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Pilot Study on Visual Occlusion of Different Driving Tasks

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Introduction

The usage of an in-vehicle information system while driving, such as a GPS guidance device or a hands-free mobile phone, can distract the driver [Nowakowski, 2002]. Systems with audio output (speech or sound) can interfere with the operator's focus on the road [Lee]. While the driver can easily handle an interruption when the driving task is not overly demanding, he/she might experience difficulties in a complex road or traffic situation. The complexity of a driving situation can be assessed by workload estimation.

This paper examines a driver workload measure for different road situations. Knowing the workload, a future in-vehicle information system could adapt to it in order not to distract the operator in a demanding environment [Vervey, 2000]. The adaptation for a speech based system could be to delay an incoming message to a later time.

Three different driving conditions were tested in this pilot study: straight road, curvy road and city driving. It was hypothesized that city driving is the most demanding and straight is the least demanding of the three environments tested. The results proved this hypothesis.

Approach

Driver workload is the demand on a driver to maintain a consistent path of travel. It can be measured by different methods, which Tsimhoni and Green categorize into the following groups [Tsimhoni]: 1) primary task measurement (e.g. steering wheel angle, lane position, pedal usage), 2) secondary task measurement (measuring performance on an additional task), 3) physiological measures (e.g. heart rate, heart rate variation), 4) subjective techniques (e.g. NASA TLX questionnaire) and 5) visual occlusion.

In this work, the visual occlusion method was applied, which proved to be very sensitive to changes in workload. For a review of earlier research on this topic refer to [Green, 1998]. In this method the driver is denied the visual image of the road driven except when asking for it by operating a push-button. In that case, the road is shown for one second and occluded again. The main idea behind this technique is that the driver will be asking for a glimpse of the scene more often when facing a difficult driving task than when the task is not overly involving. Therefore he/she must be asked to operate the push-button as frequently as needed to perform the driving task safely.

The experiments were conducted in a high fidelity driving simulator. It has a motion platform mounted console capable of tilting movement, thus simulating acceleration/braking effects. Its field of view is 180 degrees, which is split up on 3 projection panels. Sounds (engine, braking, etc.) as well as vibrations of the console add up to its fidelity.

Experiment Setup

The experiment scenario can be divided into 3 groups:

1) straight non-urban road driving
2) curvy non-urban road driving
3) city – urban driving

All scenarios featured two lane roads, one in each direction. The lanes had a standard width of 12ft (3.6m). There was ambient traffic (randomly generated vehicles) present in all of the simulations. The density of traffic was around 8.2 vehicles/minute per lane measured at a fixed point. The straight and curvy roads were concatenated as shown in Figure 1. The first winding section consists of two left and three right curves, while the second consists of three left and two right curves, all with a radius of 200m. Curves with smaller radii were taken into consideration, but they were eliminated from the experiments because they tended to cause discomfort with test subjects. There was a leading vehicle on the non-urban type of road traveling with a velocity of 60mph. The subjects were asked to follow this vehicle at a constant distance (without enforcement). They had feedback information on the distance to the leading car.

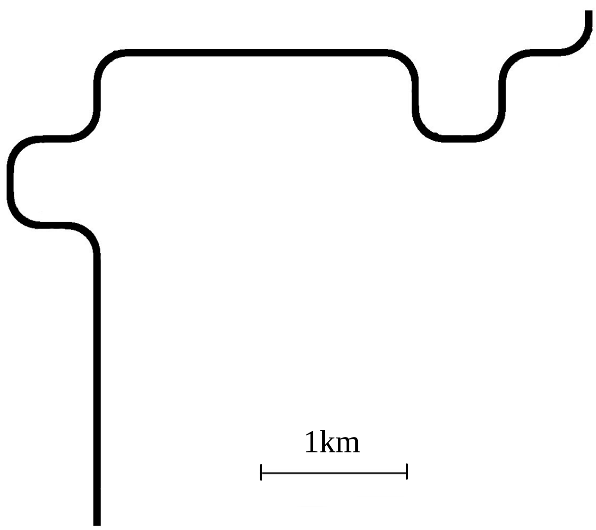

Figure 1 Straight/curvy non-urban road

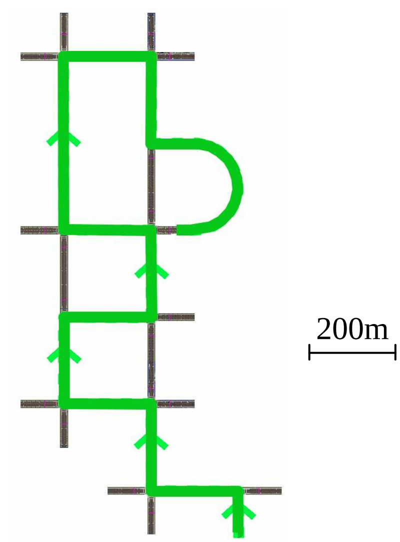

Figure 2 City roads

The city scenario consisted of straight sections, intersections and a curve as shown in Figure 2. Most of the intersections had only one possible direction for exiting. This was achieved by placing appropriate traffic signs, blocking vehicles, working zone cones, etc. Only two intersections had two allowed possibilities of turning. This was resolved by telling the subjects prior to the start of the experiment which streets they have to take: “Turn right on Broadway St. and right again on Elm St.” Two out of ten intersections were controlled by traffic lights.

The occlusion of the scene was started by pressing a push-button located near the automatic gearshift and the emergency brake lever. A one second glimpse of the roadway was acquired by pressing another button at an adjacent position. Test runs were made also with a foot pedal which was used in other works published in this field [Tsimhoni], but it proved to be inconvenient to use, by subjective opinions of the subjects.

The subjects were 5 graduate students of the ECE Department of the University of New Hampshire, between ages of 22 and 24, all familiar with driving in the simulator. They were all in possession of valid driving licenses for 7.4 years on average. They drove 12.2 thousand miles on average annually.

The subjects were first given an introduction to the roads to be driven and to the visual occlusion method, which requires some time to adapt to, because of the flickering of the scene due to frequent operation of the push-button. After practice, the subjects drove the straight and curvy roads and then the city roads. The value to be measured was the average period of time between two operations of the push-button (the so called occlusion period) which enabled the driver to get a glimpse of the road scene.

Results

The visual occlusion method gave highly discriminative results for straight and curvy road driving. Figure 3 and Figure 4 show the results for one subject for this mixed type of roads. The curvy part of the road was driven when the steering wheel angle had high oscillations in Figure 3, i.e. from the 80th second to the 130th second and from the 240th to the 330th second. The other parts were straight road driving.

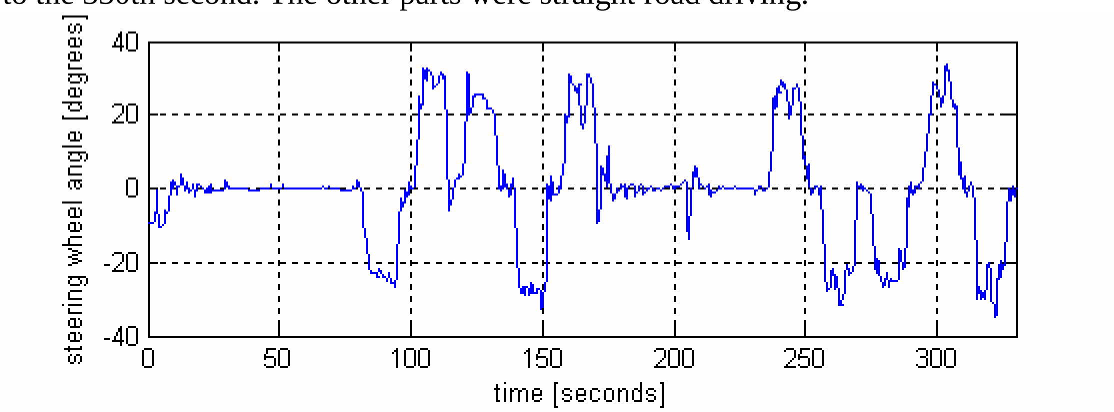

Figure 3 Steering wheel angle for one subject

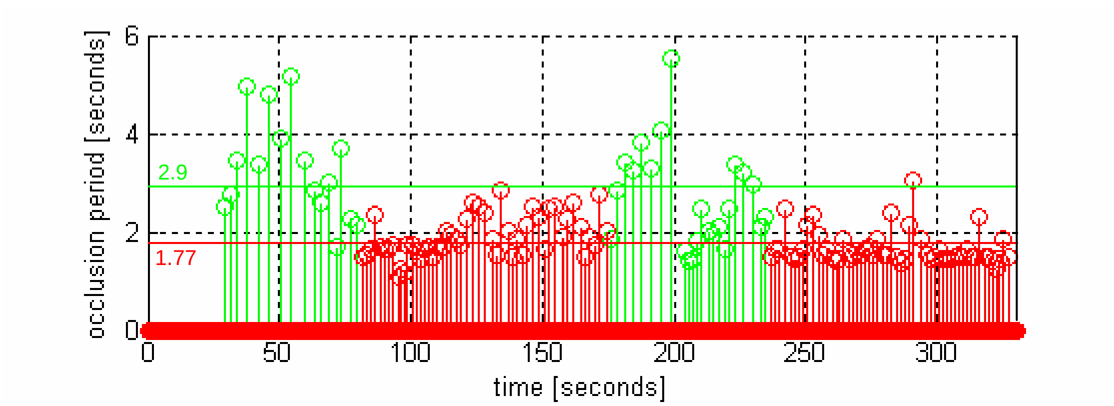

Figure 4 Occlusion period for one subject

Figure 4 shows the lengths of the occlusion periods. For example, if a sample has a value of 5s, it means that the subject was driving in the dark for 5s without operation of the glimpse giving push-button. Green samples represent the periods of occlusion while driving on the straight segments of the road, while red samples represent driving in a curve. It is obvious that the period between two glimpses is on average longer on straight roads, i.e. the subjects are driving longer 'in the dark'. This means that the driver workload is higher when driving in curves compared to straight roads. The mean values of occlusion are given in Figure 4, and they are depicted with horizontal green and red lines. In this graph the mean value for the straight section is 2.9 seconds (in green) while for the curvy section it is 1.77 seconds (in red). Based on a premise, that visual occlusion is an appropriate measure of visual workload, it can be concluded that it is visually more demanding to drive in a curve compared to a straight section.

Results for the city scenario are similarly analyzed as explained above. The average occlusion period for straight road driving was 2.7 seconds, for the curvy road 1.95 seconds and for city driving 1.7 seconds.

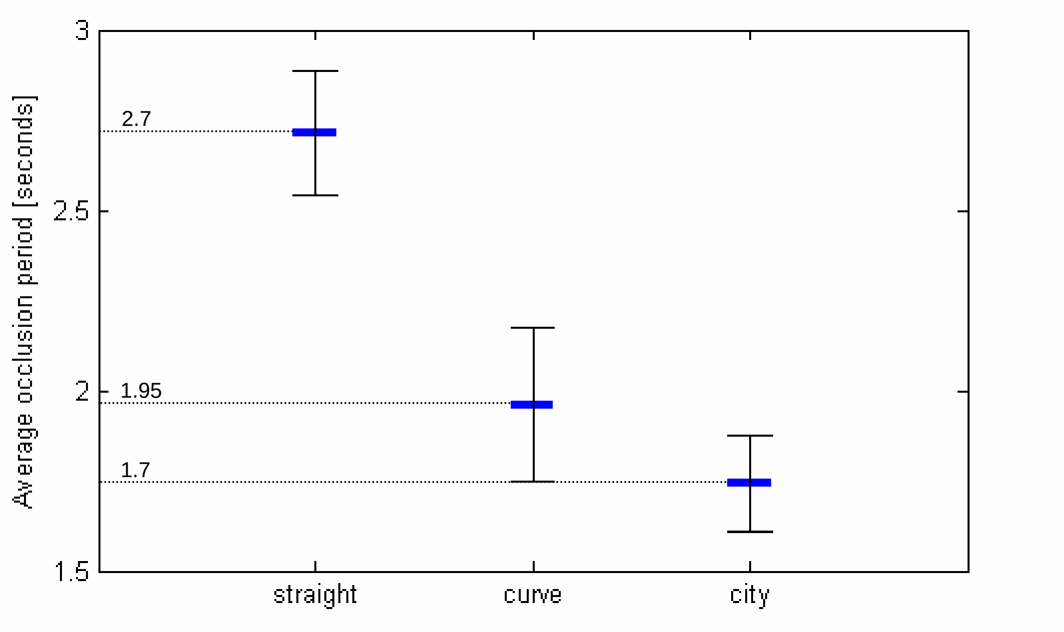

Figure 5 Mean and standard deviation of occlusion periods for different road types

In Figure 5 blue lines represent mean values for different road types averaged over all participants, while black horizontal lines represent the +/- one standard deviation limit. There is an obvious difference between the mean occlusion periods for the three scenarios. ANOVA statistical tests were performed on the collected data. They show that the difference between driving on a straight and curvy road is statistically significant ($p=0.0167$), as is the difference between driving on a straight road and city driving ($p=0.0083$). The difference between driving in curves and city driving is not statistically significant ($p=0.3191$).

When using visual occlusion or a secondary task method, only the effect of driving on the additional task is measured. But in reality the visual occlusion also affects driving to some extent. This causes more variation in lane position and some lane departures. In our pilot study we observed that this effect was reduced over time when the subjects got more accustomed to the experimental method.

The city driving data can be further analyzed, because it consists of distinctive types of roads: straight portions, intersections, curves, traffic light situations, school zones, etc. Analyzing all the collected data (acceleration, lane position, braking, steering wheel angle, occlusion period, etc.) it can be inferred that there is a strong connection between taking turns and visual occlusion, i.e. between the steering wheel angle and the frequency of the occlusion (1/occlusion_period) as shown in Figure 6.

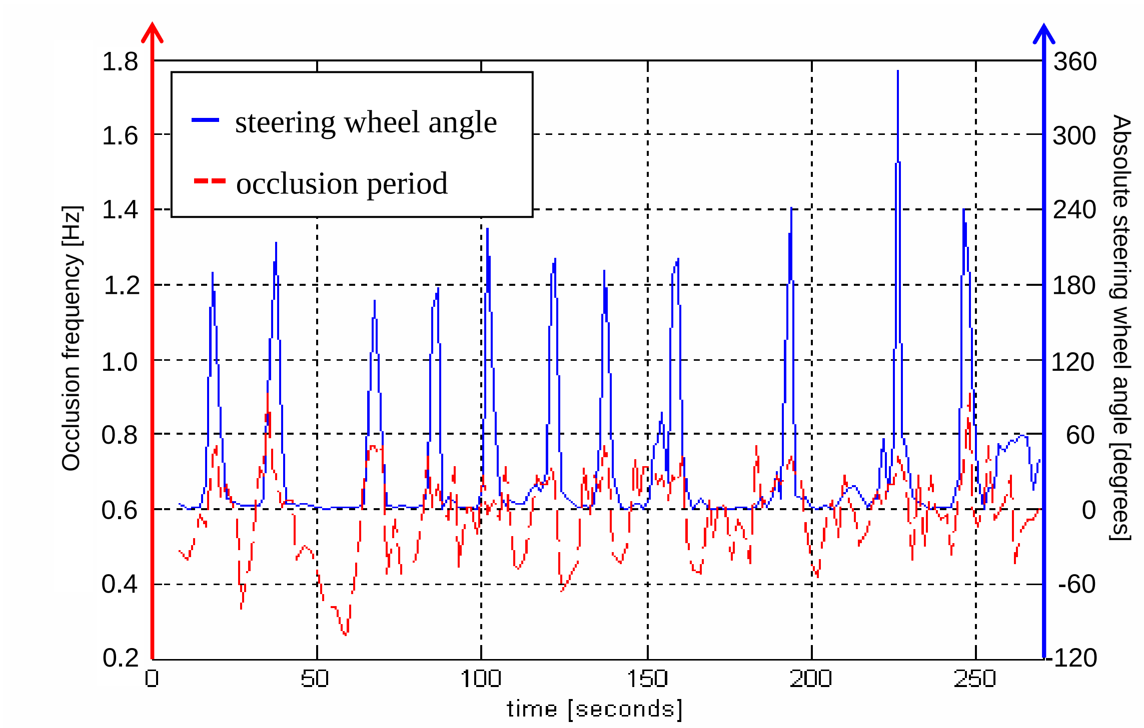

Figure 6 Occlusion and steering compared

The occlusion frequency is the measure of how many times the subject pressed the push-button in a second. It is shown in Figure 6 with its axis on the left. In the same figure the steering wheel angle is shown with its reference axis on the right side of the graph. It can be noticed that these two signals are somewhat similar. This similarity can be shown by their cross-correlation, depicted in Figure 7.

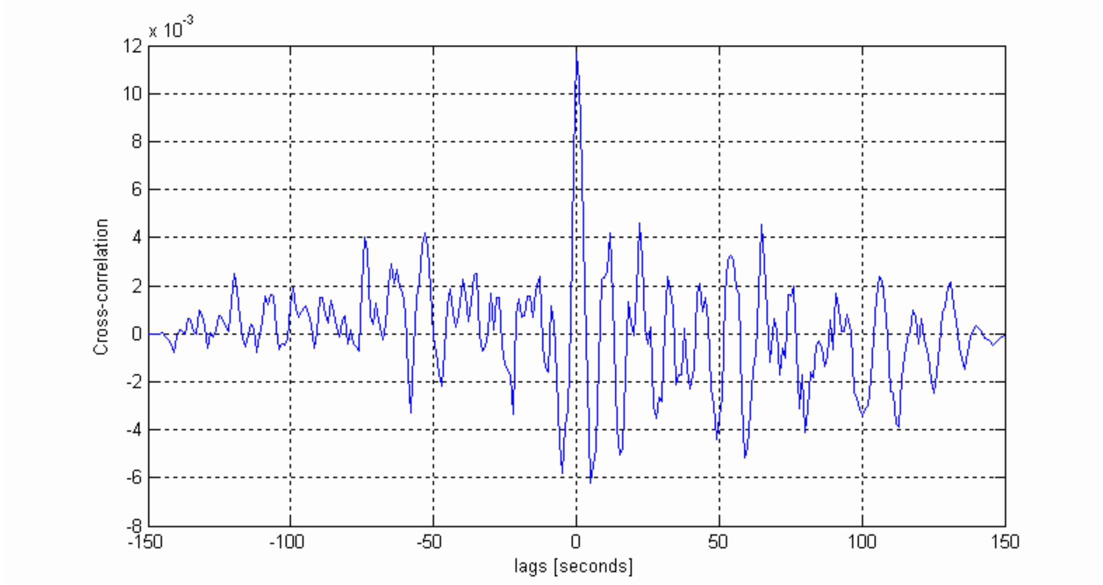

Figure 7 Cross-correlation between occlusion frequency and steering wheel angle

It is obvious from the above figure that there is a strong correlation between the two signals, at 0 seconds lag. Based on the above figure and the premise that visual occlusion is a good measure of visual workload, it can be said that driving tasks which include large scale steering wheel operation (e.g. turning at an intersection, driving in a curve, etc.) result in higher driver workload.

Conclusion and Future Work

The results of this pilot study show that driving a city scenario has the highest driver workload of the three situations examined; driving on curvy roads is less difficult, while straight road driving is the least difficult. The study also shows that city driving can be further analyzed to find exceptionally demanding sections. These were connected to steering wheel operation by cross-correlation.

We intend to conduct further analysis of different road situations. City driving is especially interesting, because it has large variations in visual workload demand. These variations may be used in a mechanism that would help decide when and how an in-car system should interact with the driver. For example, interaction may have to be completely suppressed when high driver workload is detected.

References

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