Enhanced lunar exploration through Earth-based teleoperation of rovers: augmented interfaces to minimize latency impact

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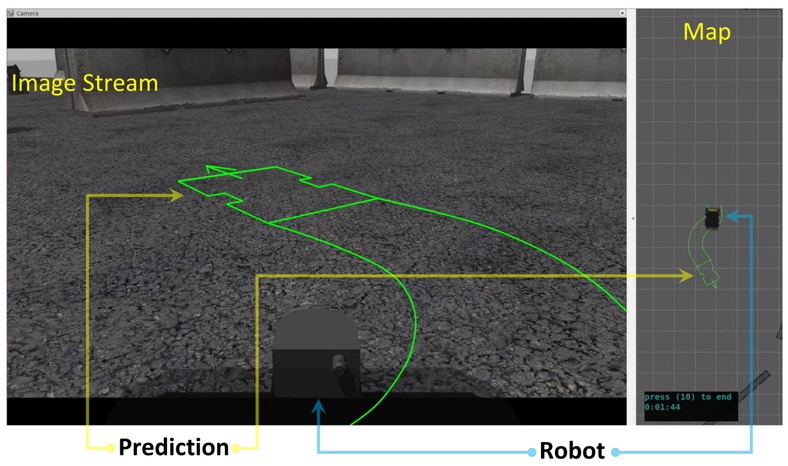
Introduction

Rovers on the lunar surface can be teleoperated from Earth with a latency of approximately 3 seconds. Therefore, investigating efficient teleoperation systems under communication latency could improve scientific data [1]. Moreover, such an approach could reduce mission costs and human risks, since the proposed teleoperation strategy does not require humans to be on the surface of the Moon or even on an orbiting station. However, the efficiency of Earth-to-Moon robot teleoperation is constrained by the challenges imposed by the communication latency, which often leads to high rates of collision, compromised robot safety [2], [3], and high levels of human cognitive workload [5]. Thus, adequate compensation methods are beneficial to support overall mission success.

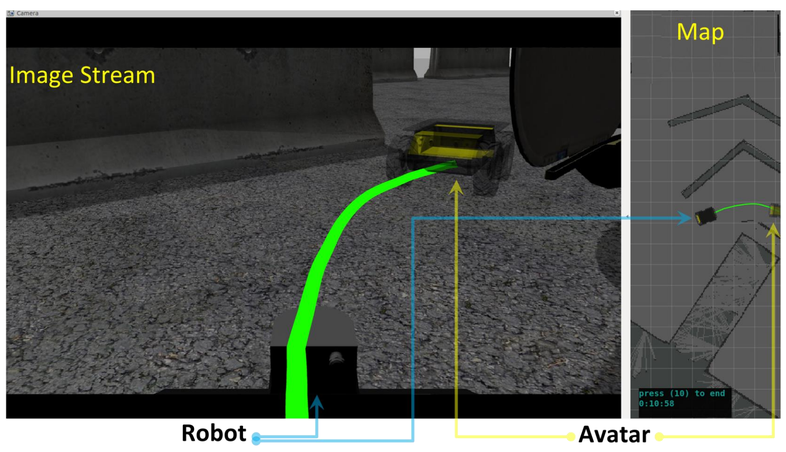
Augmented Interfaces

Predictive Interface (PI)



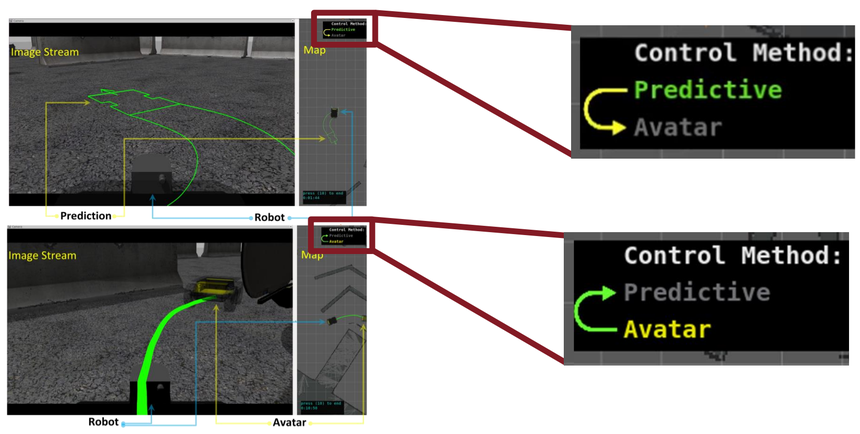
Predictive interface with direct control: The predictive elements (final position and trajectory) are represented in green.

Avatar-Aided Interface (AAI)



Avatar aided interface with semi-autonomous control: Avatar is augmented on the image stream with some transparency and planned trajectory is represented in green.

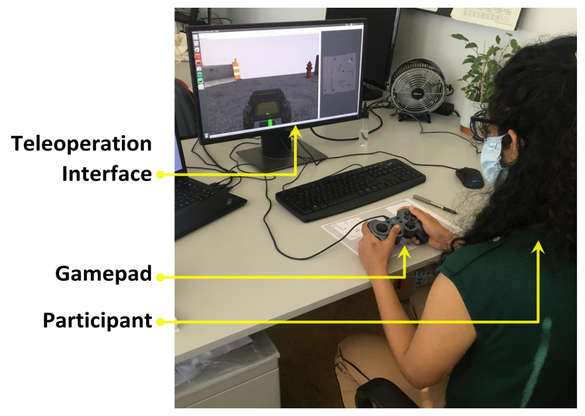
Hybrid Interface (HI)



Hybrid interface: the operator has the option to change between PI (Predictive) and AAI (Avatar) at any point of the task. Active method is highlighted in color and transitions between them are represented with an arrow.

Systematic User Study

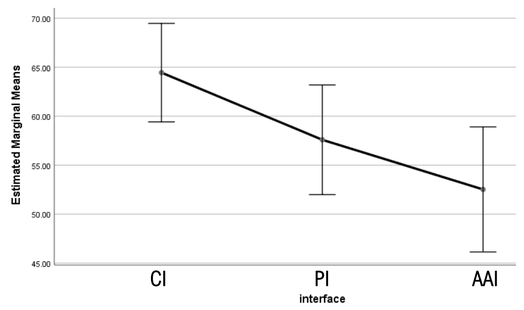
Experimental Apparatus



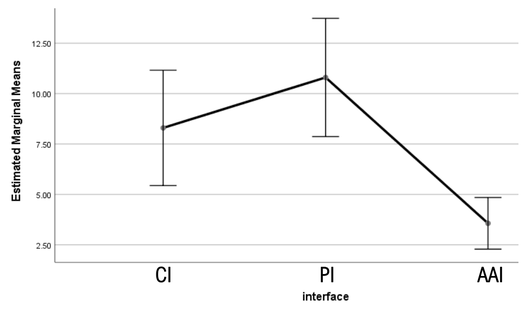
Operator using the avatar aided interface in the context of the experimental apparatus

- 30 participants.
- Four experimental conditions:
  - PI, AAI, CI, and HI
  - Control interface (CI) has no augmented information.
- Search and Inspection task.
- Simulated robot and environment with traction losses.

Preliminary Results



Workload results (NASA-TLX [5]): AAI shows lower workload than CI (p=0.021)



Number of collisions results: AAI shows lower number of collisions than CI (p=0.004) and than PI (p<0.001)

Usability: USE questionnaire [6]:

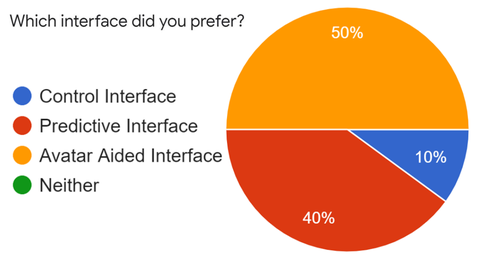
- AAI is easier to use than CI (p=0.016) and PI (p=0.021)

Task completion time:

- No statistically significant difference.

Tip-overs of the robot:

- CI: 13.3% of the participants
- PI: 13.3% of the participants



Interface preference reported by the participants.

Conclusions

The PI did not show significant improvements in the analyzed metrics, which might arise from the frequent traction losses and the consequent uncertainty of long robot's movements not incorporated in the prediction.

AAI showed improvements in robot safety and lower workload. However, the autonomy onboard the robot had difficulty coping with traction losses, often leading to reported frustration.

Participants reported that HI allowed coping with both PI and AAI limitations by switching between these during non-nominal circumstances.

References

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Acknowledgments

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