Human-Robot Interaction in Sloping Jobsites (Demolition): Exploring Impact of Visual Interfaces

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Abstract— **In hazardous and uncertain sites, teleoperation is often utilized to execute scheduled procedures from a safe location. A visualization interface, which provides the remote operator with visual information to enhance spatial awareness, is essential to understand site information and receive feedback from the robot. To be effective, the interface must convey contextual information in an intuitive way. The provision of excessive or non-intuitive information not only reduces the operator's performance but also increases the cognitive load. In this study, the impact of different visual interface settings on workers' performance and their presence perception with perceived workload during a teleoperation task is examined and explored with eye gaze data. The results suggest that the development of human-centric interfaces for remote manipulation of construction robots is crucial, which allows to create intuitive and informative interfaces.**

I. Introduction

The use of remote manipulation in hazardous and uncertain sites has become increasingly prevalent due to its ability to execute scheduled procedures from a safe location (Hiramatsu et al. 2002). In this context, teleoperators' performance are heavily relying on the visual information since it directly affects their spatial awareness, enabling them to collect site information and receive feedback from the robot (Lee et al. 2022a; Shigematsu et al. 2021). However, to achieve optimal performance, the interface must not only contain contextual information but also be intuitively communicated (Lee et al. 2022a; Wang and Dunston 2012). Providing excessive or non-intuitive information could impede the operator's performance potential and increase their cognitive load (Naceri et al. 2019).

This study investigates the impact of different visual interface settings on workers' performance and cognitive load during teleoperation tasks. Understanding how the interface design affects task performance and cognitive load could be beneficial in designing more robust human-robot interfaces for teleoperation (Hiramatsu et al. 2002; Shigematsu et al. 2021). The study aims to contribute to the development of human-centric interfaces for remote manipulation in construction tasks and provide the groundwork for creating intuitive and informative interfaces suitable for specific task settings. By addressing the design of human-robot interfaces in hazardous and uncertain sites, this research could improve worker safety and performance in the challenging work environments.

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II. Related work

Toward the visualization enhancing the situational awareness, previous studies have suggested minimizing the number of displays to avoid distraction (Nielsen et al. 2007; Yanco et al. 2004), but this may not be suitable for excavator operators who require a comprehensive understanding of their surroundings. Other studies (Nielsen et al. 2007; Tanimoto et al. 2017) has highlighted the significance of incorporating supplementary visual information from multiple viewpoints in visualization interfaces for teleoperation in the construction. Meanwhile, construction sites in sloping terrain pose a significant challenge for excavator workers, leading to an increased risk of accidents, injuries, and reduced productivity (Shigematsu et al. 2021). Limited spatial awareness is a major challenge in teleoperation, and the distorted view in uneven and sloping environments can reduce the intuitiveness and lead to a degradation of spatial awareness (Lee et al. 2022b). While multiple viewpoints and 3D user-centered wearable displays can enhance depth perception and overcome this issue, providing more information to the operator does not necessarily result in higher performance, as per the Yerkes-Dodson Law (Yerkes and Dodson 1908). There is a need for further research to investigate how added viewpoints, such as multiple screens and 3D displays, could enhance teleoperators' spatial awareness in challenging environments, especially in sloping terrain.

III. Methods

The impact of visualization interface settings on teleoperation performance and cognitive load during excavator tasks in challenging sites was examined.

A. Design of Visualization Interfaces

Three visualization interfaces are designed: single screen display, multiple screen display, and HMD (head-mounted display). The default screen was set to 1st person view (figure 1) for all participants. In the multiple screen display, participants were additionally provided with 3rd person viewpoints (figure 2), such as the top-view (Kamezaki et al. 2016) and side-view (Ito et al. 2017).

Figure 1. 1st person view in the normal (left) and sloping site (right).

Figure 2. Assistive viewpoints in the normal (left) and slopping site (right).

B. *Tasks and Scenario Setup*

The experimental task in this study involved moving debris around destroyed buildings. To simulate this task, we created two scenes, both of which included obstacles, debris, and a dumping area. One scene was designated as the baseline, while the other was designated as the challenging scenario with a hazardous terrain taking account of a slope and closer obstacles, which imposed greater physical restrictions during work.

Figure 3. Experimental setting with excavation simulator.

Participants were tasked to collect debris, avoid obstacles, and deposit the collected debris in a designated location within both hazardous and non-hazardous terrains. Bricks were used to represent the debris within the model.

C. *Procedure*

The experiment was conducted in two sections: a baseline section and a hazardous terrain section. All participants in the study were randomly exposed to three visualization interfaces, namely single screen, multiple screen, and Head-Mounted (HMD) display, allowing for a comparison of interface effects on performance. Each set of trials was limited to a maximum of 10 minutes to prevent motion sickness.

D. *Surveys*

After each trial ended in given display types, participants were asked to rate their cognitive load based on NASA-TLX (Hart and Staveland 1988). Additionally, to examine the effect of scene conditions and display types on objective measures, Presence Questionnaires (Witmer and Singer 1998) were conducted with each participant at the end of each section.

E. *Participants*

A pilot study was carried out at Texas A&M University with 10 graduate students (8 males and 2 females) with a mean age of 24 years (SD = 1.95).

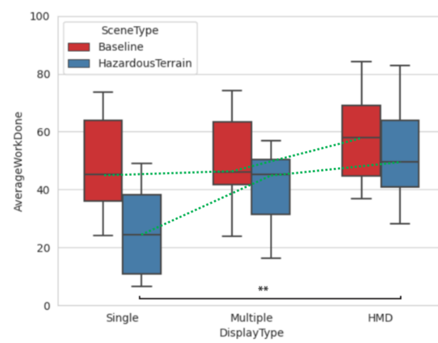
F. *Measures*

During the experiment, we recorded participants' eye gaze data and collected both objective measures and subjective ratings. To analyze the data, we utilized the One-way repeated measures analysis of variance (ANOVA) with a Tuckey-adjusted post hoc paired t-test for comparison and linear regression analysis. We used objective measures such as completion time, work completed, and collision occurrences to evaluate the impact of visualization interfaces on task performance. We calculated the average amount of work done as the average amount of pickup and dump during the four trials. We also evaluated the effect of visualization interfaces on participants' perception of workload.

IV. RESULTS

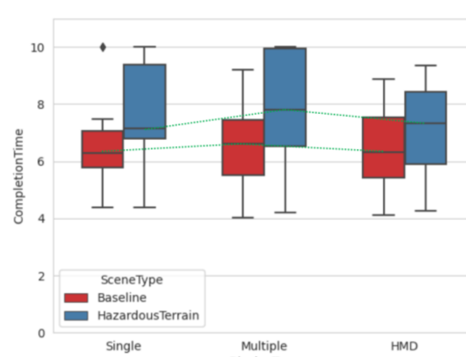
The study investigated the impact of visualization interfaces on the performance of teleoperators in challenging sites (Figure 4). Results showed that there were significant differences in performance between the two scenes ($p < 0.01$). The results indicated that, in the flat scene, the average amount of work completed did not significantly differ across the three visualization interfaces. However, in the sloping scene, the HMD display interface resulted in significantly more work completed than the single screen display interface ($p < 0.01$).

Figure 4. Average amount of work done in three types of visualization interfaces both in hazardous terrain and the baseline.



The number of collisions did not significantly different among the three types of visualization interfaces in the baseline scene, but in the hazardous terrain, the use of HMD display could significantly reduce the number of collisions ($p < 0.02$). In terms of completion time, each type of visualization interface doesn’t show significant difference, but the median completion time was the highest in multiple display cases (Figure 5). Participants had significantly higher NASA-TLX scores in the hazardous terrain, and there were significant differences in scores between single screen display and HMD display in both scenes ($p < 0.01$).

Figure 5. Completion time comparison among the interfaces both in hazardous terrain and the baseline.

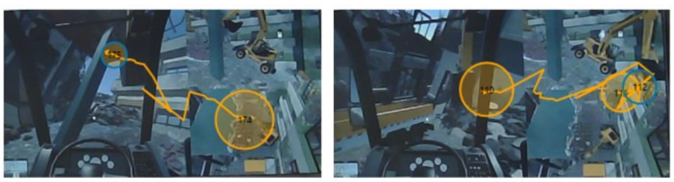


We also investigated the impact of visualization interfaces on the perception of workload and presence. Results showed that the mean differences of presence perception among the visualization interfaces were significant ($p < 0.01$), indicating that regardless of how challenging the scene was, the interface affected teleoperators in terms of presence perception. The results showed that there is a significant negative linear relationship between presence perception and perceived task workload. The results were $R^2 = 0.33$, $F(1,58) = 7.05$, $p = 0.01$. It could be inferred that participants who feel less present in the environment are likely to perceive the workload as higher.

V. Discussion

The results of the study revealed that the visualization interface had a significant impact on work performance in hazardous and challenging site conditions, emphasizing the need for worker-centered visualization interfaces in physically demanding environments. The study employed adding viewpoints and implementing a worker-centered 3D display to enhance visual comprehension of the site. The results showed adding additional viewpoints did not result in significantly better performance and may even distract participants, as shown in the eye gaze data during collisions (figure 6).

Figure 6. Eye Gaze Pattern during Collision Occurrence



The findings indicate that the incorporation of additional viewpoints should be tailored to the specific needs of teleoperators in different environments, which could improve the effectiveness of human-robot interfaces in supporting teleoperators by reducing distractions and enhancing visual attention during task execution. Additionally, there is a significant difference in presence perception between screen displays and 3D display. Even though added visual information is given, how to convey the information could affect the operators' presence perception. To improve validity, future research should include more participants due to limitations in sample size.

VI. Conclusion

In order to address the issue of degraded spatial awareness from the limited viewpoints for teleoperation in demolition sites, incorporating information from multiple viewpoints in the visualization interface is crucial for supporting teleoperators. This issue is even exaggerated in the sloping terrain where the alignment of viewpoints can be distorted. However, this approach may pose a challenge of data overload, which underscores the need to explore how additionally given viewpoints affect teleoperators in the human-robot interface design phase. Despite the potential benefits of incorporating multiple screens to enhance visibility, this study revealed that the additional viewpoints could lead to distractions, which can negatively impact teleoperator performance. This study highlights the significance of designing an interface that conveys information to teleoperators to enhance presence perception without overwhelming them with information, emphasizing the need to rigorously evaluate the impact of the design on the work performance.

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