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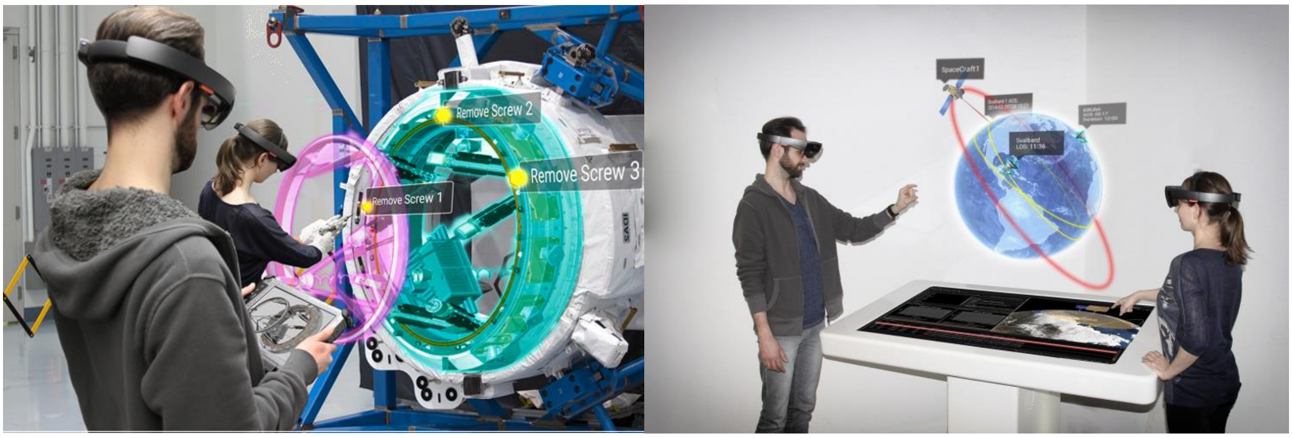
Augmented Reality Techniques to Enhance the Execution of Operational Procedures by Astronauts and Spacecraft Operators - Executive Summary Report



Prepared: Ruediger Gad

Digitally signed by Ruediger Gad
DN: c=DE, st=Hesse, l=Darmstadt, o=Terma GmbH, ou=IT DE, cn=Ruediger Gad, email=ruga@terma.com
Date: 2019.03.06 17:54:13 +01'00'

Ruediger Gad — Date 2019-03-06
Team Member

Approved: Ruediger Gad

Digitally signed by Ruediger Gad
DN: c=DE, st=Hesse, l=Darmstadt, o=Terma GmbH, ou=IT DE, cn=Ruediger Gad, email=ruga@terma.com
Date: 2019.03.06 17:54:34 +01'00'

Ruediger Gad — Date 2019-03-06
Project Manager

Checked:

Dan Søren Nielsen — Date 2019-03-06
Quality Manager

Authorized:

Michela Alberti — Date 2019-03-06
Department Manager

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1 Introduction

1.1 Purpose

This document contains the executive summary report of the “Augmented Reality Techniques to Enhance the Execution of Operational Procedures by Astronauts and Spacecraft Operators” study Proof of Concept (PoC).

1.2 Scope & Applicability

The Executive Summary Report provides a concise summary of the most important findings and outcomes of the activity. It provides a high-level overview, which aims on being also understandable by non-experts.

1.3 Document Structure

The document is structured as follows:

1. Introduction – This section contains an introduction for the general document.
2. Executive Summary Report – This section contains the executive summary report.

1.4 References

Ref.	Doc. No.	Title	Date/Issue
SoW	ESA-DOPS-SYS-SOW-0001	Augmented Reality Techniques to Enhance the execution of operational procedures by Astronauts and spacecraft operators	2016-12-19 Issue: 1

1.5 Abbreviations

Abbreviation	Definition
FoV	Field of View
HBD	Head Bound Display
KO	Kick-off
MCS	Mission Control System
MIB	Mission Information Base
MOE	Multi-purpose Operation Environment
MOM	Minutes of Meeting
MoM	Message-oriented Middleware
MPS	Mission Planning System
MRS	MOE Robotic Services
OHBD	Optical Head Bound Display
OS	Operating System
PoC	Proof of Concept

Abbreviation	Definition
SDD	Software Design Document
TC	Telecommand
TM	Telemetry
VM	Virtual Machine

2 Executive Summary Report

2.1 Overview

Augmented reality displays are image-forming systems that use a set of optical, electronic, and mechanical components to generate images somewhere on the optical path in between the observer's eyes and the physical object to be augmented.

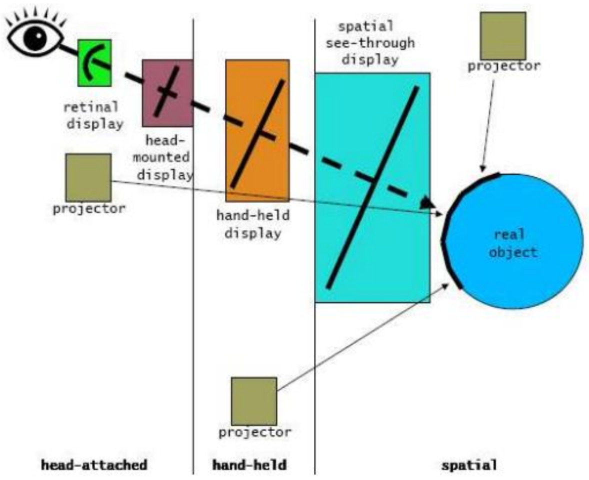

Figure 2-1 Image generation for Augmented Reality displays[1]

Figure 2-1 illustrates the different possibilities of where the image can be formed to support augmented reality applications, where the displays are located with respect to the observer and the real object, and what type of image is produced (i.e., planar or curved).

AR provides a live direct or indirect view of a physical, real-world environment and augments (or supplements) this view with computer-generated input such as sound, video, graphics, 3D objects or GPS data.

Figure 2-2 shows an example mock-up for a potential cooperative repair or training scenario. Repair instructions are shown overlaid on the real environment. Parts of special relevance are highlighted with additional overlays.

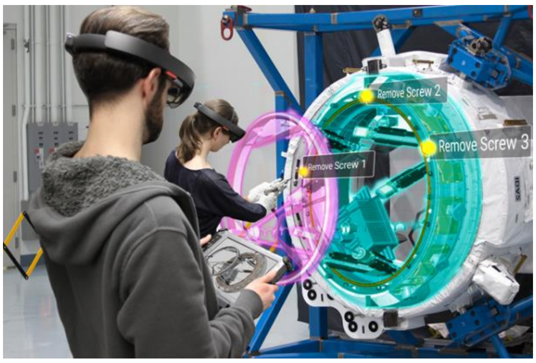

Figure 2-2 Augmented Reality Cooperative Repair or Training Scenario Example Mock-up

[1] O. Bimber, R. Raskar Siggraph 2005 - Spatial augmented reality: merging real and virtual worlds, ISBN 1-56881-230-2

Figure 2-3 shows an example mock-up of a cooperative analysis and planning scenario for spacecraft operation. A virtual Earth model is projected in a central place and the users with AR support can cooperate interactively for analysing and planning.

Figure 2-3 Augmented Reality Cooperative Analysis and Planning Example Mock-up for Spacecraft Operation

Figure 2-4 shows an example mock-up for cooperative analysis and planning with augmented reality in the scope of rover operation.

Figure 2-4 Augmented Reality Cooperative Analysis and Planning Example Mock-up for Rover Operation

AR improves users' experience by enabling them to interact with and learn from whatever they are observing. The deployment of AR tools within a field service environment can have a measurable improvement on key performance indicators (KPIs) related to quality, productivity, and efficiency such as Mean Time to Repair, First Time Fix Rate, and Mean Time between Failures.

2.2 Scope and Aim

The overall scope in which this activity is situated is the incentive to improve ESAs space operations with the help of Augmented Reality (AR). AR offers promising features that appear to have the capability to improve space operations in various areas.

The aim of this study was to explore the potential of modern AR technologies, to identify and analyse application scenarios in the area of ESAs operations, and to investigate possibilities for integrating AR with ESAs ground system software, specifically a mission control system (MOE). Thereby, the scope was twofold: on one hand, the identification and analysis of application scenarios which was purposely kept open to not limit the process of finding application scenarios by potential limitations of the current technology. On the other hand, a concrete PoC was implemented to gain hands-on experience with and showcase the application of AR. Furthermore, both, application scenarios and the PoC are intended to serve as basis for future activities.

2.3 AR Application Scenarios for Proof-of-Concept (PoC)

The use cases selected for the PoC should demonstrate selected AR-related technologies and demonstrate the utility of AR for ESAs operations at EAC and ESOC.

From an AR-technology point of view, the following technology-aspects were considered most important for the PoC:

- Advanced AR Tracking
  This point considers the “quality” of the tracking solution, which impacts, e.g., how easily the tracking can be initialized and how precise the tracking is.
- Application of Wearable AR Devices
  This point considers the applicability of AR using wearable devices such as the HoloLens head bound display.

From the use cases mentioned during the concept definition, three were chosen for the further selection process for the PoC. Table 2-1 shows an overview of the pre-selected use case candidates.

Table 2-1 Pre-selection of Use Case Candidates for the PoC

	Interactive Manual	**AR Spacecraft**	**AR Rover Operation**
Description	EAC Life Support Rack Assembly Interactive Manual	Display Spacecraft “on the Table” Show TM etc.	Overlay real Rover with TM (Speed, Battery Status, …) Indicate Position
Application	Training (and Operation?)	Planning (and Operation?)	Operation (and Planning?)
Hardware	iPad Pro (Use on ISS?)	HoloLens (and iPad?)	HoloLens (and iPad?)
ESA SW Integration	No (?)	Yes	Yes
AR Tracking	Advanced	Simple	Simple & Advanced
Users	EAC	ESOC	ESOC (and EAC?)

Based on the targeted users, EAC and ESOC, and the selected AR-technology aspects, two use cases were finally selected for the PoC:

- Interactive Training and Manual
  For interactive training and manual, AR is used for displaying instructions in form of virtual elements overlaid on top of the real world. Examples for such instructions are

highlighting of important parts such as levers or screws or showing animations, which, e.g., illustrate the work process step-by-step. From the AR-technology perspective, this use case was primarily intended to demonstrate advanced AR tracking.

- Rover Operation
  This use case considers the operation of a rover on a celestial body surface. From the AR-technology perspective, this use case focused on the application of the HoloLens device. The use case was further split up into:
  - Ground Control Operating a Rover
    In this use case, AR devices are used by operators located at ground for monitoring the operation of a rover on a celestial body surface.
  - Astronaut Cooperating with Rover
    In this use case, an astronaut and a rover are located together on a celestial body surface. The astronaut could use AR, e.g., for getting information about the rover or for controlling the rover.

2.4 Proof of Concept

2.4.1 Interactive Training/Manual

For the interactive training/manual use case, the focus was on the AR-tracking to properly overlay real objects with virtual elements. For tracking, the VisionLib[2] library originally developed by Fraunhofer IGD and now continued and marketed by their Visometry GmbH spin-off is used. VisionLib employs model-based edge-based tracking to achieve fast initialisation and accurate tracking.

Figure 2-5 shows an example of model-based tracking taken during the development of the interactive training/manual use case. It can be seen that the 3D-model, shown in Red, is precisely aligned to the real object.

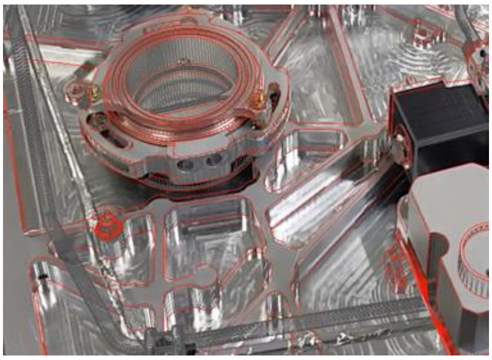

Figure 2-5 Model-based Tracking In-development Example

The model-based tracking was even capable to tolerate certain differences between the 3D-model and the real object. Figure 2-6 shows an example of such a difference in which a part of the tubing and connector present in the 3D-model is not present in the real object.

[2] https://visionlib.com/

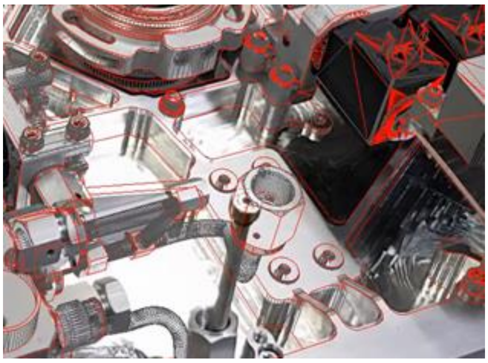

Figure 2-6 Model-based Tracking In-development Example Difference Model/Reality

A weakness that was discovered at this development stage was that milling tracks, which can, e.g., be seen in Figure 2-5, could “confuse” the tracking solution. One possible explanation for this is that the sharp visual “edges” of the milling tracks were mistakenly interpreted of “real edges” of the three-dimensional structure of the object.

Figure 2-7 shows close-ups of a later in-development version. The aim is to illustrate the precision of the model-based tracking. It can be seen that even the screw holes respectively the screw itself are properly aligned, which illustrates the precision of the tracking approach.

Figure 2-7 Illustration of Model-based Tracking Precision

Figure 2-8 illustrates more advanced visualisations. The example shows the illustration of the physical and chemical processes inside the object. The object was made partially transparent to visualize the internal working principles.

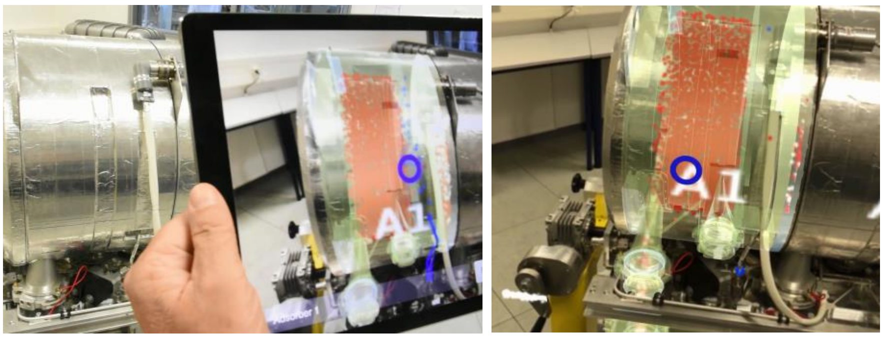

Figure 2-8 Interactive Visualization of Processes

2.4.2 Rover Operation

For the rover operation use case, the achieved results can be categorized into:

- AR and ESA Software Integration
- AR Application Functionality

Figure 2-9 shows the integration status at the end of this activity. The Orange marked parts indicate the integration-related components, which now offer significantly more functionality and can be employed in a more generic way.

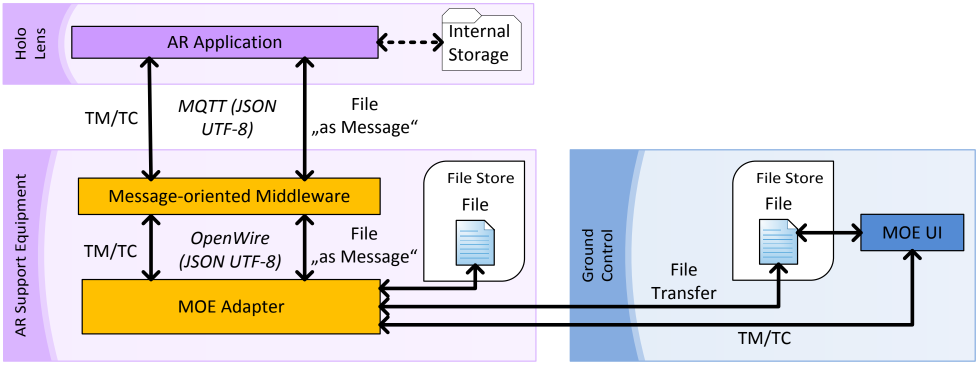

Figure 2-9 MOE to AR through MoM Integration

Regarding the use cases targeting EAC and ESOC, two different AR operation modes were implemented for the AR application:

- EAC – Astronaut Cooperating with Rover
- ESOC – Rover Ground Operator

For the ESOC use case, it showed that it is useful to scale the rover and the virtual environment. In some cases, it could be beneficial to display the rover and the environment in full size, e.g., to allow proper assessment of sizes or distances. Figure 2-10 shows a virtual rover in AR with a coordinate system displayed in full-size.

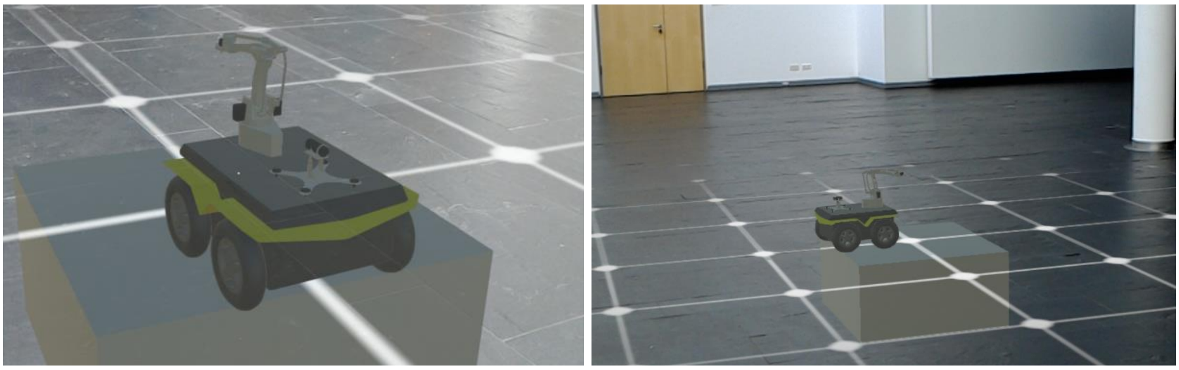

Figure 2-10 Virtual Rover in AR Full-size

In other situations, it may be more desirable to get a birds-eye perspective and thus scale the rover and environment down. Examples for such situations could be an operator wanting to display the rover AR display on their table or displaying the AR display in a meeting or cooperative situation on a meeting room table possibly augmented with additional information on displays etc. Figure 2-11 shows an example for such a situation.

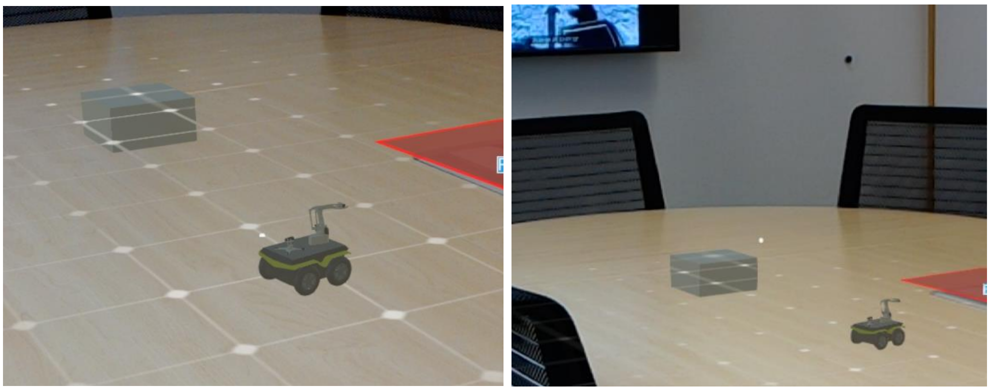

Figure 2-11 Downsized Virtual Rover in “On-table” Situation

One potential future direction for extending the work from this study could be to assess co-operative multi-user AR use cases. Figure 2-12 shows an example mock-up for a coopera-tive multi-user AR rover operations use case. We call this a mock-up because, while the shown AR overlays are results of the rover operations PoC implemented in this activity, the cooperative multi-user AR scenario could not be covered within the scope of this activity and is only symbolised in the figure by showing two persons wearing AR devices.

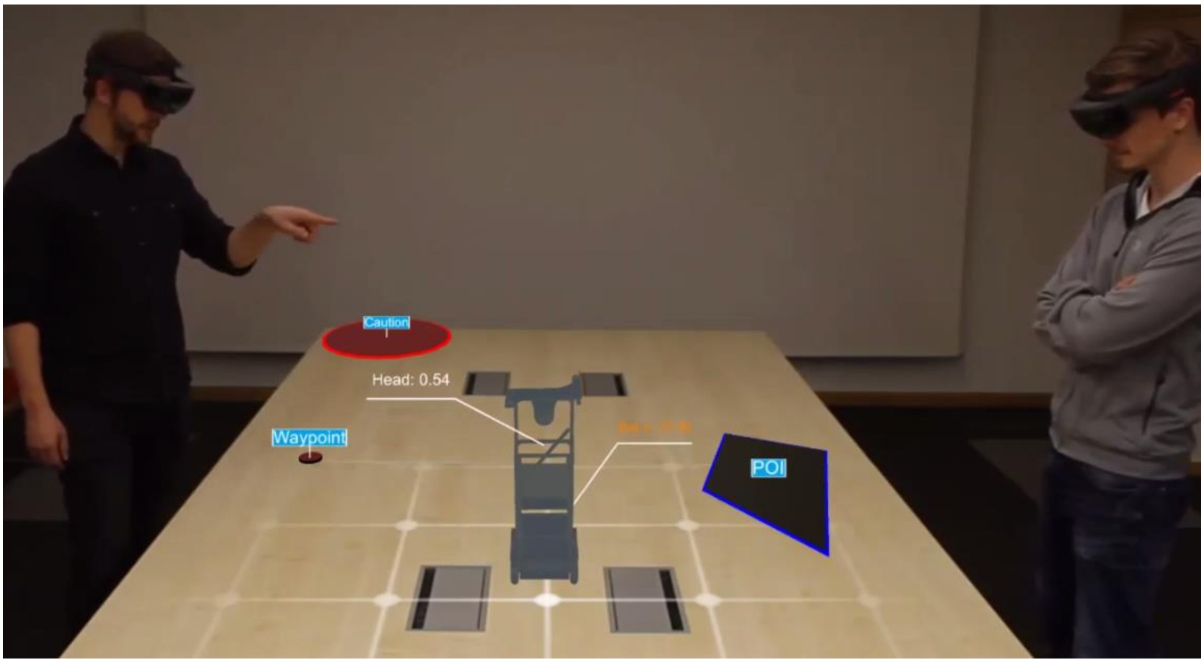

Figure 2-12 Mock-up for Cooperative Multi-user AR based on the Rover Operations PoC

2.5 Conclusion

The study aimed on evaluating whether AR can be meaningfully applied in scope of ESAs operations. The study covered a conceptual/exploratory phase one, during which ideas were gathered and systems were evaluated on a high abstraction level, and a more concrete and technical phase two, during which a PoC was developed.

The exploratory phase provided a wide range of ideas for use cases of AR in scope of ESAs operations. In phase two, for illustrating the capabilities and utility of AR two PoCs were implemented:

- A PoC using an interactive training/manual use case served as example for evaluating “advanced” AR tracking techniques. The employed VisionLib library showed to deliver highly accurate tracking.
- A PoC using a rover operations use case served as example for leveraging the wearable HoloLens AR device. This use case helped to demonstrate the integration of AR devices with ESA software and to evaluate different application scenarios in scope of manned space operations and in ground control environments. The PoC covers:
  - Integration of ESA Software (the MOE MCS) with AR (the HoloLens Device)
    - Forward Rover TM to the AR
    - Forward AR TM (from the HoloLens) to MOE
    - Command the AR Support Software etc. from MOE
    - Send Simple Commands from AR to the Rover (through MOE)
  - Support for two Use Cases
    - Rover Ground Control
    - Astronaut with Rover Cooperation
  - Demonstrate three Tracking Modes
    - “Room-based” Tracking for the Ground Control Use Case
    - Marker- and Model-based Tracking for the Astronaut Use Case
  - Cooperation between Ground Control and AR User using the Example of Entity File Editing
    - Upload Entity Files from MOE to AR
    - Edit Entity Files in AR and Forward to MOE
  - Configurable TM Display in AR
    - Head-up-display-like at fixed Positions in the View Field
    - Superimposed TM Textual Display near Rover
    - Superimposed Graphical Display (Movement and Rotation Arrows) near Rover
  - Simple Voice-based Commanding
- Scalable Visualisation to Aid in the Ground Control Use Case, e.g., to Switch from Close-up to Birds-eye Perspective

We come to the following conclusions:

- "Advanced" AR tracking improves the precision and aids in using AR technologies.
- The integration between AR and ESA software is possible. This was demonstrated by integrating a HoloLens AR application with the MOE mission control system.
- With respect to wearable AR devices, the HoloLens platform was employed. It showed that conceptually use cases for AR exist, e.g., in scope of manned space operations and in control room scenarios.
- Further activities in scope of AR may be useful, e.g., to
    - Improve the TRL of the PoC implementations, e.g., for manned space operations or rover operations.
    - Assess cooperative scenarios with multiple AR devices, e.g., for cooperative rover ground control or operation planning.