Technical Capabilities & Redundancy

- Backup system required
- Interdependy with other systems should be avoided to enhance reliability

Contribution

- The findings of our study suggest that the **implementation of AR HUD technology may indeed effectively alleviate challenges** encountered by the Apollo crews, such as unfavorable lighting conditions, decreased situational awareness, and high workload demands
- We **demonstrated the viability of virtual testbeds** as a methodological tool for facilitation of contextual enquiries concerning prospective and hypothetical systems

User Study 2: Navigation

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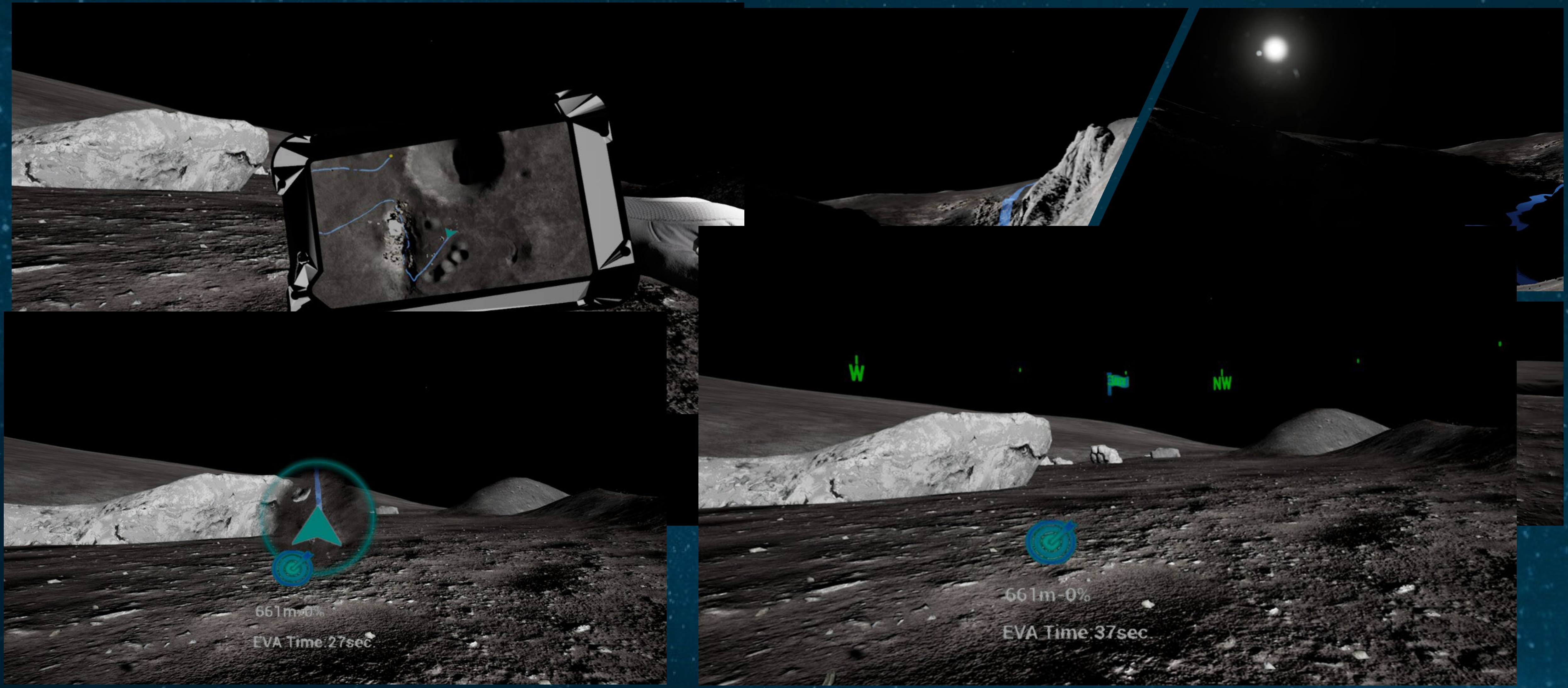
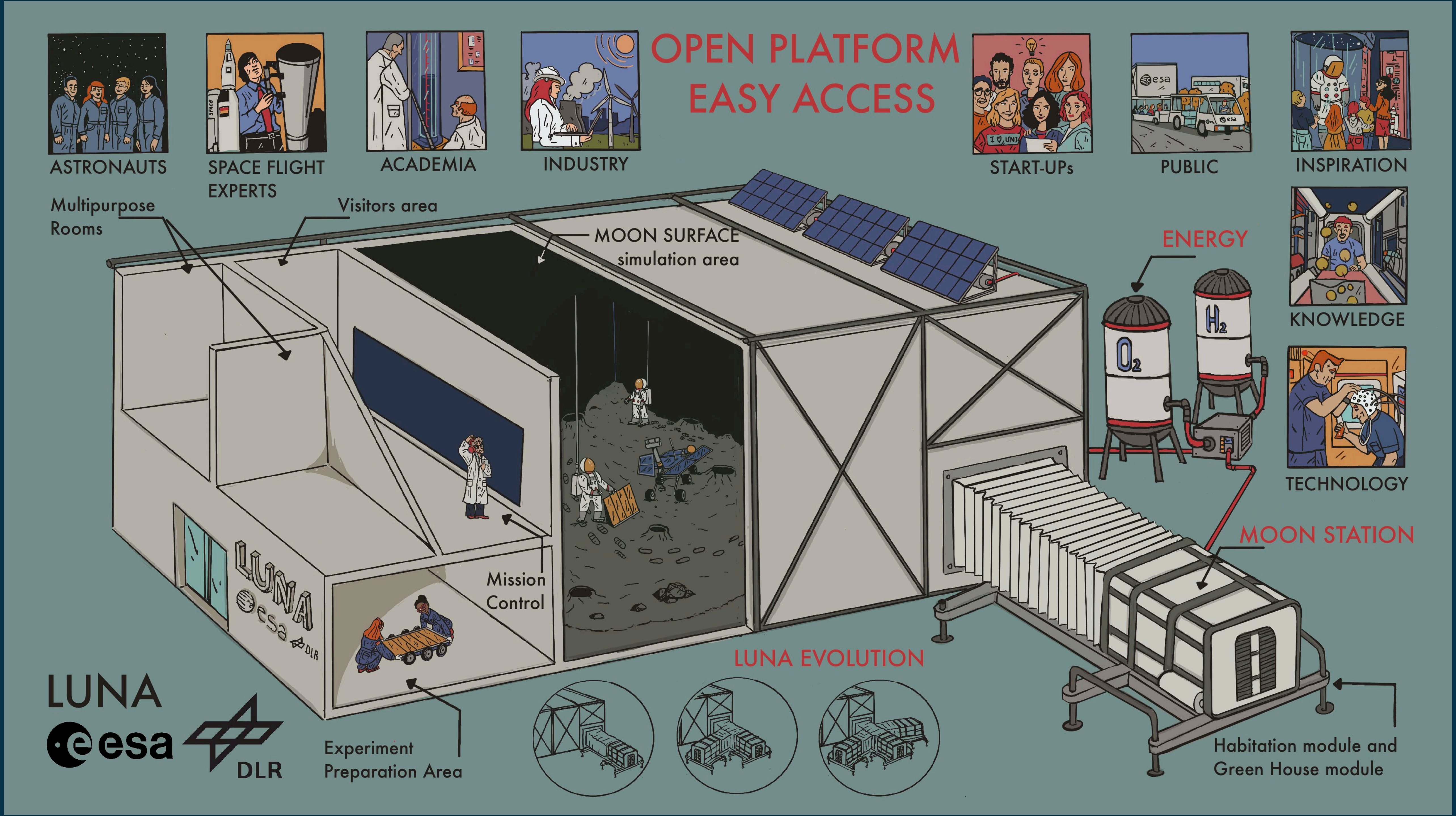


Future Work

- **Incorporating the explored AR features into the virtual testbed** to simulate their feasibility and effectiveness in lunar EVAs, especially the use of terrain awareness cues
- Exploring the interaction with the HUD (also needs to work when the hands of the astronauts are occupied)
- **Improving the realism of the VR environment** through simulating suit constraints, terrain or haptic feedback
- Test more advanced features in LUNA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TECHNOLOGY
Multipurpose Rooms
Visitors area
MOON SURFACE simulation area
ENERGY
O2
H2
MOON STATION
Mission Control
LUNA
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LUNA EVOLUTION
Experiment Preparation Area
Habitation module and Green House module
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LUNA FEATURES

- Gravity offload system
- Sun simulator
- Ground segment
- Dust and gas laboratories & regolith research
- Deep floor area & ramp
- Rover
- Exploration Medical System (ExMS)
- EVA suits
- Crew quarters (DLR :envihab)
- Energy module
- Habitation module (FLEXHab)
- EDEN LUNA
- eXtended Reality (XR) & digital media
- Visitors' room

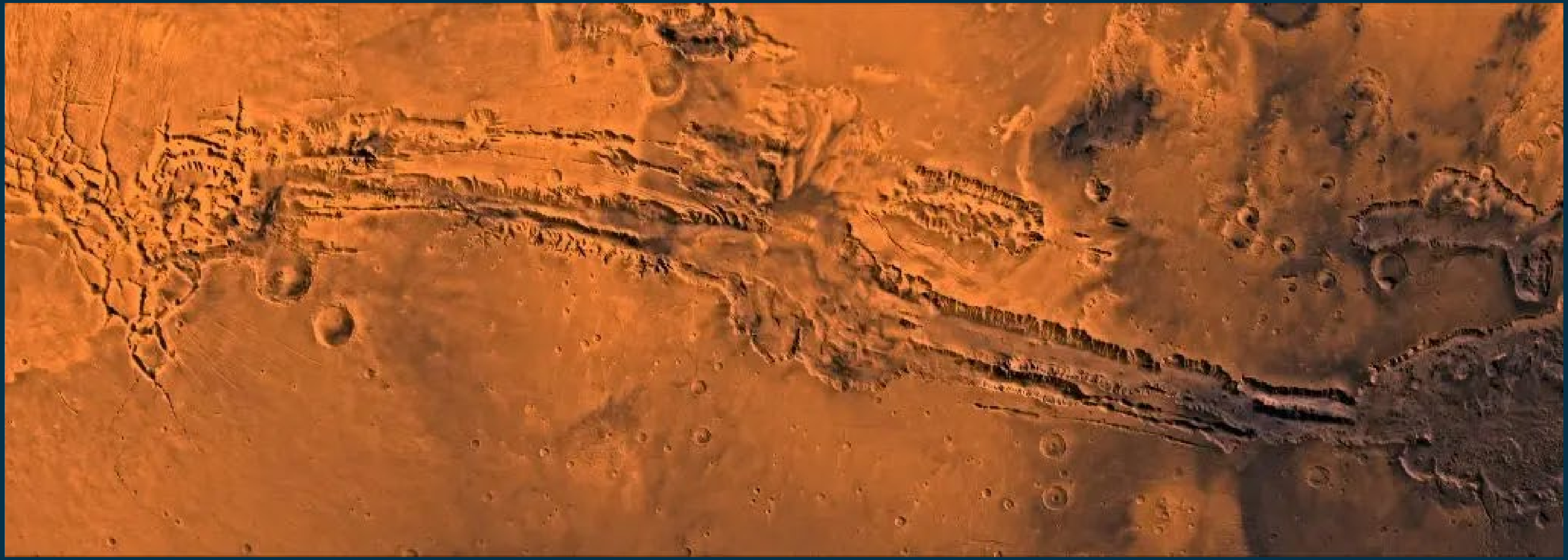
VaMEx Virtual Test - Bed

Valles Marineris Explorer (VaMEx)

Concept for a future Mars mission

- Utilizes an autonomous drone swarm
  - Consists of rovers, crawlers and unmanned aerial vehicles (UAVs)

Target: Search for non-terrestrial life in the Valles Marineris



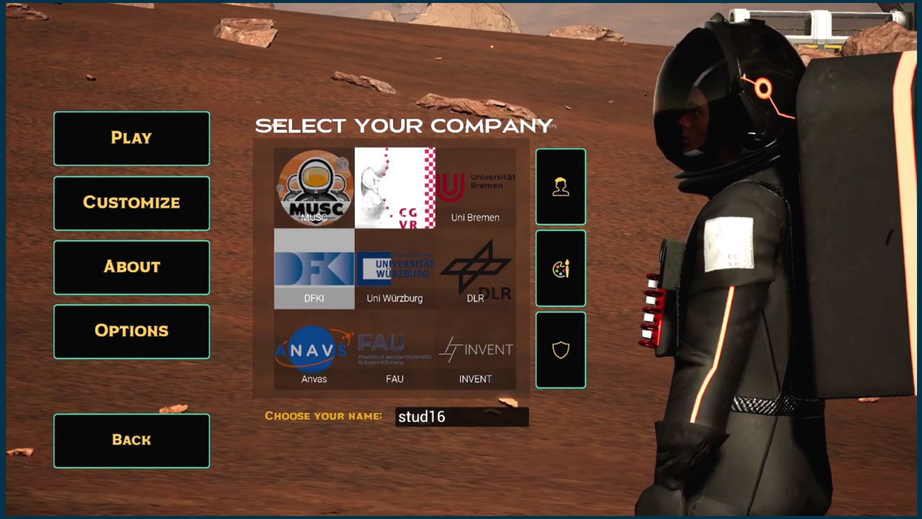
VaMEx: Virtual Testbed (VTB)

VTB simulates swarm units on Mars

- Simulates sensors and actuators
- Enables testing of algorithms and the mission concept virtually on Mars

VR mode

- Immersive high-fidelity visual feedback and interaction during the testing



VaMEx: Virtual Testbed (VTB)

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- Multi-user support (VR/non-VR)
  - Enables joint exploration and interaction
- Natural user interaction in first-person view through VR and roomscale tracking
  - Additionally: Virtual tablet and various tools
- Detailed environment, weather effects
  - Provide immersive, dynamic experience and realistic test situations

VaMEx: Virtual Testbed (VTB)

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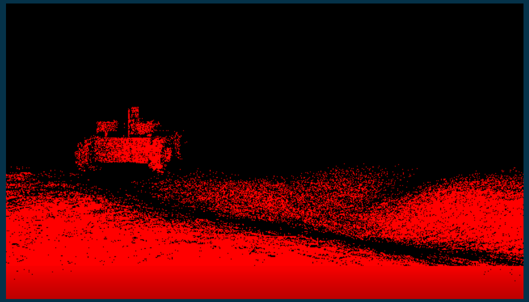
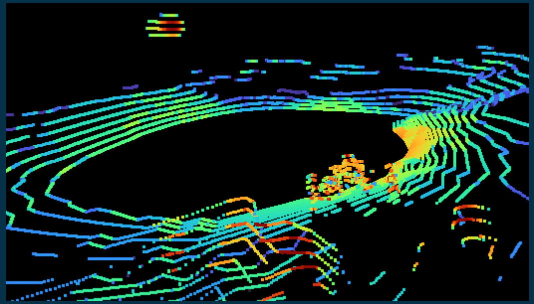
Data for visualization:

- RGB / Depth cameras
- LiDAR sensors
- IMU data
- Points of Interests
- Robot state (battery, target, …)
- …

RGB camera



Depth camera



LiDAR sensor

IMU data

Conclusion

- Astronauts face extreme challenges during future EVAs (e.g. difficult lighting, high workload)
- Our research shows that AR **HUD technology could be a feasible solution** to these challenges
- We could demonstrate in two studies that **VR is indeed a flexible, location independent and cost –effective tool** to simulate HUDs in a lunar environment
- VR testbeds **can also be used to simulate other conditions, such as Mars** and it **can be used to simulate real time robotic data** (e.g. LIDAR or depth camera sensors)