

A Simulator Study on the Effects of Teleoperation Video Quality and Driving Support by White Line Highlighting

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Introduction: In recent years, demand for remote driving technology has increased to support mobility in areas such as depopulated regions; however, reducing video resolution to lower communication loads impairs driving precision. This study focuses on the reduced ability to recognize road geometry caused by lower resolution. We hypothesized that reinforcing white line visibility through white line highlighting enables stable steering even under reduced video quality. To verify this hypothesis, we conducted a driving simulator (DS) experiment to analyze the effects of white line highlighting on driving performance and gaze behavior.

Methodology: To evaluate the effect of white line highlighting on driving performance under low-resolution video conditions, a DS experiment using CARLA was conducted. Participants first completed two trial runs under a high-resolution baseline condition, followed by two cycles of four conditions combining different resolution levels and the presence/absence of white line highlighting, with one run per condition. (Table 1) Seventeen participants completed the driving task at a constant speed of 60 km/h on a course containing two left and two right curves with a radius of 120 m (180° turn), presented in randomized order.

Table 1 Experimental Conditions

Condition	Resolution [px]	Highlight
Base	High (1920 * 360)	—
MR_noH	Middle (480 * 90)	—
MR_H		○
LR_noH	Low (240 * 45)	—
LR_H		○

Results and Discussion: Figure 1 shows the results of the two-way ANOVA and multiple comparisons with resolution and the presence of white line highlighting as factors. Steering entropy (SE), which represents operational stability during curve negotiation (Fig. 1(a)), increased in the low-resolution condition without highlighting (LR_noH), whereas it significantly decreased with white line highlighting (LR_H). The limited difference in the medium-resolution (MR) condition is likely because the effect of resolution degradation itself was small; overall, white line highlighting is effective in suppressing the increase in SE. Regarding the vertical gaze position (Fig. 1(b)), while gaze was concentrated near the vehicle (lower part of the screen) in LR_noH, it significantly decreased in LR_H, indicating a shift toward the distance. For the subjective evaluation of road geometry predictability (Fig. 1(c)), adding white line highlighting recovered the score to a level equivalent to the Base condition, even under reduced resolution. In conclusion, resolution degradation impairs road geometry predictability, concentrates gaze near the vehicle, and induces an increase in SE. In contrast, white line highlighting maintains distance visibility and predictability, preventing gaze concentration near the vehicle, thereby suppressing the degradation of driving performance under low-resolution conditions.

Conclusion: In this study, to examine white line highlighting support under low-resolution conditions during remote driving, we experimentally verified the effects of white line highlighting during front-view resolution degradation through objective and subjective evaluations. As a result, even under low resolution, enhancing white lines improved the visibility of the distant road geometry, thereby suppressing gaze concentration on the near region and maintaining stable remote driving.

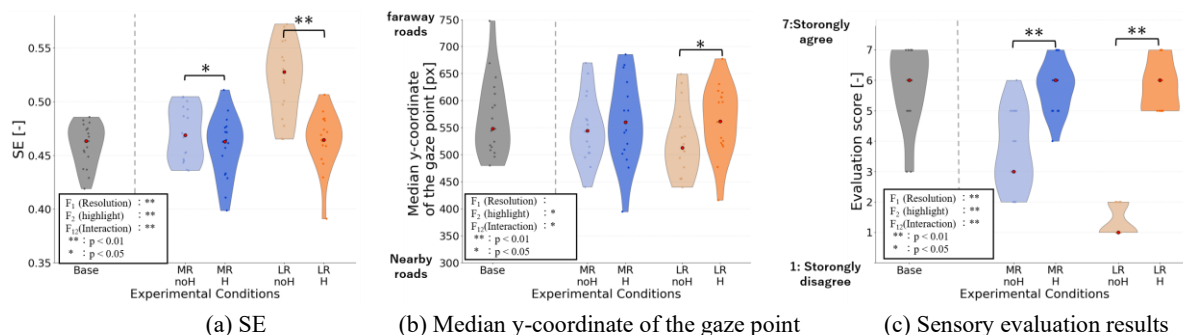


Fig.1 Results of various analyses