A VISUAL AID FOR CURVE DRIVING

Mestre D [1] , Mars F [2], Durand S [1], Vienne F [3], Espié S [3]

1. UMR Mouvement et Perception
CNRS/ Université de la Méditerranée
Marseille

2. Institut de Recherche en Communications et Cybernétique de Nantes (IRRCyN)
CNRS/Ecole Centrale de Nantes/Université de Nantes/
Ecole Nationale Supérieure des Techniques
Industrielles et des Mines de Nantes

3. Modélisations, Simulations et Simulateurs de Conduite
MSIS-CIR, INRETS
Arcueil

Abstract

From the analysis of optic flow patterns due to observer self-motion and from analyses of the driver's gaze direction during curve driving, previous studies have suggested that: 1) the driver has a tendency to look at a spot close to the tangent point on the inside edge of the road and 2) this visual strategy can be partly explained as an optimization of information pick-up.

The main objective of the present study was to investigate, in an interactive simulation context, if and how this perceptual strategy might be transformed into a visual aid for curve driving. In the ARCOS project (www.arcos2004.com) framework, we use a class SIM² mini-simulator developed by INRETS (MSIS-CIR group) in collaboration with FAROS company, with two main original characteristics : 1) during curve driving, the tangent point can be calculated and inserted in the visual scene in real-time and 2) a real-time eye-recording system (EYELINK ® , SMI) allows us to evaluate the relationships between driving performance, gaze direction and the on-line presentation of the tangent point. Future developments will be discussed in terms of the definition of visual guiding systems for curve driving in real conditions.

Résumé

A partir de l'analyse du pattern de flux optique généré par un observateur en mouvement et de la mesure de la direction du regard du conducteur lors de la prise d'un virage, des études précédentes ont suggéré 1) que l'observateur avait tendance à fixer le point tangent (point de corde) du virage, 2) que cette stratégie de fixation du regard pouvait s'expliquer par une optimisation de la prise d'information utile au contrôle du déplacement.

L'objectif général de notre travail est donc d'étudier, en situation interactive, comment cette stratégie perceptive "naturelle" peut ici être utilisée pour définir une aide visuelle au contrôle de trajectoire en virage. Dans le cadre du projet ARCOS (www.arcos2004.com), nous utilisons un mini-simulateur de classe SIM² développé par l'équipe MSIS-CIR de l'INRETS, en collaboration avec la société FAROS, avec deux particularités : 1). Le point de corde lié à la trajectoire du sujet dans un virage peut être calculé et figuré en temps-réel dans la scène visuelle et 2) un système d'analyse en temps-réel des mouvements oculaires (Système EYELINK, SMI) permet d'étudier les interdépendances entre la qualité du contrôle de trajectoire, la stratégie de fixation oculomotrice des sujets et la figuration du point de corde. Nous discuterons les implications de ces travaux sur la définition d'aides visuelles en situation réelle de conduite.

Introduction

The basic problem of the elucidation of useful visual information for the control of self-motion remains a serious one, notably in the field of car driving, due to the singularities and complexity of the road environment. In the 50's, Gibson (1958) introduced the concept of "optic flow", to describe the transformations of the light pattern (optic array) projected onto the entire retina during self-motion. He suggested that our motion through the environment produces a pattern of optic flow that specifies the properties of our displacement.

Today, this problem remains active, and alternative sources of useful information for the control of self-motion have been suggested, beside the utility of the global pattern of optic flow (see Wann & Land, 2000; Fajen & Warren, 2000, for an overview). Among potential visual cues for the control of self-motion during car driving, Gordon (1966) already noted that " (..) when the moving vehicle is aligned with the highway, each point on the road border and lane marker falls on the angular position previously occupied by another point of the border, and the road assumes a "steady state appearance". Whereas drivers are keen to use optical flow to control their trajectory, they are equally susceptible to use optical stability to steer their vehicle, using edge lines. Driving corresponds in this case to a tracking task, the problem being to maintain visual stability of edge lines. Riemersma (1981) demonstrated that, during simulated road driving, edge line motion was an effective visual cue for the control of heading and lateral control. One interesting consequence of this is that, under nighttime conditions, delineation systems appear to be a privileged visual cue for facilitating driving on straight and curved roads.

It becomes then obvious that, beside the global optic flow pattern, the road environment structure plays a role in the perception of a car’s trajectory. In this sense, the "objects" along the road, including road signs, might also play a role. This approach suggests only that every road element has to be taken into account in a "dynamic visual approach" to driving. In research, it corresponds to a new viewpoint on optic flow, suggesting that object-based visual information has to be taken into account. Secondly, the role of singular objects (or locations) might be greater than we think. In this approach, Land and Lee (1994) introduced new methodological tools, by recording gaze behavior during car driving. They demonstrated that, in curve driving, the eyes tend to fixate the inside edge of the road near a point known as the "tangent" or "reversal" point of the road, which is a singular point where the inside of the curve changes direction (Figure 1). This suggests that subjects pick up useful information for the control of self-motion around this point.

In recent psychophysical experiments (Mestre, 2001; Mestre & Durand, 2001), we evaluated the ability of human observers to discriminate variations in their direction of self-motion during simulated curvilinear trajectories, as a function of the part of the global optical flow field they were looking at. In a dark room, observers were presented with random-dot optic flow stimuli of brief duration (200 msec), back-projected on a large screen. Self-motion was simulated through a tunnel of fixed curvature. In a two-alternative forced-choice adaptive procedure, in which the path of self-motion was varied around the constant tunnel curvature, subjects had to determine the path of lowest curvature. A central fixation mark was used to control eye position. The overall optic flow was positioned relative to the fixation mark, such that different parts of the optic flow pattern fell on the fovea. The results clearly show that discrimination thresholds varied as a function of the part of the optic flow field being fixated.

They were minimal when subjects looked directly at the tangent point of the tunnel. As the horizontal angle of gaze departed from the tangent point, thresholds increased notably. They were moreover linearly correlated with the local magnitude of optic flow motion. These results confirm the idea that, in tasks such as curve driving, the tangent point of the curve acts as a singularity in the visual field, enabling optimal control of self-motion.

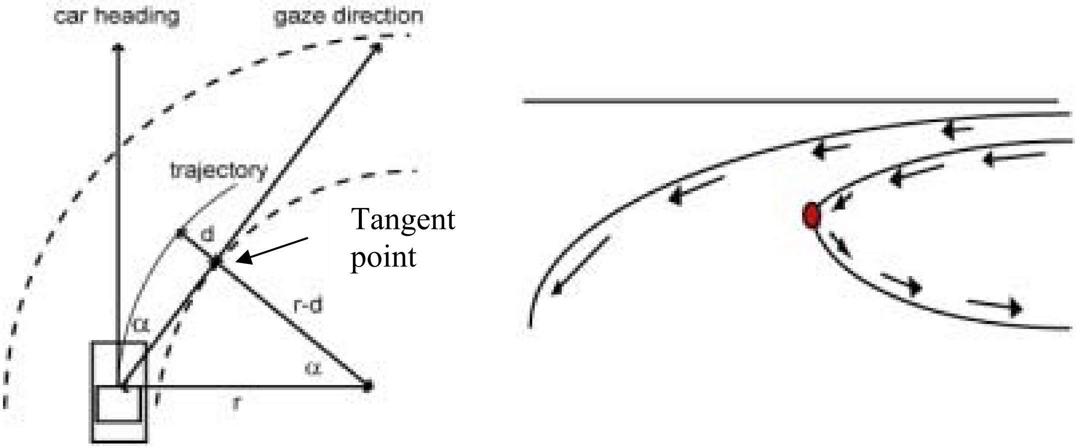

Figure 1. In a curve of radius r, the tangent point corresponds to the intersection point between the tangent to the inside edge line of the road (passing though the subject's point of view) and this edge line. (α is the gaze angle with respect to the straight-ahead direction). On the right, a perspective view of the curve shows that the tangent point (red dot) is visually motionless when the observer's trajectory follows the road (adapted from Land, 1998).

To summarize, it appears, from geometrical analyses of optic flow during curve driving and from experimental studies, that an observer has a "natural" tendency to fixate the tangent point of a curve. This visual strategy can be considered as an active optimization of information pick-up. In the present study, we aimed at searching whether this strategy could be used to define a visual aid for curve driving. In order to do so, we defined a simulation paradigm. We used a simulation facility, developed by INRETS (MSIS-CIR unit, Arcueil, France). During interactive simulations of car driving along a sinuous road, we investigated the role on performance of the figuration of the tangent point, while recording gaze behavior.

Methods

Subjects

Seven undergraduates, aged between 25 and 32 years, participated in the experiment. They all had normal vision (for correct eye recording). They all were active drivers, for at least five years. Before the experiment, they signed an informed consent form.

Apparatus

Driving simulator. We used the driving simulator developed by INRETS in collaboration with FAROS company (figure 2). It enables full control of driving scenarios, real-time interactive driving, visual and auditory feedback, and on-line recording of simulated trajectories, for off-line analyses (Espié et al., 2003). The visualization part of the simulation software was upgraded, in order to allow real-time computation of the tangent point during curve driving, and presentation of this tangent point in the visual environment during simulated driving (figure 3). The angular position of this point was calculated from the driver's viewpoint.

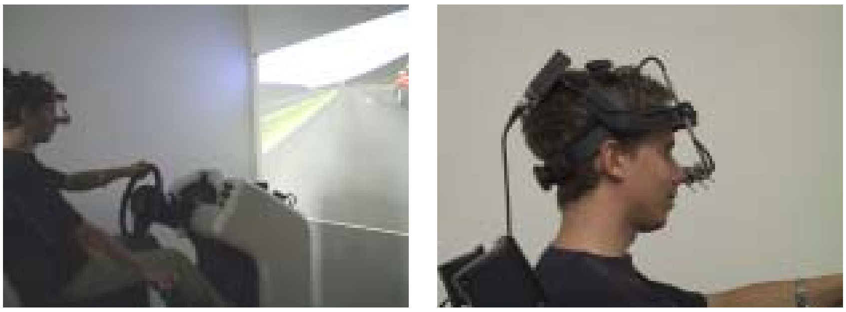

Figure 2. Experimental set-up showing the simulator in front of a wide-angle visual scene representing the road environment. On the right, a close-up view of the "driver", showing the gaze recording device, using high-frequency miniature video camera facing the subject's eyes.

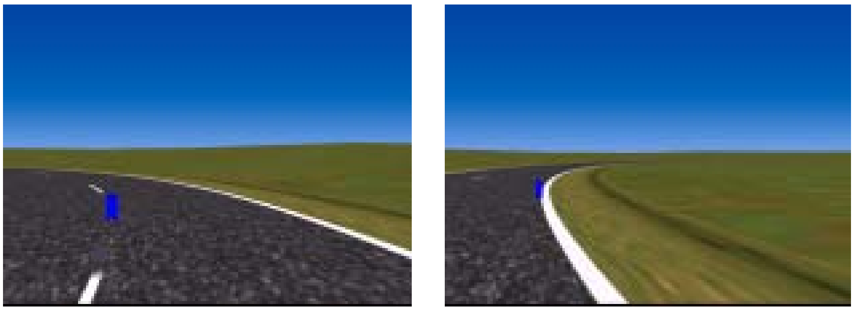

Figure 3. Snapshots of the visual road environment, showing the tangent point, having the form of a blue post, lying on the center line during a curve to the left and on the edge line of the road during a curve to the right. No objects (cars, buildings, vegetation) were present.

Gaze recording. Gaze direction was measured on-line during the simulated driving task (figure 2), using a video-oculographic system "Eyelink" (Sensomotoric Instruments GmbH). In short, the system consists in infrared video cameras, which deliver, at 250 Hz, the angular position of the eye, in pixels, with reference to a previously calibrated visual screen. A second camera, on the subject's forehead measures the position of infrared emitters (of known positions) located at the four corners of the visual projection screen (on which the visual road environment is presented). This second camera allows (through specific software) compensation of the subject's head movement. At the end of the processing chain, gaze direction is directly available. The Eyelink system has thus the great advantage of allowing the subject to have his/her head free of motion, while gaze movements are monitored. This aspect is crucial, notably in terms of ecological validity of the data. The Eyelink system uses its own computer. A direct Ethernet connection was established between the "Eyelink" and "simulator" computers, in order to synchronize simulation and gaze data during a driving session. This link was also used to initially calibrate the gaze data with reference to the visual road environment.

Experimental procedure. In a first step, subjects were trained on the simulator, during three trials on the road depicted in figure 4 (left). This road consisted of a series of curves with constant radii of different values (20, 50, 100 and 200 meters), in each direction (to the left and to the right), separated by portions of straight lines. This initial step was meant to let the subjects get used to this particular simulator and to sharp curve driving. They were instructed to drive at sustained speed without leaving the right lane (3.5 meters wide). The road edge lines were continuous, while the center line was discontinuous (figure 4, center). Subjects were selected for the actual experimental sessions, provided they could drive this road in "reasonable" time (as compared to a baseline defined by the experimenters), without running off the road.

Figure 4. Representation of the training (left) and experimental (right) tracks. The center of the figure is a bird's eye view of the road textures.

The experiment itself consisted of three sessions, each lasting for about 30 minutes (including gaze calibration phases). The road environment is depicted in figure 4 (right), and consisted of a randomly ordered succession of curves of various radii (50, 100, 200, 500 meters), with each radius appearing in each direction (right and left), giving a total of 8 curves separated by portions of a straight line.

In each session, three runs were conducted. Gaze direction was always recorded. In the first session, the tangent point (figure 3) was not represented. This enabled us to evaluate driving performance and gaze behavior in initial (no tangent point) conditions. In the second session, the tangent point was represented. In the last (third) session, it was no longer presented. This manipulation aimed at separating potential effects (both on performance and gaze behavior) of the representation of the tangent point from strict learning effects. The experimental and subsequent analysis plan can be represented as follows

$$\text{Subjects}_7 * \text{Session}_3 * \text{Repetition}_3 * \text{Direction}_2 * \text{Radius}_4$$

where S_7: 7 subjects; Session3: 3 experimental sessions; Repetition3: 3 runs in each session; Direction_2: 2 directions of curve (right/left); Radius_4: 4 values of radius of curvature (50, 100, 200, 500 meters).

Data Analysis

The data files recorded from the simulated driving tasks were used to evaluate driving performance, in a classical way. We will present here analyses concerning the standard deviation of the lateral position of the simulated vehicle, with respect to the road center line. This is a simple way to characterize the "stability" of a trajectory. Note that the data were analyzed for each of the eight curves of the experimental track (figure 4).

As concerns gaze data, the spatial and temporal calibration procedures enabled us to synchronize these to the simulator data. This was crucial, since the simulator data files contained the positions of the tangent point in the visual scene. We will present here data representing the average angular distance between gaze direction and angular position of the tangent point in the visual scene, for each of the eight curves of the track.

Results

Driving performance

Subjects were required (and managed) to stay in the right lane of the road, being 3.5 meters wide. On average, the standard deviation (SD) of the lateral position (across sessions and subjects) is equal to 0.29 meters (± 0.2), meaning that the overall driving performance was quite satisfactory (the subjects managing to always stay in the right lane).

A repeated-measure analysis of the variance (ANOVA) reveals a main significant effect of the curve direction (left or right). SD of lateral position is equal to 0.32 meters for curve to the left and to 0.27 meters for curves to the right. This first result suggests that left curves are harder to drive that right curves. The precise reasons for this difference remain to be further investigated. It might be due to the fact that, on right curves, subjects visually rely on a continuous edge line, while, on left curves, they are using a "dotted" line (figure3), which might hamper the monitoring of its visual motion and/or the extraction of the tangent point visual motion. However, it seems also plausible that drivers have a tendency to "cut" curves, and that imposing them to stay in the right lane in left curves might have induced lateral performance degradation. Nevertheless, there is a significant interaction effect between the curve direction effect and the "session" factor (figure 5).

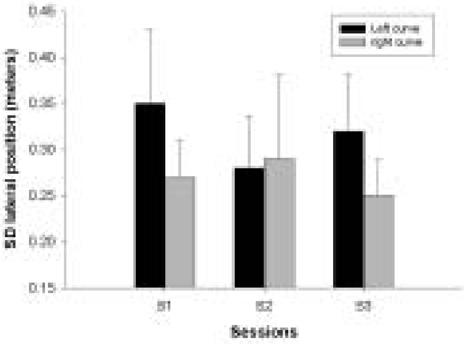

Figure 5. Average values of the SD of lateral position as a function of session, for left (black) and right (gray) curves (vertical bars represent 95% confidence intervals).

This result means that the "direction effect" is significant for both sessions 1 and 3, in which the tangent point is not represented in the visual scene, while it is no longer present (significant) when the tangent point is represented in the visual road environment. This suggests that the presence of the tangent point helps the subjects on left curves, which are otherwise more difficult to deal with than right curves.

Analyses also reveal a significant radius effect, "sharp" (small radii) curves leading to degraded performance (higher values of SD of lateral position, see figure 6). Post-hoc analyses further reveal that the smallest radius of curvature (50 meters) is significantly more "difficult" than the others (figure 6). In particular, in session 1 (S1 in figure 6), the direction effect is mainly due to the 50m radius. This direction effect disappears in session 2 (S2), in which the tangent point is represented, but reappears in session 3 (S3, figure 6). This pattern of results suggests that the suppression of the direction effect is somehow linked to the presence of the tangent point. It cannot be a simple "learning" effect, since it reappears in session 3, in which the tangent point is no longer present.

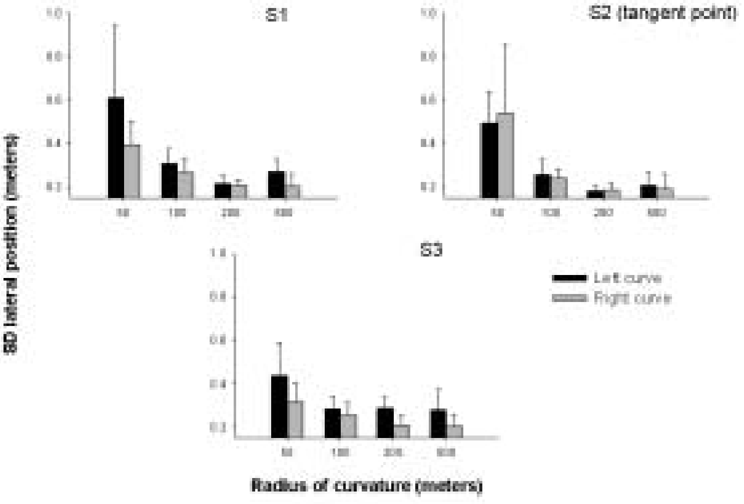

Figure 6. Average values of the SD of lateral position as a function of the radius of curvature, for left and right curves and for the 3 sessions (S1 to S3) (vertical bars represent 95% confidence intervals).

Gaze behavior

The main result here is that the average distance (across subjects and conditions) between gaze direction and tangent point is equal to about 4 degrees, and in all cases inferior to 8 degrees (see figure 7). This simple result confirms Land & Lee (1994) data, in showing that in our conditions subjects also have a "natural" tendency to locate their gaze near the tangent point, during curve driving.

We also observe, as for performance data, a significant effect of the radius of curvature (figure 7), suggesting that the subjects' gaze is located farther away from the tangent point, as the curves become "sharper".

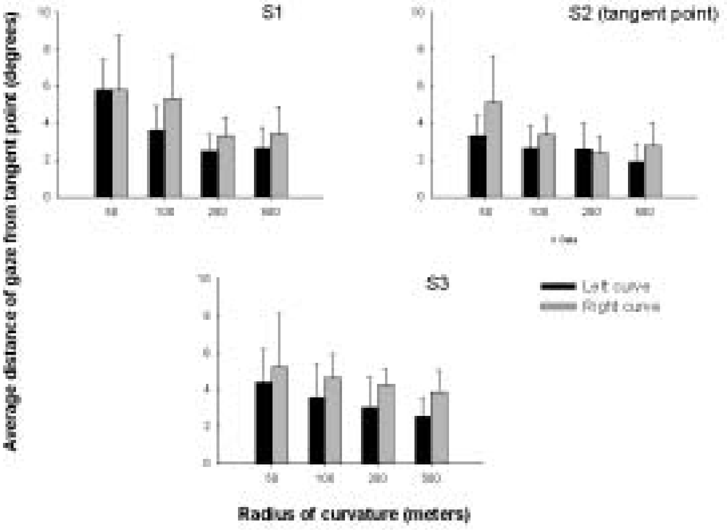

Figure 7. Average values of the average angular distance between gaze direction and tangent point, as a function of the radius of curvature, for left and right curves and for the 3 sessions.

Figure 7 also shows a reduction in the distance "gaze-tangent point" between Session 1 and 2, this effect being not significant. However, post-hoc analyses show that gaze is closer to the tangent point for the smallest radius, in session2 as compared to session 1. Finally, average distances are significantly higher, in session 3, for right curves than for left curves.

Discussion and Perspectives

Concerning the positive role of the display of the tangent point during curve driving, hence its applicability as a driving aid in real conditions, much has to be done (both in experimental and technological terms). In particular, this first attempt to link driving performance and gaze behavior has to be pursued, in terms of a closer analysis of spatio-temporal aspects of the coupling between the direction of gaze and the location of the tangent point during a curve. Here, The analysis unit was the whole curve, and we presented only the average angular distance between gaze and tangent point. We already know from studies on car driving (i.e. Land & Tatler, 2001), that an anticipatory behavior is involved (gazes deviates toward the curve apex before the actual turn). It is certainly interesting to study this coupling in simulation conditions and in situations where the tangent point is (or not) displayed in the visual scene. Such analysis has also to be linked to driving performance.

However, a few comments can be derived from available data. First, it seems that small radii give rise to both poorer performance and a gaze direction being farther away from the tangent point, as compared to larger radii. It is also for small radii that the figuration of the tangent point significantly reduces the "gaze-tangent point" angular distance. Secondly, it seems that the figuration of the tangent suppresses the direction effect (left curves being harder to drive than right curves), mainly related to small radii. It can then be hypothesized that the figuration of the tangent point during curve driving acts as an "equalizer", reducing the differences in performance linked to the road geometry and architecture. Finally, some effects observed in the present experiment might suggest that the figuration of the tangent point might not be optimal in its current format. The blue post (figure 3) might indeed mask or distort useful visual information. We are currently working on that aspect of the problem and on the integration of eye movements recordings in the simulation software for on-line processing, which should open new lines of investigation.

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