The role of optic flow in manipulating pointing devices for in-vehicle control systems

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Abstract. Performing a pointing task to operate in-vehicle control systems has increased its popularity in daily driving. Usability and safety concerns regarding in-vehicle control system applications have become important topics in modern car industry. In this study, we examined the pointing performance when using a hand-held joystick in a driving simulator. A pointing task was conducted in four driving simulation scenarios considering various driving environments and optic flow conditions. Participants were asked to manipulate a joystick to point to the orientation of a visual target with no visual feedback about the pointing action. Visual targets with eight orientations were superimposed on the background driving scene. Experimental results based on 10 participants were evaluated by statistical analyses. A 2x2x2 ANOVA showed no significant effect of driving environment on pointing performance, while optic flow and pointing orientation had significant effects. Pointing accuracy was higher when performing a diagonal pointing task than orthogonal orientations. Besides, pointing tasks were better performed with the presence of optic flows. Findings from this study may be considered in the development of in-vehicle control systems.

Keywords. pointing performance, in-vehicle control system, input interface, optic flow, joystick, orientation

1. Introduction

The advance and popularity of advanced driver assistance systems (ADASs) and in-vehicle information, communication, and entertainment systems has been growing rapidly in the modern car industry. Various user interface designs and adapted input devices for such a system may be found from different car manufacturers. For example, the Multi-Media Interface (MMI) provided by Audi requires the driver to manipulate a control dial and side buttons for navigating through a display. Or the Remote Touch controller from Lexus uses an input device that is similar to a computer mouse or joystick, and allows the driver to operate an on-screen cursor on the vehicle's GPS navigation system screen. Other systems, e.g. Ford Sync, Mercedes-Benz COMAND, BMW iDrive, etc., may have a different approach and arrangement of used input techniques such as voice commands, controllers similar to a computer 3D mouse or a joystick, buttons, or a touch screen.

The manipulation accuracy and behavior of performing a pointing task, i.e. the input command with input device to the control center, is important when one is driving. Ergonomic user interface design for such a system is essential, which should enable a simple yet efficient operation mode, but not to cause too much overhead and distraction of the driver during driving. One typical type of the operation control is a radial selection, that is, to start at a central location and to point or drag to a radial target. The operation media could be one's finger sliding when a touch screen is used, or a pointing device, e.g. joystick, manipulated radially with one's hand. While many different types of operation mode may be found, the application of a joystick control for radial selection, i.e. a pointing task, is the focus of this study.

In addition, car driving is a dynamic event, particularly in terms of the visual cues occurring during driving. In different driving areas, hours, and traffic conditions, drivers are facing and receiving various optic flows in daily driving. In this study, we aim to investigate the potential effect of optic flow on pointing behaviors with the use of a computer joystick in a driving simulator. In this experimental study, we implemented various scenarios in the simulated driving scene (i.e. highway and city) in order to provide drivers various optic flows. For instance, the driving speed and visual complexity in a highway condition and in a city condition are quite different, therefore, the optic flow patterns generated would also differ. Additionally, Huang and Menozzi (2014) reported that a lower attention performance was found in the visual environment at a higher complexity level of visual information presented. Similar effect, i.e. reduced performance, might be expected in this study as the over-loaded information and the distracting effect could play a role in a pointing task. The pointing task was carried out in four test scenarios. One was a dynamic highway driving scenario (video-based) with optic flows, and one was a static highway scene (image-based) with no optic flow. The other two scenarios were dynamic- and static city driving environment.

From a previous study, manipulation errors in a blindfolded pointing task with fingers-held joystick have been found to be mainly associated with diagonal pointing orientations, i.e., 45°, 135°, 225°, and 325°, but not with orthogonal ones, i.e., 0°, 90°, 180°, and 270° (Huang & Menozzi 2013). This finding is consistent to the oblique effect in the haptic perception of spatial orientations (Gentaz 2008). Other control devices for manipulating a pointing task, e.g. mouse, trackpad, and trackball, were evaluated and the manipulation with a hand-held joystick was preferred by the participants (Menozzi & Huang 2014). In this study, the pointing task was defined as to manipulate the hand-held joystick and point it to a given orientation as shown on the projection screen. There were eight pre-defined orientations (four orthogonal and four diagonal) of the visual targets presented in different optic flow conditions. We aim to investigate the potential effect of optic flow on pointing orientations. In general, since it is very difficult to avoid manipulation errors in radial selections, a better understanding of manipulation patterns and behaviors could enhance the optimal criterion for discriminating the responses. In this paper we demonstrate the pointing accuracy of different sets of pointing orientations and in various optic flow conditions. Outcome of this study should provide a better view on drivers' pointing orientation performance and accuracy and further enable a better design of the in-vehicle driver control center.

2. Methods

An experimental study conducted in a driving simulator was designed to investigate potential effects of various driving environments, conditions of optic flows, and pointing orientations on pointing performance and accuracy when a computer right-hand-held joystick was used for the manipulation.

2.1 Participants

A total of ten participants took part in this study. The participants consisted of four females and six males with ages ranging from 25y to 57y and with mean age of 32.4y. All participants had normal or corrected-to-normal vision. None of them had any self-reported eye disease and/or simulator sickness. This study was conducted in accordance with the ethical principles of the current Declaration of Helsinki. Participants gave their informed consent before taking part in this study.

2.2 Instrumentation

A driving simulator that consisted of a projection system, a driver's control interface, an additional computer joystick, and a computer as a controlling and recording center was used to conduct the experiment. The projection system included a 3x3m^2 white projection wall at a distance of 3m to the driver's seat and a BarcoSIM5plus projector with a Field of View of 49.12°(H) x 37.85°(V). Participants sat on the driver's seat in a right-hand traffic setting. They performed a pointing task using a hand-held computer joystick (Logitech Extreme 3D Pro) positioned on their right-hand side with an elbow-rested posture. A computer with LabVIEW recording tools was used to send the scenario videos/images signal to the projection system and to receive the responses from the joystick.

2.3 Experimental setup

In four pre-recorded driving scenarios from a driving simulation program, as shown in Fig. 1, participants were asked to perform the pointing task, which required them to operate the joystick according to the orientation of a visual target superimposed on the background scenario. The first scenario was a dynamic video of highway driving, with an average speed 100 km/h of the car. The second scenario was a still image of highway driving, so there was no speed and therefore no optic flow perceived by the participant. The third scenario was a dynamic video of city driving, with an average speed of 40 km/h. And the last scenario was a still image of city driving with no optic flow. Every scenario was 3 mins long, and there were 80 pointing trials per scenario. Participants were instructed to fixate at the center of the projection screen throughout the experiment, where the visual target was presented.

The visual target was randomly assigned in its orientation from eight pre-defined orientation (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 325°), and participants were asked to point to the presented orientation with the joystick. Each of the eight orientations were randomly assigned several times to each participant. The coordinates of the joystick were stored in the format of pairs of coordinates (x, y), indicating the starting point and the end point of each pointing action.

The pointing task program and the response recording were done in LabVIEW VIs. When the pointing task was performed, there was no visual feedback from the screen, and the actual movement of the hand and the joystick was covered by a shield.

Figure 1. *(Left) A screenshot of the highway driving scene. (Middle) A screenshot of the city driving scene. (Right) A template of the pointing task frame demonstrating a pointing orientation of 180°.*

2.4 Data analysis

A total of 320 pointing responses were collected from each participant. The angle of each pointing was calculated by the two pairs of coordinates regarding to the starting and end points of a movement. For each pre-defined orientation, there were a set of angles associated with it. The complete radial selection range, i.e. 360°, was divided into eight portions with equal angular size, i.e. 45°, centered with the pre-defined orientations. For each pre-defined orientation, a response which was located within a ± 22.5° to the assigned orientation was considered as a correct detection. Otherwise, when a pointing response was located outside of the ± 22.5° range of the assigned orientation, the pointing performance was considered as a false manipulation. The detection rate of trials of the four orthogonal orientations were combined and categorized as "Orthogonal detection rate." Same as the other four diagonal trials were calculated for "Diagonal detection rate." And the four test scenarios were named as "Highway-Dynamic," "Highway-Static," "City-Dynamic," and "City-Static" while Highway/City referred to the driving environment, and Dynamic/Static referred to the presence of optic flow or none.

3. Results

The average detection rates of orthogonal orientations and diagonal orientations in the four scenarios are shown in Tab. 1. The diagonal detection rate was consistently higher than the orthogonal detection rate in all scenarios. In the same driving environment, i.e. highway or city, the detection rate was consistently higher in the dynamic condition (with optic flow) than in the static condition (without optic flow). In Fig. 2 we have plotted the experimental results graphically.

Table 1. *Average pointing detection rates and SDs of the two orientation groups (orthogonal, diagonal) in four test scenarios (N=10).*

	Orthogonal detection rate	Diagonal detection rate
S1: Highway-Dynamic	43.48 % (SD 23.18 %)	79.82 % (SD 20.94 %)
S2: Highway-Static	34.39 % (SD 16.10 %)	78.88 % (SD 21.29 %)
S3: City-Dynamic	38.89 % (SD 13.22 %)	81.50 % (SD 25.12 %)
S4: City-Static	34.14 % (SD 17.08 %)	79.15 % (SD 24.29 %)

A three-factorial ANOVA was carried out considering the two-level within-subjects factor of driving environment (highway, city), the two-level within-subjects factor of optic flow (with/without optic flow), and the two-level within-subjects factor of pointing orientation (orthogonal, diagonal). Results showed no significant effect of environment ($F(1, 9) = 0.097$, $p = 0.763$, effect size partial $\eta^2 = 0.011$, observed power = 0.058) and a significant effect of optic flow ($F(1, 9) = 8.512$, $p = 0.017$, effect size partial $\eta^2 = 0.486$, observed power = 0.738) as well as a significant effect of orientation ($F(1, 9) = 55.066$, $p < 0.000$, effect size partial $\eta^2 = 0.860$, observed power = 1.000). There was no significant interaction among the three factors.

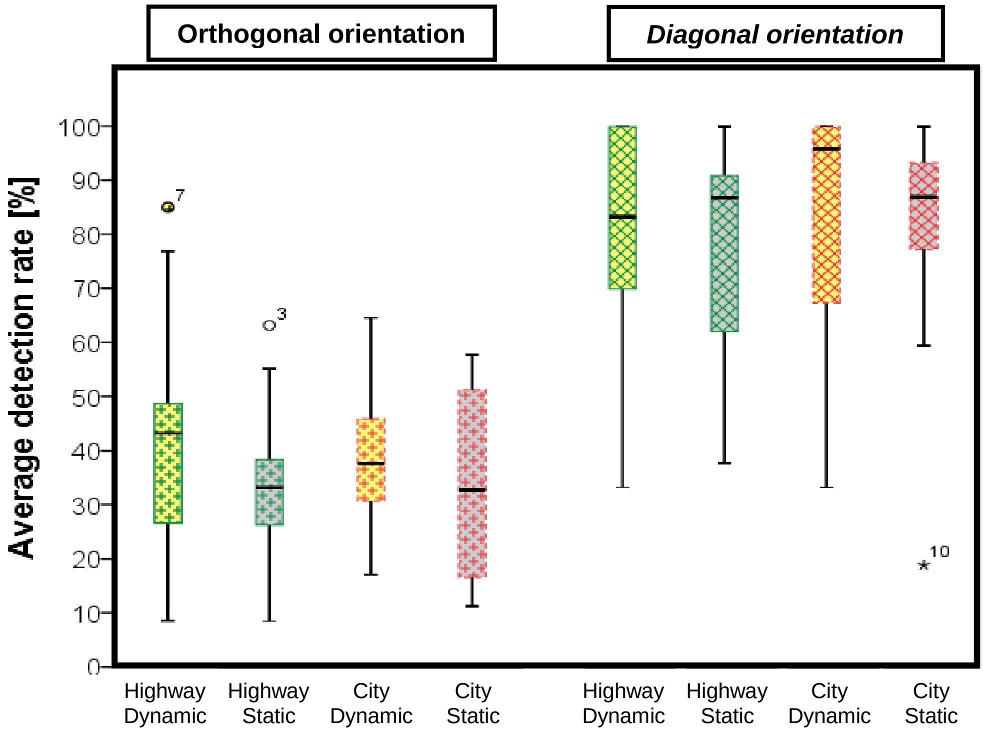

Figure 2. *Boxplots of pointing performance in each test condition. Left side of the chart indicates the orthogonal pointing orientations. Right side of the chart indicates the diagonal pointing orientation.*

4. Discussion

The pointing performance with a hand-held joystick was found to be significantly more accurate when a pointing task was manipulated towards diagonal orientations than orthogonal pointing operations. Such a result could be caused by the movement of the wrist when manipulating the joystick in different orientations. For instance, when we point the joystick downwards (180°), this generates an awkward and uncomfortable posture and movement of the wrist. Besides, with the presence of optic flow, the pointing task was performed significantly better. Therefore, when driving a car, we can probably benefit from the natural optic flow to better perform a manipulation task with a joystick pointing device. And the effect seemed to be stronger in the orthogonal operation cases, which could compensate a bit for the general lower performance found in this study.

Not as expected, the two different driving environments made no difference in the pointing performance. We would expect a lower performance in a higher complex visual environment, i.e. the city driving, due to overloaded information and more distraction. However, we might have considered other factors in the two environments which may affect the pointing performance, such as the different driving speeds, which could cause various forms of the optic flow that may result in other effects.

5. Conclusions

For designing the user interface and choosing an input device for in-vehicle control systems, a hand-held joystick for manipulating radial selections could be a good choice. Supported by the findings in this study, we would highly recommend to simplify or constrain the operation mode for diagonal pointing orientations only, or to minimize the use of orthogonal operations with the joystick. Optic flows generated during driving could enhance our pointing performance.

6. References

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