Investigation of Minimum Frame Rate for Low-Latency Planetary Surface Teleoperations

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Introduction & Background

The Global Exploration Roadmap indicates the need for increased human exploration of under-sampled regions of our solar system. The high costs and dangers of landing humans on planetary bodies in our solar system necessitates the use of human-robotic partnerships. Low-latency planetary surface teleoperation is an example of a human-robotic partnership that provides an exciting option for effective, low-cost scientific discovery. Initially this partnership will be utilized at the Deep Space Gateway in cislunar space, and will play a significant role in the first human Mars missions. However, low-latency telerobotic exploration needs to be tested for its limits and effectiveness. Our research focused on a human operator's ability to identify exploration targets in an unfamiliar environment using low-latency telerobotics under various frame rate (FPS) conditions.

Experimental Design

COURSE:

- 216 “interesting” objects (exploration targets)
- Each exploration target was a painted rock with a symbol
- Each exploration target was randomly distributed throughout the course

ROVER:

- Rover was remotely controlled using joysticks with a command computer
- Joystick commands were sent via Xbee RF module to a microcontroller on the rover
- One joystick controlled the rover and the other manipulated the top camera
- Two cameras were mounted on the rover: one camera was forward facing and the other was mounted on a mast
- Two Raspberry Pi’s collected video and sent it through WiFi to the command computer

TRIALS:

- Human operators explored the course via control of the rover in search of exploration targets
- A trial consisted of identifying one exploration target
- The following frame rates were tested: 4 FPS, 5 FPS, and 6 FPS
- Time to discovery was the metric used to quantify exploration success for each trial

Fig. 1: Rover in search of exploration targets.

Fig. 2: Operator commanding the rover.

Results & Discussion

1. The Single-Sample Test for Evaluating Population Skewness and Kurtosis was used to determine that the data was not normally distributed. We used statistical tests designed for non-normal data.
2. Variance Analysis
   a. Levene’s Improved Test for Homogeneity of Variances using the Absolute Deviation from the Medians was used as an ANOVA to determine that the variance at each frame rate was not equal.
   b. The post-hoc analysis of the variance was done with the Games-Howell test: variance at 4 FPS was greater than the variance at 5 FPS and 6 FPS at the 95% confidence level.
3. Time to Discovery Analysis
   a. An ANOVA was performed on the mean time to discovery (MTD) to determine that the MTD at each frame rate was not equal.
   b. The post-hoc analysis of the MTD was done with the Games-Howell test: MTD at 4 FPS was greater than the MTD at 5 FPS and 6 FPS at the 95% confidence level.
4. These results indicate that 5 FPS is the threshold frame rate for telerobotic exploration with operational parameters similar to those used in the experiment.

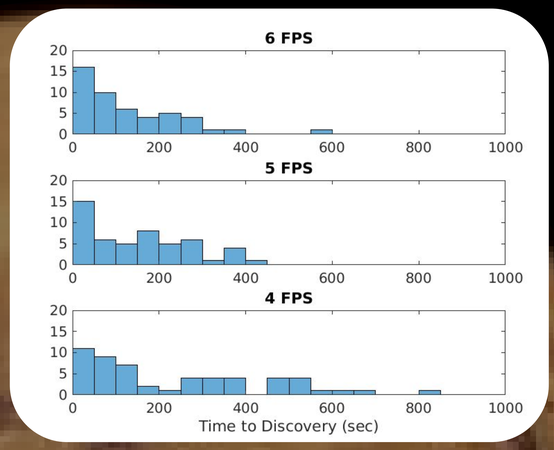

Fig. 3: Visually the dispersion of time to discovery increases as frame rate decreases. Also notice the long tails for each frame rate’s distribution that indicates a non-normal distribution.

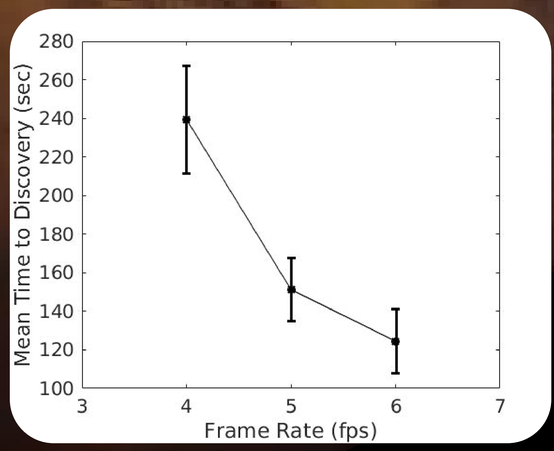

Fig. 4: The MTD at each frame rate. Notice the significant jump in MTD moving from 5 FPS to 4 FPS. Note: lines connecting data points are included to help guide the eye.

Conclusions

Our results show a threshold for exploration discovery occurs at 5 FPS. Moving to a lower FPS causes a large jump in MTD. There are many variables that determine the exact placement and shape of the MTD curve. These variables include: FPS, resolution, colorscale, task performed, force-feedback, etc. Our data fit the trend that many other frame rate experiments produced and shows that exploring unfamiliar environments given our resolution, colorscale, and operation speed requires a minimum of 5 FPS. Therefore, as the available bandwidth between the rover and the command station drops due to variable line-of-sight, it is imperative not to operate below 5 FPS.

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