International Conference on Artificial Reality and Telexistence
Eurographics Symposium on Virtual Environments (2024)
T. Tanabe and V. Yem (Editors)

Poster

Development of a Haptic Feedback Interface to Enhance Obstacle Awareness and Reduce Stress of Driver in Shared Spaces

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Abstract

In this study, we developed a novel haptic feedback Human-Machine Interface (HMI) designed for immovable joysticks in small electric vehicles, such as wheelchairs. This HMI aims to improve driver awareness of surrounding obstacles by providing intuitive force feedback. By applying pressure stimuli to the outside of the hand, the system conveys both the direction and distance of obstacles. Experimental results showed that the HMI enabled participants to accurately perceive the presence and direction of obstacles, reducing the need for frequent visual checks and thereby lowering cognitive load.

CCS Concepts

• ***Human-centered computing*** $\rightarrow$ ***Haptic devices;*** *Touch screens; Virtual reality;*

1. Introduction

Shared Space, proposed by Hans et al. [MCB06], removes traditional boundaries between sidewalks and roadways, allowing vehicles and pedestrians to move freely. While intended to reduce accidents, it poses safety risks by requiring drivers to monitor all directions, increasing cognitive load and stress. This research proposes a Human-Machine Interface (HMI) to enhance situational awareness and support safer decision-making in Shared Space environments.

Previous research indicates that tactile feedback can produce faster driver reactions than visual or auditory cues, with various haptic devices (e.g., belts, steering wheels) effectively enhancing safety and reaction times. While haptic feedback on the steering wheel is intuitive, consistency can be affected by hand position, and signals can be disrupted by road vibrations or clothing. [XWL*21] The hand shows promise as an ideal point for feedback, though challenges remain, such as clarity in signal location, intuitive response to external obstacles, and limitations of simulator-based studies.

This paper presents a haptic feedback device designed to provide drivers with spatial information on surrounding obstacles. The HMI uses pressure-based stimuli, applied to the outside of the hand, for intuitive and precise detection. Experiments conducted under acceleration test the system's potential to enhance decision-making during evasive maneuvers and reduce monitoring stress.

2. Proposed Method

Figure 1 illustrates the proposed HMI, which consists of a joystick surrounded by four manipulators designed to provide haptic feedback to the driver about the direction and distance of obstacles located at the rear. In this configuration, the center of the right hand gripping the joystick lever is conceptually regarded as the center of the vehicle.

When an obstacle is between 14 and 21 meters away, static pressure stimuli are applied, varying between 0 and 8 N as the obstacle approaches, signaling increasing proximity. For distances under 14 meters, periodic pressure stimuli are used, with frequencies ranging from 0 to 4.5 Hz, increasing as the obstacle nears to convey urgency. Additionally, when an obstacle is positioned between two manipulators, the system finely indicates its precise direction by adjusting the output ratio of pressure stimuli between the two manipulators based on the obstacle's relative location.

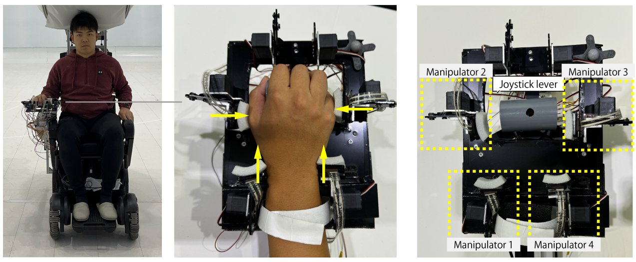

Figure 1: *Proposed force feedback HMI*

3. Evaluation Experiment

The experiment examines the discrepancy between HMI-indicated and visually perceived obstacle directions and distances. It also

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DOI: 10.2312/egve.20241399

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tests whether the HMI enhances decision-making reliability and reduces stress in monitoring the surrounding environment.

The experiment was conducted in Large Space which is a large virtual reality experimental facility at University of Tsukuba. A full-scale virtual vehicle served as the obstacle. Four obstacle scenarios were tested: left rear, right rear (each 2 meters laterally and 15 meters behind the start), directly rear, and no obstacle. The obstacle began moving randomly between 1 and 7 seconds after the participant started, traveling parallel to the start-goal line at a constant speed of 10 km/h. A WHILL Model CR was chosen as the experimental vehicle to simulate interactions common in Shared Spaces and allow testing under realistic acceleration conditions.

In the experiment, participants drove a wheelchair 15 meters toward a target, avoiding virtual obstacles while free to look around as needed. Upon reaching the goal, they stopped the wheelchair. This sequence was repeated under two conditions: with and without the HMI, in random order. Each condition included 12 trials covering all obstacle scenarios (left rear, rear, right rear, no obstacle), totaling 24 sessions per participant. In HMI-enabled trials, participants completed a feedback questionnaire after each session focusing on discrepancies between HMI-indicated and visually perceived obstacle directions and distances. At the end of the experiment, a final comparative questionnaire assessed whether the HMI improved decision-making

4. Result and Discussion

Table 1: *HMI-perceived and actual obstacle direction error*

Approach	5°	15°	30°	45°	90°
Left Rear	61.1%	22.2%	11.1%	5.6%	-
Rear	61.1%	27.8%	5.6%	-	5.6%
Right Rear	72.2%	16.7%	5.6%	-	5.6%

Table 1 presents the results of the discrepancy between the obstacle direction intuitively perceived via HMI and the actual obstacle direction. Overall, over 80% of trials fell within a 15-degree accuracy range, indicating high directional precision across various approach angles. However, rear approaches showed slightly higher deviation, suggesting that rear obstacles were more challenging to discern due to simultaneous left and right haptic stimuli.

Table 2: *Number of Discriminable Levels*

	Static Stimuli		Periodic Stimuli	
Approach	**Mean**	**Std Dev**	**Mean**	**Std Dev**
Left	1.8	0.9	2.7	0.7
Rear	1.8	1.2	2.6	0.7
Right	1.9	1.1	2.5	0.9

Table 2 presents number of discriminable levels for pressure and frequency as reported by participants in a questionnaire on their subjective perception of distinguishable levels. The number of descriminable levels in pressure stimuli averaged below 2, indicating that participants found it challenging to differentiate between varying pressure levels. In contrast, the frequency resolution scores averaged above 2.5 levels, suggesting a moderate ability to distinguish frequency levels, though achieving very high resolution in frequency perception remained difficult.

These results showed that users could recognize obstacle presence and direction effectively, though distance, speed, and trajectory were harder to interpret, likely due to the low resolution of the stimuli, as well as driving vibrations, inertia, and divided attention. This made it challenging to intuitively grasp obstacle speed and trajectory. A possible solution is to increase the amount of information conveyed by improving the algorithm, such as varying the patterns of periodic pressure stimuli.

The survey results, based on a 9-point Likert scale (with 9 as the maximum score), indicate that the HMI enhances obstacle awareness and alleviates user stress. Specifically, participants rated the HMI's support for obstacle avoidance at a mean of 7.8 (SD = 1.5), ease of obstacle detection at 8.6 (SD = 0.5), and clarity in indicating obstacle direction at 7.8 (SD = 1.1). Additionally, stress reduction while monitoring the environment was rated at 8.5 (SD = 0.8), and the sense of safety achieved a score of 8.5 (SD = 0.5), suggesting an overall enhancement in user confidence and security.

Comfort scored moderately at 6.8 (SD = 1.5), indicating variability in user comfort with the HMI. Additionally, ratings for specific obstacle information provided by the HMI exhibited some inconsistency: obstacle distance scored 6.5 (SD = 1.5), movement direction 6.8 (SD = 1.7), and speed 5.5 (SD = 2.9). These results may be attributed to limitations in stimulus resolution, as well as the need for users to infer speed and direction from positional data, which may reduce intuitiveness.

5. Conclusion

This study introduced a joystick-based HMI that enables drivers to perceive surrounding obstacles through haptic feedback without tilting the joystick. Results showed that drivers could reliably detect obstacle direction and presence, with over 80% of trials achieving a resolution within 15 degrees, reducing stress by minimizing the need for visual checks and enhancing safety. However, limitations were noted in conveying precise distance, movement direction, and speed of obstacles, suggesting a need for algorithmic improvements, such as varying periodic pressure patterns. Future research should address multiple obstacles by prioritizing imminent threats and ceasing feedback for visually confirmed objects to reduce cognitive load.

References

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