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Assessment Of Distractions Inferred By In-Vehicle Information Systems On a Naturalistic Simulator

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***Abstract*— Driving inattention is a major factor to highway crashes. The National Highway Traffic Safety Administration (NHTSA) estimates that approximately 25% of police-reported crashes involve some form of driving inattention. Increasing use of in-vehicle information systems (IVISs) such as cell phones or GPS navigation systems has exacerbated the problem by introducing additional sources of distraction. Enabling drivers to benefit from IVIS without diminishing safety is an important challenge. In this paper, an automatic distraction monitoring system based on gaze focalization for the assessment of IVISs induced distraction is presented. Driver's gaze focalization is estimated using a non-intrusive vision-based approach. This system has been tested in a naturalistic simulator with more than 15 hours of driving in different scenarios and conditions and 12 different professional drivers. The purpose of this work is, on the one hand, to assess the detection capacity of the monitoring system and, in the other hand, to study drivers reactions to different IVISs. Gathering this information the optimal IVISs location and the way the indications should be delivered to the drivers can be studied to reduce the interference with their driving.**

I. INTRODUCTION

Driving inattention is a major factor to highway crashes. The National Highway Traffic Safety Administration (NHTSA) estimates that approximately 25% of police-reported crashes involve some form of driving inattention (including fatigue and distraction) [1]. Driving distraction is more diverse and is a greater risk factor than fatigue and it is present over half of inattention involved crashes, resulting in as many as 5,000 fatalities and $40 billion in damages every year [2]. In [3], driving distraction is defined as "when a driver is delayed in the recognition of information needed to safely accomplish the driving task because some event, activity, object or person within or outside the vehicle compelled or tended to induce the driver's shifting attention away from the driving task". Thirteen different types of potentially distracting activities are listed in [2]: talking or listening on cellular phone, dialling cellular phone, using in-vehicle-technologies, etc. Since the distracting activities take many forms, NHTSA classifies distraction into 4 categories from the view of the driver's functionality: visual distraction, cognitive distraction, auditory distraction (e.g., answering to a cell phone), and biomechanical distraction (e.g., manually adjusting the radio volume) [1]. Some activities can involve more than one of these components (e.g., talking to a phone while driving creates a biomechanical, auditory and cognitive distraction). Increasing use of in-vehicle information systems (IVISs) such as cell phones, GPS navigation systems, DVDs and satellite radios has exacerbated the problem by introducing additional sources of distraction [4]. Enabling drivers to benefit from IVIS without diminishing safety is an important challenge.

One promising strategy to mitigate the effects of distraction involves classifying the driver state and then using this classification to adapt the in-vehicle technologies. The literature contains 3 main categories according to the signals used to detect distractions: biological signals, vehicle signals and driver images. The biological signal processing approaches directly measure biological signals (EEG, ECG, EOG, EMG, etc) from driver's body and as consequence they are intrusive systems [5] [6]. Only a few works, focusing in cognitive distractions, have been reported to use this kind of approach. The main reason may be that using biological signal to analyze distraction level is too complicated and no obvious pattern can be found. Vehicle signals reflects driver's action, then measuring it, the driver's state can be characterized in an indirect way. Force on pedals, vehicle velocity changes, steering wheel motion, lateral position or lane changes are normally used in this category [7] [8]. The advantage of these approaches is that the signal is meaningful and its acquisition is quite easy. This is the reason why some commercial systems use this technique [9] [10] [11]. However, they are subject to several limitations such as vehicle type, driver experience, geometric characteristics, condition of the road, etc. Finally, approaches based on image processing are effective because the occurrence of distraction is reflected through the driver's face appearance and head/eyes activity. Different kinds of cameras and algorithms have been used: methods based on visible spectrum camera [12] [13]; methods based on IR camera [14] [15] [16] [17] and methods based on stereo cameras [18] [19]. Some of them are commercial products as: Smart Eye [16], Seeing Machines DSS [17], Smart Eye Pro [18] and Seeing Machines Face API [19]. However, these commercial products are still limited to some well controlled environments, so there is still a long way to go in order to estimate driver's distraction state.

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To date, realistic studies that provide information on the impact of distracting activities have been developed as small-scale studies. An effort is needed to study distraction problem using naturalistic situations. Simulation is an optimal method of experimentation to acquire knowledge of driver's behaviour. The simulation methodologies applied in Europe to the road transport sector research are demonstrating their profitability and efficiency [20]. The main objective through the simulation, is to immerse the driver in his normal work environment. In order to do this, a cockpit fully equipped is required to perform the driving task.

Previous work scoping the prediction of drivers behaviour mostly rely on lane position and vehicle sensors. Also a video signal of the driver is frequently used but manual annotation or very simple head position estimation is used [21]. In this paper, a non-intrusive automatic distraction monitoring system for the evaluation of IVISs induced distraction is presented. Driver's gaze focalization is estimated using a non-intrusive vision-based approach. This system has been tested in a naturalistic simulator with more than 15 hours of driving in different scenarios and conditions and 12 different professional drivers.

The remaining of the paper is organized as follows. In sections II and III the experimental environment and protocol are described. Section IV presents the non-intrusive vision-based distraction monitoring system. Results and discussion are addressed in section V and finally, the conclusions and future work are presented in section VI.

II. Experimental Environment

A. Truck Driving Simulator

The experiments were performed in the facilities of CEIT [22] in San Sebastián (Spain), in a room with controlled light and sound. The simulator [23] (Fig. 1) consists of a real truck cab equipped with the common IVISs: GPS, Tachograph, Hands-free devices and On-board Computer. These devices send information to a central host for a posterior analysis.

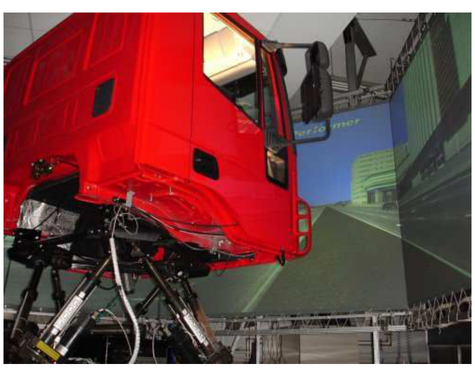


Fig. 1. Real truck cab simulator

The visualization system is composed of three wall-backprojection system with a total surface of $22m^2$. The fact that the screens have no marked separation plus the geometry of the image system makes for a flawless overall impression. Moreover, two monitor screens are used as mirrors.

The cab is assembled on a moving platform with 6 degrees of freedom on which drivers can feel the vehicle accelerating, braking, its centrifugal force, etc.

B. Camera Vision System

The designed hardware for image capture is divided into three parts: the stereo capture system, the illumination controller and the infrared illumination system. This system is located on the truck dashboard, in front of the driver pointing to his face. The cameras are separated a distance of 20cm and the driver is placed at 60 - 100 cm from them (Fig. 2).

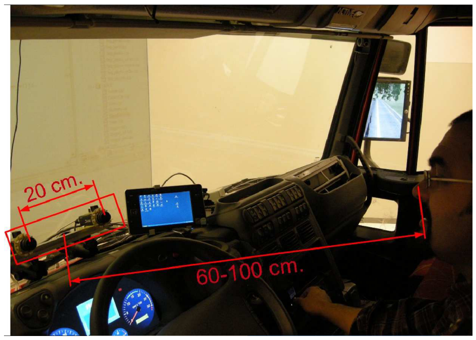


Fig. 2. Camera Vision System

III. Experimental Protocol

To design the experimental protocol we have based on the following initial hypothesis: "The potential driver distraction due to on-board devices is determined by the level of attentional demand required by them while driving, decreasing the effectiveness of the primary task: driving."

By analysing the professional drivers behaviour, the basic and most representative features in the context of this activity are identified [24]. Some scenarios, types of vehicles, incidents, on-board systems and critical situations are selected. Thus, the professional drivers behaviour should be generically represented. Taking into consideration this basis, that involves observation and information recording during the task of driving, the next step is to define the basic simulation exercises.

Experiments have been designed with the goal of refuting the initial hypothesis of the research regarding the potential distraction of four different on-board systems which are commonly used in professional driving task. These devices are digital tachograph, GPS, hands-free device and on-board computer.

Under these conditions, four scenarios have been created (inter-city, mountain, urban and long-distance). Based on these scenarios, 16 exercises were implemented: five of them were based on the inter-city scenario, four on the mountain, three on the urban and the last four on the long-distance one. Each one includes different incidences: motor, tires or ABS breakdown and different vehicle incidences such as sudden brake of the precedent vehicle, broken down vehicles on the road, vehicles running a red light, etc.

The first exercise of each scenario is the "Control Exercise" which corresponds to the exercise undertaken by each driver in the different scenarios without external perturbations. Subsequent exercises of each driver can be compared to the control exercise and a differential analysis of the driver behaviour can be performed. Once the chain of exercises is finished, we have enough information about the drivers behaviour while driving in order to generate a distraction pattern for each one.

A. Subjects

According to the previous considerations, the number of exercises and their configuration, we have defined a minimum number of participants of 12 in order to have one participant for each designed exercise to detect the dependent behaviour variables. Previous studies with similar conditions used groups from 7 to 30 participants [25] [26].

It is important to highlight that every participant needs to pass a 15-20 minutes test to exclude people with propensity to suffer simulator-sickness. Thanks to this test, drivers also become familiar with the simulator. This way, the external variables due to driver's lack of experience with the simulator or IVISs are avoided.

All subjects were informed of the purpose of the experiment and the security procedures in the simulator facilities.

IV. Automatic Vision-Based Distraction Monitoring System

This section presents a brief description of the gaze estimation using computer vision. A block diagram of the algorithm is shown in Fig. 3.

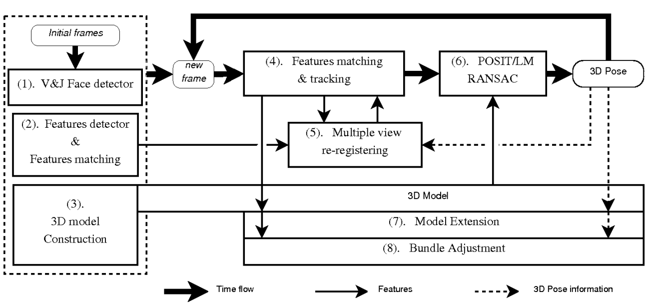
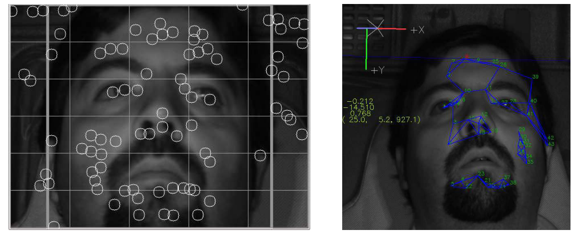


Fig. 3. General architecture of the face pose estimation algorithm

The method consists of the following steps:

0) **Calibration of the stereo-rig.** After this off-line process, all the following operations are fully automatic.
1) **Model creation.** Face is searched on the images using the Viola & Jones (V&J) algorithm. To find interesting features on the driver's face the Harris corner detector [27] is used (Fig. 4 (a)). A 3D model of the face is created with the 3D coordinates correspondence of the points in both images (Fig. 4 (b)).
2) **Feature tracking.** 3D points are tracked over images. We use a single historic of 2D image patch projections from both right and left camera images in conjunction, along with its associated yaw rotation angle. Correspondences are obtained via thresholded matching between patches from the historic and the images (Fig. 5).



(a) (b)

Fig. 4. (a) Viola & Jones detected fade, and initial distribution of feature candidates. (b) Automatic 3D face model.

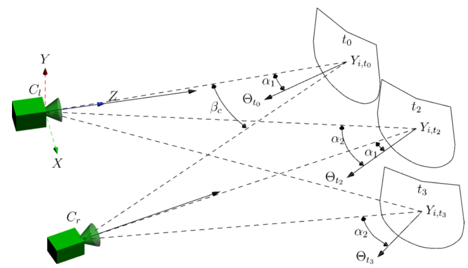


Fig. 5. Model is initially created with pose Θ_0. C_l sees Y_i with an angle α_1. After some rotation, at t_2, now C_r sees Y_i with the same angle α_1, and consequently with a very similar appearance to that saw by C_l at t_0, which was stored. At the same time, C_r stores the new appearance. At t_3, the camera C_r sees Y_i such as C_l did at t_2, with and angle α_2

3) **Pose estimation.** We estimate the pose of the model by means of the LM algorithm within a RANSAC [28] process to reject tracking errors and outliers.
4) **Model correction.** After pose estimation, 3D model may be increased as required to previously occluded parts of the face. A background bundle adjustment [29] optimization refines the model as long as we add new 3D points to the model.
5) **Gaze direction estimation.** In order to improve the accuracy of the gaze direction detection, an algorithm to detect the eyes direction has been developed. This algorithm obtains the horizontal and the vertical eyes angle to modify the face direction previously calculated.

A visual interface shows the driver's gaze focalization on the simulator's screen at every frame. To do so, the obtained gaze angles are projected on the image plane and the gaze focalization coordinates are obtained. Using this visual interface is possible to know where the driver was looking at every time. This interface also classifies the actual direction into 10 different interest regions (front, left/right mirrors, GPS, etc...) as depicted in Fig. 6.

Using this interface it is possible to know where the driver is looking or how long the driver's gaze remains fixed on a point. This is very important to infer the driver's intentions and take them into account when delivering alarms or how

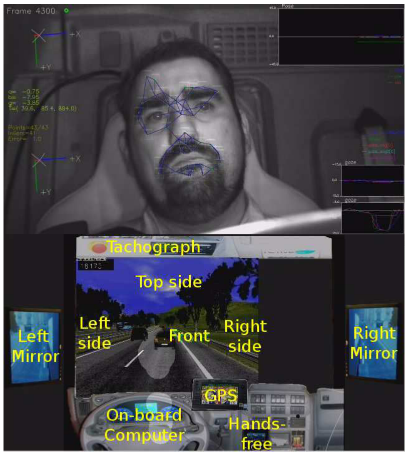


Fig. 6. Gaze focalization visual interface

the driver typically reacts in similar situations (to determine the importance of the warning).

V. Experimental Results

The proposed automatic distraction monitoring system was installed in the simulator described in section II-A and tested with 12 professional drivers in different distraction situations and environments. The purpose of these trials is, on the one hand, to assess the detection capacity of the monitoring system and, in the other hand, to study drivers reactions to different IVISs. Gathering this information the driver's planned actions can be predicted and the different alerts and indications delivered by IVIS and ADAS can be selectively adjusted based on the drivers state. Moreover, the optimal IVISs location and the way the indications should be delivered to the drivers can be studied to reduce the interference with their driving.

As explained in section III the drivers were asked to perform cognitive, visual and auditive demanding tasks while driving such as answering the phone and following indications, receive corrections of previous indications to get to a place or to operate the on-board computer or the tachograph. In table I the recorded incidents while using the different IVISs are shown.

TABLE I
Accident percentages due to each IVIS

	Crashes	Near Crashes	Incidents
Hands-free	58%	53%	48%
GPS	42%	47%	40%
On-board computer	0%	0%	12%
Tachograph	0%	0%	0%

Most of the accidents occurred while receiving or executing the indications from the GPS or the hands-free device. As expected, the more cognitive demanding a task is the higher the risk of being involved in a distraction related incident. Results on Table I also show that the use of tachograph and on-board computer is not very cognitive demanding since it only requires quick looks, similar to a common mirror checking. The challenge now is to study drivers reactions to different IVISs and find out the optimal IVISs location and the optimal way to deliver indications and warnings to them.

A. *Hands-free device*

Most of the incidents were registered while the driver was using the hands-free device. This, together with the fact that 85 percent of people admitted to using a cell phone while driving at least occasionally makes phone use one of the most dangerous activities while driving. The recorded consequences of using the hands-free device are an increase in the corrections of the in-lane position, short braking, non constant speed and fixed gaze.

Fig. 7 shows an example of the truck's position in the lane while driving without external perturbations (red *), and using the hands-free device (blue -). As can be seen, the driver has trouble to keep the position in the lane, even careering over onto the contiguous lane. Frequent corrections of the position are performed while driving in a straight road and also the speed shows a similar pattern. This is due to a recurrent loss of attention to the road and a sudden realization of this loss of attention when the corrections are performed.

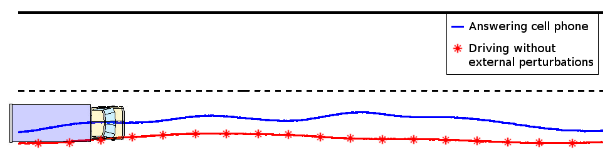


Fig. 7. Truck's position on the lane while answering a phone call and without external perturbations

On Figure 8 the gaze focalization of the driver for the same exercise is shown. Continuous looks to the hands-free device (H) and no checking to the vehicle speed (C) or rear-view mirrors (M) are detected while answering the phone call. On the other hand, on the control exercise, the driver remains attentive to the road (F) (Fig. 8).

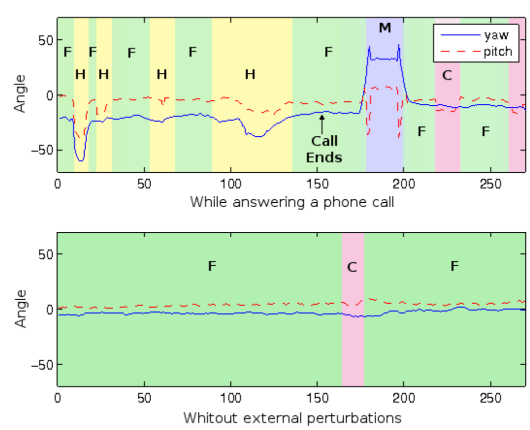


Fig. 8. Driver's gaze focalization while answering a phone call

B. GPS

The second higher cause of incidents was the use of the GPS device. In our experiment, incidents were caused while setting up the GPS device and while following the indications. When setting up the GPS the loss of attention to the road was the main cause of incidents. During these loss of attention the gaze was fixed on the GPS device for long periods of time. But also the indications received from the GPS caused and increment in the incidents rate, mainly caused by a decrease in the attention paid to the road information (traffic signs, overhead panels), and a loss of attention to the road with frequent looks to the GPS device.

I.e. Fig. 9 shows the truck position on the lane while driving without external perturbations (red *), as well as truck position on the lane while following GPS instructions (blue -). The lack of attention paid to the road information while using the GPS, makes the driver to start an overtaking manoeuvre while approximating the exit he has been asked to take. As shown in the figure, the driver is overtaking a very slow moving vehicle when GPS informs him of taking the next exit. To accomplish this instruction, a two-lane changing is required in less than 4 seconds. Instead, when driving without external perturbations, the driver checks the traffic signs to reach his target. The driver is aware that he has to take the next exit in advance and decides to wait behind the slow moving vehicle.

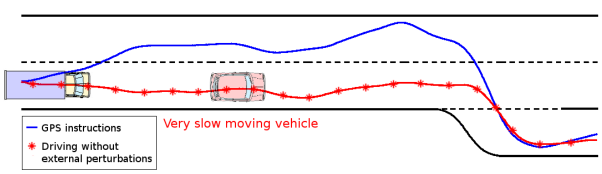


Fig. 9. Truck's position on the lane while following GPS instructions and without external perturbations

In Figure 10 the gaze focalization for the same example is shown. As depicted, reiterative checks of the rear-view mirrors (M) are performed in advance to start overtaking the slow moving vehicle. On the control exercise the overtaking intentions of the driver are also detected in the mirrors (M) and signals (S) checking but the driver is aware of the closeness of the highway exit and decides not to start the dagerous manouver. Predicting the drivers intentions, the indications delivered by the GPS can be modified and warn the driver about the incoming exit or advise the driver to stay on the right lane. Dangerous situations as well as annoying indications or warnings can be avoided by predicting drivers intentions.

C. General Statistics

Human factor studies have shown that reaction times are influenced by secondary tasks such as IVIS usage. Table II shows some statistics obtained after the complete evaluation of the gaze focalization for all the subjects and exercises (where A1, B1, C1, D1 are control exercises and A[2-5], B[2-4], C[2-3] and D[2-4] are distracting exercises). As an

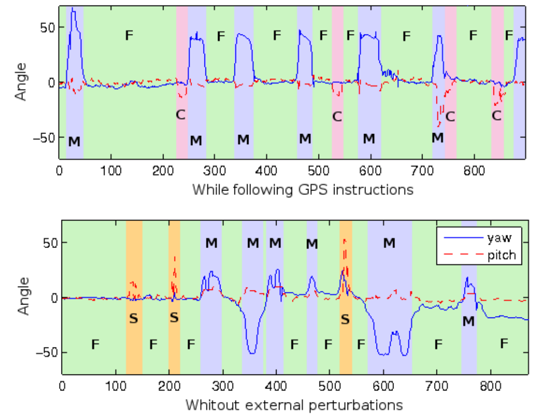


Fig. 10. Driver's gaze focalization previous to overtaking

example, on exercise D3, few drivers were able to avoid hitting an on-road obstacle, while they perfectly did it, up to 12 seconds in advance, if they were not distracted. Many of them overpassed speed limits more often, and needed more time to notice a mechanical failure. One of the subjects needed more than two minutes to notice that he was driving the truck with a flat tyre. Being attentive, he needed just a few seconds to notice the same anomaly. The gaze estimation system allows to study what was the subject doing before noticing the anomaly, and why he was not aware of that for such a long period.

TABLE II
DRIVER REACTION TIMES

Scenario	Exercise	Overpass speed limit	Time in advance to avoid an obstacle	Reaction time after a mechanical failure
			max - min	max - min
A. Inter-city	A1	0	25 - 5	5 - 9
	A[2-5]	2	15 - 3	32 - 81
B. Mountain	B1	2	19 - 5	5 - 9
	B[2-4]	6	13 - 2	24 - 131
C. Urban	C1	0	16 - 3	4 - 11
	C[2-3]	0	4 - 0	4 - 43
D. Long-distance	D1	1	34 - 12	-
	D[2-4]	4	20 - 0	-

Detecting this distraction is important to avoid dangerous situations as well as to study the arrangements and the ways of delivering information in which the IVISs create a higher level of distraction. Warnings and preventive measures, such as early pre-breaking, require a very precise knowledge not only of the driver's state and intentions but also of the vehicle's surroundings state.

On table III the mean time the drivers used looking at the different zones is shown. As can be seen, the time spent at the mirrors and front is clearly different when the drivers are using the hands-free and the GPS. This can be detected to change the way the information is delivered to the driver or the positions and interfaces of the different IVISs can be redesigned to get a gaze focalization more similar to normal conditions and thus, get a safer driving.

TABLE III

MEAN TIME USED BY THE DRIVERS LOOKING AT THE DIFFERENT ZONES

	normal conditions	using the phone	using GPS
FRONT	75%	85%	49%
MIRRORS	4%	1%	1%
SIGNALS	9%	2%	2%
IVISs	3%	6%	38%
COMPUTER	5%	2%	1%
OTHERS	4%	4%	9%

VI. CONCLUSIONS AND FUTURE WORK

In this paper we have proposed a non-intrusive automatic distraction monitoring system and evaluated the effect of IVISs induced distraction in both the driving and driver behaviour. More than 12 different professional drivers have tested the system in a naturalistic truck simulator in 16 different exercises, adding up more than 15 hours of driving.

Drivers reaction times and gaze focalization have being studied to draw conclusions about the detection capacity of the monitoring system and to study drivers reactions to different situations while using IVISs. Results show that IVISs induced distraction significantly increased the risk of crash or near crash incidents. Moreover, inattention patterns while using different IVISs were found, and can be used to warn the driver or change the IVISs location or the way they deliver the information.

Further studies about the optimal location of the different IVISs and the way the information is delivered are being designed by psychologists to reduce the distraction induced by these systems. New tests with these modified IVISs will be performed on the simulator to evaluate the improvements of the new designs.

VII. ACKNOWLEDGEMENTS

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