Audiovisual Feedback for Augmented Manual Activities During Spacewalks

Executive Summary

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I. Introduction

In the vast silence of space, astronauts face a unique challenge — the absence of sound. In microgravity and vacuum, auditory cues we rely on Earth are useless. Precise audiovisual feedback is vital for safety and quality in space tasks. Space tasks demand extraordinary precision. A small error can have huge consequences. To empower astronauts, we present a project using augmented reality (AR) for audio and visual feedback. This system enhances human capabilities during spacewalks and other critical activities.

This report explores how AR transforms space operations by merging audio and visual feedback for efficiency and safety. Auditory cues confirm actions in real-time, while visual enhancements provide guidance and situational awareness.

In summary, the project contributions are:

1) Investigating the benefits of audiovisual augmentation for maintenance tasks.
2) Demonstrating how audiovisual cues reduce workload and improve task performance.
3) Using additional cues in spacewalk activities on the International Space Station (ISS) with a virtual reality (VR) simulation.

II. Project Flow

The project, spanning one year from October 1, 2022, to September 30, 2023, was managed by Gunjan Kumari and Georg Stolz. Gunjan Kumari handled documentation, simulation, user studies, and publications, while Georg Stolz focused on spatial audio, physical prototype development, and the final project report. Both actively participated in scenario development, architectural design, and prototype creation.

The project aimed to create an AR simulation for a maintenance task in space. It began with the decision to incorporate AR features into a VR simulation. The project was divided into eight working packages (WPs) with ten milestones to track progress effectively.

In the beginning, the project defined the experimental scenario and architecture. The scenario involved creating an AR simulation in VR for a space mission, emphasizing augmented visualization and audio. The central questions revolved around how artificial sound and AR objects influenced task execution and the astronaut's overall experience. The project specified stages and hardware, including the HTC Vive Pro 2.

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Regarding the visual VR environment of the space station, the focus was on creating a detailed and immersive environment, including the ISS model and interactions with the robot arm. We adapted the maintenance task scenario to involve controlling three fluid pumps with a control unit. One pump was designated as faulty and needed to be switched off, while the other two required adjustments to maintain liquid flow. This scenario allowed for easier haptic interaction and the use of spatial audio to locate the malfunctioning pump.

A physical counterpart of the control unit for the pumps was constructed to provide users with a more tangible haptic experience. The control unit featured push-buttons, rotary encoders, and a lever, with a microcontroller transmitting control data to the VR application.

Additionally, sound enhancements were added to objects to create a more immersive auditory environment. Ambient sound, such as industrial machine recordings, was included, along with specific sounds for buttons and pumps. Sound intensity and filters were adjusted to represent the status of the pumps.

All the before mentioned features including all projects components was combined into an experimental setup. A physical control unit was used, hand tracking was employed instead of VR controllers, and the OptiTrack system was implemented to enhance tracking and provide haptic feedback. The chosen maintenance task was based on familiar scenarios involving machines with rotating elements, where sound played a critical role in identifying malfunctions. With this prototype, a user study was conducted to assess task performance under different audiovisual support conditions. Participants were divided into groups receiving audio, visual, audiovisual, or no additional support. The study found that the audiovisual group achieved the shortest task completion times, demonstrating the effectiveness of audiovisual cues.

III. Conclusion

The project is an first exploration of the benefits of audiovisual augmentation for maintenance tasks. We began by creating an immersive VR simulation with audiovisual feedback, providing a realistic environment for participants.

Subsequently, we conducted a user study with 43 participants from diverse backgrounds and skill levels. Through six questionnaires, we gathered data on workload, user presence, and other crucial dimensions. Our study indicates that audiovisual cues can significantly reduce workload and enhance task performance in maintenance tasks. It underscores the effectiveness of audio and visual enhancements in supporting individuals during such tasks.

Looking ahead, we aim to refine our experimental setup for greater accuracy and comprehensiveness. We plan to involve field experts to gain insights from their experience and expand our research to encompass various scenarios, broadening our understanding of audiovisual augmentation's role in maintenance tasks.