

Effects of Viewpoint Position on Steering Characteristics in Remote Operation of Autonomous Buses

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The introduction of autonomous driving technology is expected to address the shortage of bus drivers. However, autonomous driving systems operate within a predefined Operational Design Domain (ODD), and remote operation is considered as a backup when operating conditions fall outside the ODD. In remote operation, operators cannot directly perceive vehicle motion and must rely primarily on visual information. This is particularly challenging for autonomous buses because of their large size and numerous blind spots. Therefore, this study investigates the effects of viewpoint position on steering characteristics during the remote operation of an autonomous bus using a heavy-duty vehicle driving simulator (DS).

A remote-operation environment was constructed by capturing images from the DS and displaying them on a remote-operation console with a 200-ms image delay. Four viewpoint conditions were examined: driver, vehicle-center, overhead vehicle-tracking, and overhead linear-tracking. The experiment was conducted with participants holding large-vehicle driving licenses. Two driving speeds, 20 and 50 km/h, were tested on a course consisting of two left and two right curves. The curve radii were 20 m at 20 km/h and 125 m at 50 km/h. After excluding data with missing values and insufficient driving proficiency, the numbers of participants were 16, 16, 12, and 13 for the driver, vehicle-center, overhead vehicle-tracking, and overhead linear-tracking viewpoints, respectively.

Lateral position and steering angle were resampled at 1 m intervals. The mean absolute lateral position (MALP), standard deviation of lateral position (SDLP), and standard deviation of steering angle were used as evaluation indices. Smaller values indicate more stable lane keeping or smaller steering fluctuations. Differences among viewpoints were analyzed using the Kruskal–Wallis test followed by Dunn's multiple-comparison test ($p < 0.05$).

The right-curve sections, where the effects of viewpoint position were most pronounced, were analyzed. Figure 1 shows the results for MALP (a), SDLP (b), and steering-angle SD (c) at 20 km/h. The overhead vehicle-tracking viewpoint showed the lowest median values for MALP (0.539 m), SDLP (0.087 m), and steering-angle SD (16.724 deg). Significant differences were observed between the overhead vehicle-tracking viewpoint and the driver and vehicle-center viewpoints for MALP, and between the overhead vehicle-tracking and driver viewpoints for SDLP. Figure 2 shows the results at 50 km/h. The overhead vehicle-tracking viewpoint showed the lowest median MALP (0.386 m), with a significant difference from the vehicle-center viewpoint. The vehicle-center viewpoint showed the lowest median SDLP (0.249 m) and steering-angle SD (6.669 deg), with significant differences from the overhead linear-tracking viewpoint for both indices. The overhead viewpoints may have facilitated perception of the vehicle position and orientation relative to the road geometry. At 50 km/h, however, the image delay may have caused delayed position correction, resulting in greater lateral-position variation with the overhead viewpoints.

Overall, the overhead vehicle-tracking viewpoint tended to facilitate for maintaining lane position during remote operation, particularly at 20 km/h. However, at 50 km/h, the effect of viewpoint position differed among the evaluation indices, suggesting that driving speed and image delay influence the effectiveness of the viewpoint.

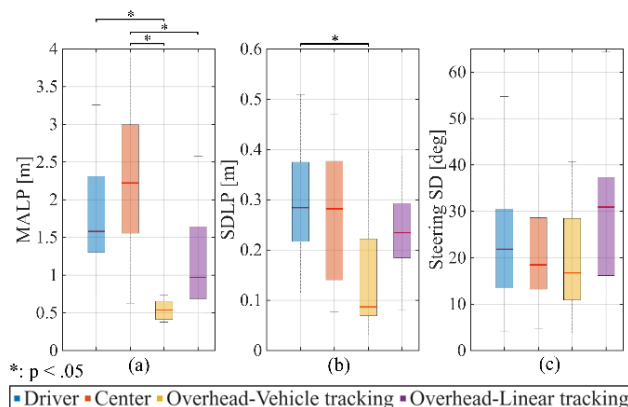


Fig. 1 Results of Right Curve Area at 20 km/h : (a) MALP, (b) SDLP, (c) steering angle SD

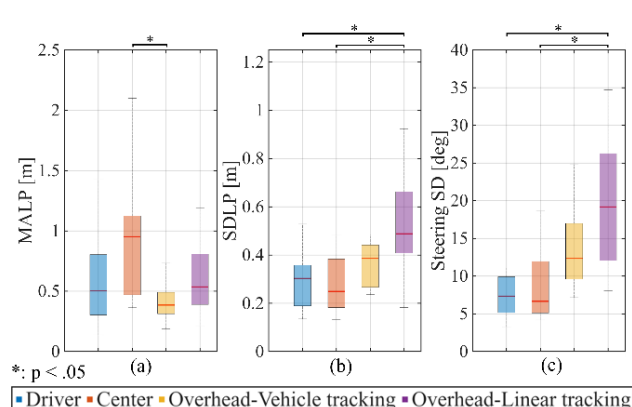


Fig. 2 Results of Right Curve Area at 50 km/h : (a) MALP, (b) SDLP, (c) steering angle SD