Reducing Cognitive Workload in Telepresence Lunar - Martian Environments Through Audiovisual Feedback in Augmented Reality

Irvin Steve Cardenas
Advanced Telerobotics Research Lab
Kent State University
Kent, Ohio, USA

Kaleb Powlison
Advanced Telerobotics Research Lab
Kent State University
Kent, Ohio, USA

Jong-Hoon Kim*
Advanced Telerobotics Research Lab
Kent State University
Kent, Ohio, USA

ABSTRACT

Navigating through an unknown, and perhaps resource-constrained environment, such as Lunar terrain or through a disaster region can be detrimental - e.g. both physically and cognitively exhausting. Difficulties during navigation can cost time, operational resources, or even a life. To this end, the interaction with a robotic exploration system in lunar or Martian environments could be key to successful exploration extravehicular activities (X-EVA). Through the use of augmented reality (AR) we can afford an astronaut with various capabilities. In particular, we focus on two: (1) The ability to obtain and display information on their current position, on important locations, and on essential objects in an augmented space. (2) The ability to control an exploratory robot system, or smart robotic tools using AR interfaces. We present our ongoing development of such AR robot control interfaces and the feedback system being implemented. This work extends the augmented reality robot navigation and audio spatial feedback components presented at the 2020 National Aeronautics and Space Administration (NASA) SUITS Challenge.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **HCI design and evaluation methods**.

KEYWORDS

HRI, Augmented Reality, Collaborative Control, Cognitive Load

ACM Reference Format:
Irvin Steve Cardenas, Kaleb Powlison, and Jong-Hoon Kim. 2021. Reducing Cognitive Workload in Telepresence Lunar - Martian Environments Through Audiovisual Feedback in Augmented Reality. In *Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction (HRI '21 Companion), March 8–11, 2021, Boulder, CO, USA.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3434074.3447214

*Corresponding author: jkim72@kent.edu

HRI '21 Companion, March 8–11, 2021, Boulder, CO, USA

ACM ISBN 978-1-4503-8290-8/21/03…$15.00
https://doi.org/10.1145/3434074.3447214

1 INTRODUCTION

Artemis is NASA's new lunar exploration program, which includes sending the first woman and the next man on the Moon. Through the Artemis program, NASA will use new technology to study the Moon in new and better ways, and prepare for human missions to Mars. This encompasses the developments of launch vehicles, spacecraft, moon landers, and the development of more sophisticated space suits. These are suits that allow astronauts to perform exploratory missions, and the technology we integrate with them, are called Exploration Extravehicular Mobility Units (xEMU).

To this end. The NASA SUITS Challenge was started. NASA SUITS stands for Spacesuit User Interface Technologies for Students. It's an ongoing yearly challenge where students propose and develop a set of augmented reality (AR) interfaces. Amongst all proposal submissions only the top 10 teams from across the country are selected for a visit and demonstration at the Johnson Space Center. These interfaces must consider a set of tasks and the interactions enabled by the augmented reality interfaces. These tasks include scientific data collection, being able to interact with the vitals information of the suit, and fixing a rover.

Research and development of tools and interaction models that will assist astronauts during X-EVAs is necessary because of the degree of uncertainty and environmental differences to which astronauts have previously been exposed to for long periods of time. Contrary to International Space Station (ISS) EVA operations, which involve a fleet of ground support personnel using custom console displays and performing manual tasks such as taking handwritten notes to monitor suit/vehicle systems and to passively adjust EVA timeline elements, lunar exploration EVA is more physically demanding, more hazardous, and less structured than the well-rehearsed ISS EVAs - as mentioned in section E of the Integrated Extravechicular Activity Human Research and Testing Plan [1]. Most critically, the reactive approach of ground-personnel, providing real-time solutions to issues or hazards (e.g. hardware configuration, incorrect procedure execution, life support system diagnosis) will not be feasible in the conditions of lunar EVA, i.e. limited communication bandwidth and latency between ground support and inflight crewmembers.

This, in turn, requires more consideration towards the list of factors that contribute to the risk of injury and compromised performance during EVA operations, covered in NASA's Human Research Program (HRP) EVA evidence report [5]. Within the risk categories listed in the HRP EVA evidence report, the "EVA Factors", "Physical

State" and "Mental State" categories contain factors that can be actively monitored and whose impact may be minimized through proactive countermeasures.

For the 2020 NASA SUITS Challenge, we presented an approach similar to our work on immersive telepresence control modalities [2, 4] in which we implement a monitoring system that is situational aware and which allows interfaces to be reactive to mission tasks and reactive to type the interaction between the agents involved in the mission (e.g. ground support team, in-flight crew, or virtual assistant). For example, it might be desirable that certain widgets of the interfaces are enlarged or remain focused depending on the criticality of information. Similarly, a summary of information (e.g. suit vitals) might be preferred during an on-going mission over fine-detail information, to reduce any cognitive overload.

Furthermore, means to dynamically (1) interact, (2) introspect, and (3) guide a smart tool (robot) during navigation were presented. This approach leveraged a set of AR interfaces and underlying data analytics systems that provided feedback to all agents - humans and robots - of current EVA timelines and internal state. We further discuss in this paper our ongoing work on AR robot interactions, under the constrains faced by an astronaut performing an exploration extravehicular activity. In particular, work around audiovisual feedback for control and guidance of robotic tool. Further details of the work presented at the NASA SUITS challenge can be found in [3].

2 BACKGROUND WORK

This work focuses on the AR robot control system presented in [3]. We focus on allowing a first-person view and a third-person view to immerse the user in the control of a robot. For example, in [4] a telepresence control suit was leveraged to teleoperate humanoid robots, and a virtual reality (VR) headset allowed the user to be visually immersed. Instead of a VR environment we used an augmented reality application to control the robot. This is similar to the work in [6] which demonstrates the use of mixed reality as a tool for providing seamless interaction between physical and virtual worlds. Among the most important benefits named by the paper is the elimination of safety risks, a primary focus of our work. We have made use of Augmented Reality in a similar way, to avoid the risk of physical harm. Furthermore, considering the constraints and non-deterministic environment, our approach considers work such as [8], which investigates the types of research essential for improving robots as a tool for use in rescue operations. One of its conclusions is that finding better ways to propagate visual information, so that it may be used by many users with many different needs, would provide significant long term benefits. More closely, [7] presents the use of AR as a tool for the coordination and informing of disaster response teams. The authors look towards developments primarily in video games and in drones, the lessons from which they apply to AR. Details of the design and implementation of the system used for the NASA SUIT challenge can be found in [3].

3 CONCEPT OF OPERATIONS (CONOPS)

Figure 2 shows an overview of the concept of operations of the underlying control system called - AARON System. Further details are provided in [3]. In short, the astronaut and the assistant can continuously communicate verbally and through gestures in the augmented space. The robot control interface is an application (app) that the AARON executive mediates. Through the executive the robot is able to receive relevant data from the astronaut's mobility unit, and vice-versa the astronaut is able to receive state information and issue commands to the robot.

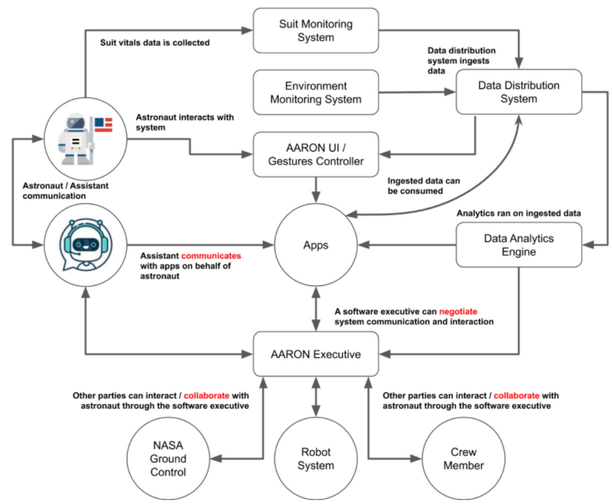

Figure 2: CONOPS Diagram

4 ONGOING WORK

In general, by using AR technology, we may be able to alleviate issues related to navigation and visibility during an exploratory extravehicular activity. This is limited by the hardware capabilities and the integration of the technology into next generation spacesuits - as it is currently explored by NASA. With this in mind, the same AR technology can be used to extend and enhance the capability of control smart robotic tools and exploration vehicles such a rover. As some rovers have been designed as land vehicles used to transport human spaceflight crew, and others serve as partially or fully autonomous robots - the opportunity to design control interfaces that fit both types of vehicles arises.

Our approach combines the use of markers, holograms, and beacons. The simplest implementation for navigation markers are bright dots showing the location of an object. More complex holograms can be used to guide a user through an area. By using location data, we can track a user as they move through 3d space relative to the location of other objects. We use this information to place markers on the screen of the AR headset. The use of high visibility colors, such as regular green (#00FF00), schoolbus yellow (#FFD800), or safety orange (#FF7900) is used as defined in [3] - this is in line with a color palette that suits dark and highly luminous environments alike. The color causes the user's eyes to be immediately drawn to them due to their contrast with the surrounding area. For users under our human-in-the-loop test that have certain types of color blindness, other colors are chosen to be used. But, this is not a constraint due to the physical requirements for becoming an astronaut. Rotational data of the user is obtained through the AR headset and an object they wish to track. We can constantly update a marker using this data, similar to how the HUD of a modern fighter jet will track an object by using lasers.

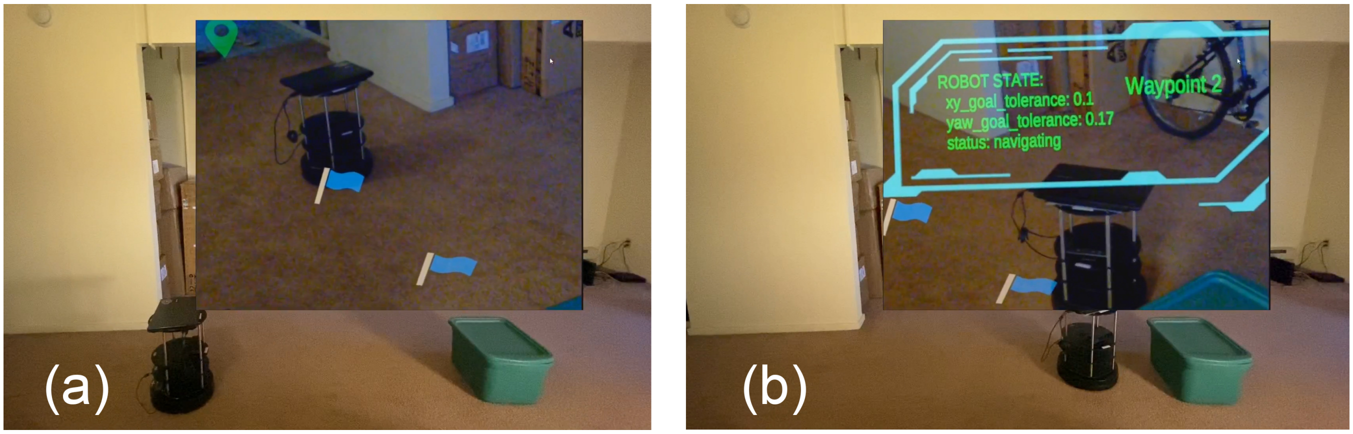

Figure 1: Robot AR interface with visual navigation markers displaying. (a) Initial starting location is defined, along with a set of navigation waypoints. (b) Robot state panel displayed

The markers used for the tracking of an object are be small, thin, and highly visible. This will allow for essential locations and objects to be marked without clogging up the user's view or making the issue of visibility worse. One such design for a marker would be a small dot in the center of a hollow square. This design puts a precise marker (the dot) in the middle of a less precise but more quickly identifiable market (the square), allowing for the object to be easily seen without being obscured. A user is able to navigate a small library of objects, using voice controls or traditional controls, to add, select, enable, disable, or delete markers. For the use of voice controls, a three digit code can be used to allow for the easy management of up to 1000 different markers. For example, a marker which holds the code "035" could be assigned to a switch that needs to be flipped by a robot, which is being operated by a human using a voice activated system. The operator may say "System, enable beacon 035" and the AR headset would display the beacon with that ID, allowing for the robot to be moved to the correct switch.

By rotating a line in a sphere or a circle, we can create a "compass" to point towards the tracked object when it and the marker tracking it are out of view. This will keep the user informed of its location relative to themselves and aid in orientation of the user. Figure 2 depicts one system used to aid the user through the use of an AR interface. Figure 2 depicts the aforementioned navigational system utilizing a tracking marker and a compass. Were the tracked object (a small, distant cylinder) to be out of view, its location would still be known thanks to the compass. Figure 3 is a system diagram depicting the method used for the targeting system. Similarly, we can visually extend the marker to allow for the control of a robot as depicted in Figure 1.

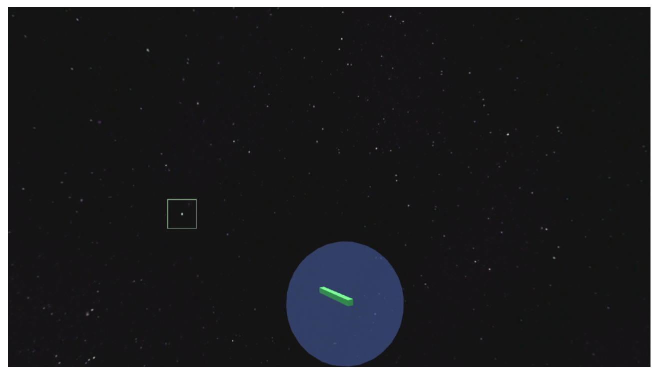

Figure 3: Marker featuring a hollow square with a central dot, colored a bright green, targeting a white capsule. The compass at the bottom of the screen points to the target, so it can be found even when not directly in view.

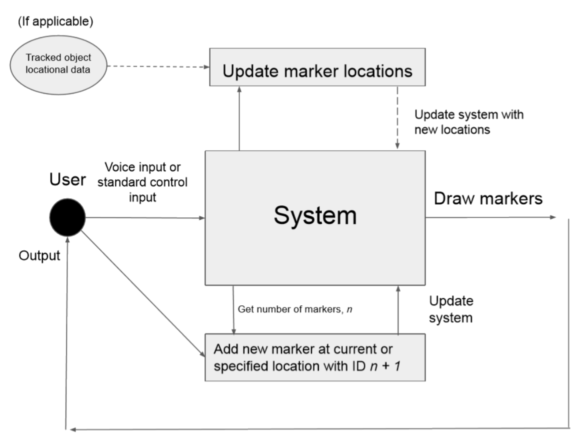

Figure 4: System diagram for audio visual display targeting

5 ASSESSMENTS OF PHYSIOLOGY IN HYBRID REALITY ENVIRONMENT

Preliminary Human-in-the-loop (HITL) testing is done through a virtual reality simulation, similar to our work in [4]. It assess average performance time to complete a task, such as fixing a rover. The physical and mental state of the subject during the performance of the task is evaluated. Further details are presented in [3]. Overall, physiological data is collected through a wearable, non-EEG, signal-based monitoring device. Similar to our work in [4], we can analyze such data in real-time or post-process to detect anomalies and correlate those to the user's performance. For example, a Galvanic Skin Response (GSR) sensor measures the electrical conductance of the skin, which can be used to detect stress. A summary of the data analyzed is listed in table 1.

Type of Bio-signal	Type of Sensor	Description of Measured Data
Electrocardiogram (ECG)	Skin/Chest electrodes	Electrical activity of the heart
Respiration rate	Piezoelectric /piezoresistive sensor	Number of movements indicative of inspiration and expiration per unit time (breathing rate)
Heart rate	Pulse Oximeter /skin electrodes	Frequency of the cardiac cycle
Perspiration (sweating) or skin conductivity	Galvanic Skin Response	Electrical conductance of the skin is associated with the activity of the sweat glands
Body Movements	Accelerometer	Measurement of acceleration forces in the 3D space

Table 1: Bio-signal monitored during HITL with VR environment

6 CONCLUSION, TESTS AND LIMITATIONS

The set of possible interactions afforded by current augmented reality is constrained by the hardware itself. The FOV is constrained by the Magic Leap 1's specifications, which has a horizontal, vertical, and diagonal FOV of 40, 30, 50 degrees respectively - with a Near Clipping Plane set at 37 cm from the device. The latter limits the level of immersiveness the user is afforded. Additionally, the software SDK has a Near Clipping Plane set at 37cm (14.57 inches) from the device, which means that objects that are too close to the user will disappear. This means the gestures that happen outside of that FOV or interaction with 3D virtual objects will not captured adequately.

Once we accept these current constraints, the interactions with an augmented reality interface are further limited by the constraints an astronaut faces during exploratory extravehicular activity. For one, we must consider the level of mobility and agility of an astronaut wearing a spacesuit. Most commonly, one would interact with an AR application through continuous gestures and postures, and presently through the use of external joystick controllers. Continuous hand gestures are infeasible or exhausting for astronauts as spacesuit gloves add additional weight. Furthermore, the integration of external joysticks in existing spacesuit designs is infeasible - it is highly likely that touch displays would be used in space. Hence, our design for setting waypoints relies solely on the Magicleaps' track pad, instead of using gestures or 3D motion with the joystick.

To assess the interactions under such limitations, we developed a psychophysical experiment where a modified version of a telepresence control garment [4] was used to monitor range of motion, gestures, postures, and physiological data. Further details are discussed in [3], and in section 5.

REFERENCES

[1] A.F.J. Abercromby, B. K. Alpert, J. S. Cupples, E. L. Dillon, A. Garbino, Y. Hernandez, C. Kovich, M. J. Miller, J. Norcross, C. W. Pittman, S. Rajulu, and R. A. Rhodes. 2019. Integrated Extravehicular Activity Human Research and Testing Plan: 2019.

[2] Irvin Steve Cardenas and Jong-Hoon Kim. 2019. Design of a Semi-Humanoid Telepresence Robot for Plant Disaster Response and Prevention. In *2019 IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS)*.

[3] Irvin Steve Cardenas, Caitlyn Lenhoff, Michelle Park, Tina Yuqiao Xu, Xiangxu Lin, Pradeep Kumar Paladugula, and Jong-Hoon Kim. 2020. AARON: Assistive Augmented Reality Operations and Navigation System for NASA's Exploration Extravehicular Mobility Unit (xEMU). In *2020 Proceedings of 12th International Conference on Intelligent Human-Computer Interaction IHCI* (Daegu, Sout Korea).

[4] Irvin Steve Cardenas, K. Vitullo, M. Park, J-H. Kim, M. Benitez, C. Chen, and L. Ohrn-McDaniels. 2019. Telesuit: An Immersive User-Centric Telepresence Control Suit. In *2019 ACM/IEEE Int. Conf. on Human-Robot Interaction HRI* (Daegu, Republic of South Korea).

[5] S. P. Chappell, Jason R. Norcross, Andrew F.J. Abercromby, Omar S. Bekdash, Elizabeth A. Benson, Sarah L. Jarvis, J. Conkin, Michael L. Gernhardt, N. House, J. Jadwick, Jeffrey A. Jones, Lesley R. Lee, Richard A. Scheuring, and Jennifer A. Tuxhorn. 2015. Risk of Injury and Compromised Performance Due to EVA Operations.

[6] W. Hönig, C. Milanes, L. Scaria, T. Phan, M. Bolas, and N. Ayanian. 2015. Mixed reality for robotics. In *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. 5382–5387. https://doi.org/10.1109/IROS.2015.7354138

[7] Nicolas LaLone, Sultan A. Alharthi, and Z O. Toups. 2019. A Vision of Augmented Reality for Urban Search and Rescue. In *Proceedings of the Halfway to the Future Symposium 2019* (New York, NY, USA) *(HTTF 2019)*. Association for Computing Machinery, New York, NY, USA, Article 22, 4 pages. https://doi.org/10.1145/3363384.3363466

[8] R. R. Murphy. 2004. Human-robot interaction in rescue robotics. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)* 34, 2 (2004), 138–153. https://doi.org/10.1109/TSMCC.2004.826267