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OBSTACLE AVOIDANCE IN SIMULATED ENVIRONMENT USING EYE TRACKING TECHNOLOGIES

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ABSTRACT

The paper is investigating the relationship between human eye movements, correlated with the visual perception of computer generated scene on one hand and obstacle avoidance strategies on the other hand, during the process of driving a computer game-like car. Several issues were investigated regarding how the gaze fixation point of the driver is moving during obstacle avoidance maneuvers. The relevance of each issue in making a decision was assessed. The main goal is to establish a correlation (mapping) system between gaze fixation parameters and obstacles avoidance strategies in order to be able to develop cognitive algorithms for driver assistance in real world driving conditions, to monitor driver's vigilance and ultimately to enable progress towards the autonomous vehicle which can avoid possible obstacles or resolve hazardous traffic situations just by monitoring the eye movements of the driver.

1 INTRODUCTION

Visual perception, in generally, is the ability of humans to understand information about its environment from the light reaching the eyes. Chapman and Underwood showed that information obtained visually is responsible for a large proportion of road traffic accidents [4]. Everyday, driving poses the biggest challenge to human cognition. Driving skills and responsive reflex put on the human more cognitive load than virtually any other activity. The response required of the brain while driving is very important, since the driver must respond instantaneously at multiple stimuli.

The speed and accuracy of the gaze detection system is critical for a good data interpretation of eye movements. Humans execute over 100,000 saccades per day. These complex movements are programmed and executed without being conscious of the goal of each saccade. Saccades, drafts and fixations are the three types of eye reactions to extrinsic visual stimuli and intrinsic physiological factors which indicate the changing in subject's attention state and the psychological reasoning process. The most widely accepted setup for optimal accuracy and availability of eye movement measurement is the hardware implemented image processing algorithms systems.

Eye movements are grouped into four categories: (1) the vestibular-ocular reflex - rotates the eyes to compensate for head rotation and translation; (2) optokinesis - stabilizes the

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retinal image caused by large-field motion; (3) smooth-pursuit eye movements - allow arbitrarily sized targets to be stabilized instead of large-field motion; (4) vergence eye movements counter-rotate the eyes to maintain the images of an object at a given depth to be maintained at corresponding locations on the two retinas [14]

During the driving process, the eyes execute continuously movements from the four categories to stabilize retinal images maintaining high acuity in the front of observer and to target different objects or regions to ensure that the image of the desired visual target is projected onto the fovea. The eye tracking devices extends the laboratory to the real world by recording what subjects look at and how their eyes move as they perform a specified task.

Over the previous century, the amount and usefulness of research involving eye movements has exploded. Diverse and important applications of eye-tracking technology are found in computer science, cognitive psychology, and education. However, many of the earlier studies using eye tracking technology were disappointing or even misleading [2].

Several eye-tracking devices types are currently considered state-of-the-art, each of which with a range of adequate applications. One classification divide eye tracking systems in 2 categories: remote and head-mounted [10]. Remote systems restrict subject's movements to a maximum outdistance, making them suitable for applications with relatively stationery positioning of the subject relatively to the tracking device, while head-mounted systems eliminate this restriction making them appropriate for a wide range of applications.

Developing algorithms for driver assistance in real world driving conditions, to monitor driver's vigilance and ultimately to enable progress towards the autonomous vehicle is also subject of numerous ongoing research projects. The main idea is to develop systems able to capture and detect in real time the driver intentions and generate decisions in order to increase the reactivity of the vehicle during the various maneuvers within the more than ever challenging nowadays traffic. In this context, capturing the eye movements and combining this information with other parameters during the car driving could be a rich source of input data for an autonomous driving system. In this paper we aim to establish a correlation (mapping) system between gaze fixation parameters and obstacles avoidance strategies in order to facilitate autonomous decisions for the avoidance of possible obstacles or resolve hazardous traffic situations just by monitoring the eye movements of the driver.

The general question that the present research tries to answer is the nature of relationship between patterns of fixations and the associated human actions.

During a driving process the central nervous system of the driver is constantly sending commands to the arm and hand muscles to maintain the car in safe conditions and steer the driving wheel toward a desired path, based on the visual information. In order to identify possible correlations between the eye movements and driving decisions, we conducted a series of simple experiments for the case of a user driving a computer game-like car performing obstacle avoidance maneuvers. Two types of obstacles have been considered (front and side obstacles) at various distances from the car. The user driving the game car was wearing an eye tracking system that allowed various parameters to be measured and analyzed. The results are then further discussed in the last section of this paper.

2 RELATED RESEARCH

From analysis of recorded eye movement and from experiments where gaze is monitored in a simulated driving environment one can understand the nature of the driving task and also can improve driver training methods. Several such experiments have been already conducted. Hayhoe et al. (2002) found that fixation patterns and attention control in normal vision is learnt [9], so visibility of task relevant information depends critically on active search initiated by the observer according to an internally generated schedule. Liang and Lee (2008) [12] indicate that changes in drivers' eye movements and driving performance over time are important predictors of cognitive distraction. A good hazardous situation detection system based on eye monitoring would need to both accurately detect driver cognitive distraction and minimize the false alarm rate.

Without special eye-tracking device, driver alertness can be monitored with a camera placed on the car dashboard [16]. In this approach, using just image processing technique, the gaze can be computed. Since the locations of the eyes and the back of head of the driver are used, the gaze direction is only an approximation.

Underwood et al. (2003) identified differences in the scan paths between novice and experienced drivers. These drivers were evaluated using different scanpaths: single fixations, two-fixation transitions and three-fixation sequences [17]

Several components jointly define the decision problem: knowledge of the state of the world (including the position and velocity of the car) and knowledge of the objective, in the presented case the obstacles. The ability to perceive and recognize potential hazards before they become actual depends on the past experience in similar situations. It appears [3] that drivers become better in the ability to detect hazards as their experience grows. Research has shown that novices are slower in detecting hazards, and they often recognize smaller numbers of hazards than experienced drivers.

Chapman and Underwood investigated the drivers' fixation patterns on straight roads [4]. They found that gaze fixation is concentrating near a point in the visual field in front of the driver where objects appear stationary, with occasional excursions to items of road furniture and road edge. Dishart et al. (1998) [7] showed that experienced drivers obtain visual information from two sections of their view of the road ahead, in order to maintain a correct position in lane whilst steering their vehicle around a curve.

The sensory inputs of the driver are plagued by noise which means that one will always have uncertainty about the car's true location. The decision the user is taking is not happening at one point of time, but is a continuous output. Nevertheless, no correlation between the eye movement and user decisions is presented.

3 THE EXPERIMENTAL SETUP

The driver's visual behaviors include eyelid movement, face orientation, and gaze movement (pupil movement). For the application developed in this experiment the ASL Eye Track 6 eye tracking system [1] was used for the real-time monitoring of eye movements. This device is a trackable head-mounted system being thus appropriate for use within desktop or immersive systems in which the user is expected to move. This system calculates gaze position through bright pupil (BP) – corneal reflection (CR) vector detection algorithms, a method that uses pupil position from the light reflecting on the surface of the corneal layer from the back of the ocular globe and the reflection of a light source on the surface of the cornea to determine eye's direction. Because head movement is allowed, the tracking is done with a state-of-the-art head tracking system (Flock of Bird magnetic tracker), to obtain the user's head position and orientation (fig. 1).

The primary goal is to estimate the variables that are relevant for making a decision and secondly to capture and analyze which parts of the scene the user is observing.

Since the contents of the virtual environment are known to the system (the parameters of the track, the obstacles position and its in-scene relationships), no further measurements are necessary compared to a real-world scenario when the gaze evaluation has to be correlated with the recorded video stream of the environment.

The generated environment is guiding the attention to stimuli with relevant content of information (obstacle, presented in the form of other cars on the road, road edge, and the middle line on the road which is also shown for additional guidance).

4 FIRST APPLICATIONS

The application developed is an experimental setup used to investigate how the drivers are avoiding obstacles in a game-like car simulator. It is a C++ server application which establishes the communication with the ASL Eye Track 6 eye tracking system and the Flock of Birds magnetic tracker (fig. 1), and generates a virtual scene, a straight-forward road with several obstacles in form of other cars placed in random positions on each side of the road's middle line. The virtual scene is generated using the OpenGL graphic library. Communication with the eye tracking system is made using the Microsoft COM Technology. The application runs on a DELL Precision 690 Graphic Workstation with an average number of frames of 17 fps. The eye tracking system provides optional data flow speeds and for our application we have chosen the speed of 120 Hz (the lowest frequency available), which is more than sufficient for our particular experiment. The Flock of Birds system gives the orientation of head with respect to an

Figure 1. The experimental setup

initial reference fixed position, in which the subject performs the eye tracking system calibration procedure.

The subject view point position is located inside a virtual moving car model (fig. 2), behind the steering wheel. He is instructed to cover the road distance going on the easiest path around the obstacles, considering the distance from the obstacle

Figure 2. The view from the driver

to road's edge. As the subject goes forward and scans the scene gazing at the obstacles in the near proximity, the eye tracking system detects the gaze point position with respect to the subject's head, which is afterwards transformed with Euler's relations into the virtual scene coordinate system, while all the interest information is stored in a data file for offline analysis. The data file contains information about car coordinates, car speed, car steering angle, distance to obstacles, gaze direction, obstacles that are being focused by the driver. This set of data makes possible an interpretation of driver's attention

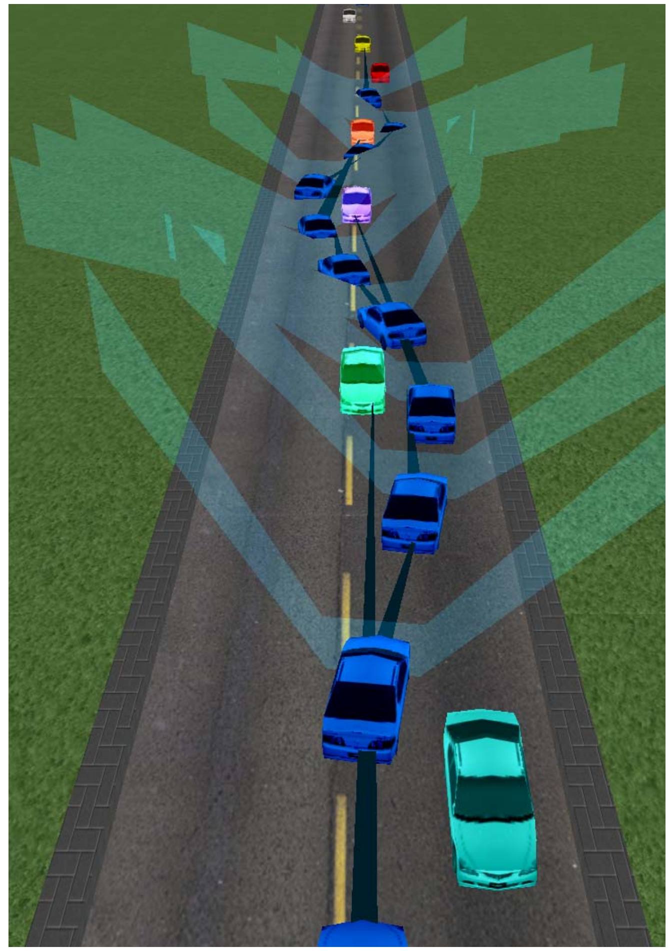


Figure 3. Time-offset positions of the car

distribution during motion.

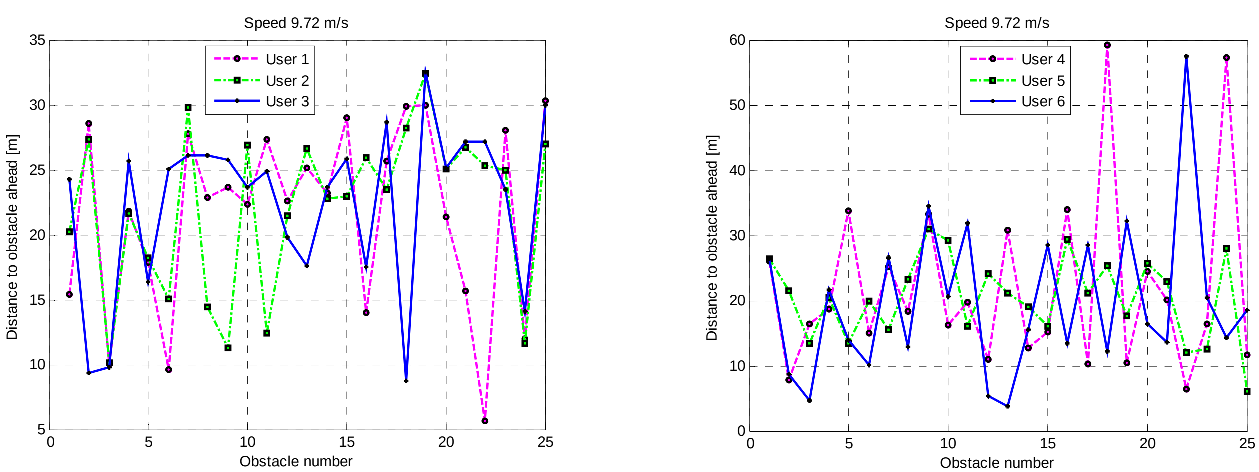


Figure 4. Distance to obstacle ahead, when last time was focused (low speed)

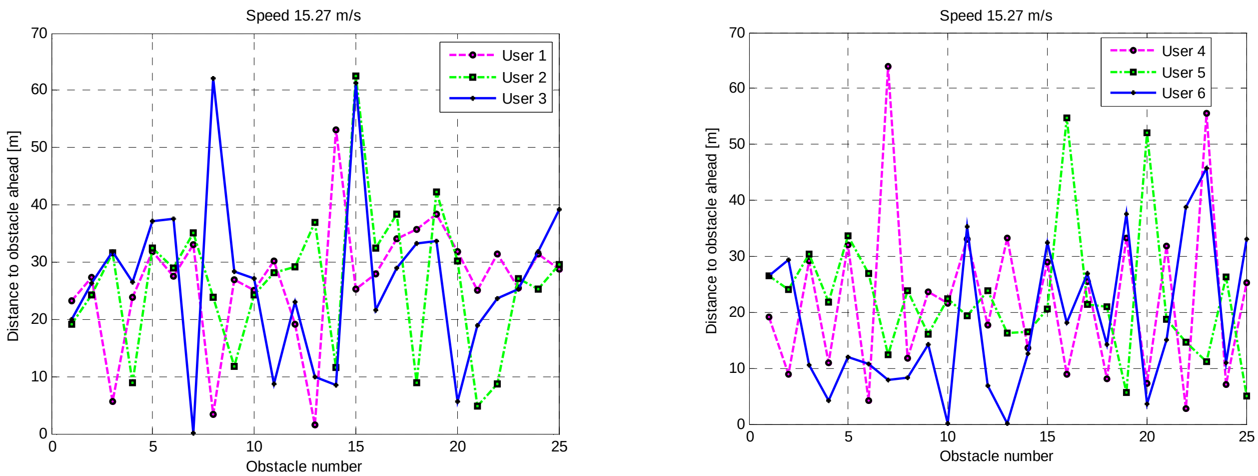


Figure 5. Distance to obstacle ahead, when last time was focused (high speed)

A number of experiments have been conducted on six driving male subjects with different experience levels (but not very experienced simulator player) going on the same route with

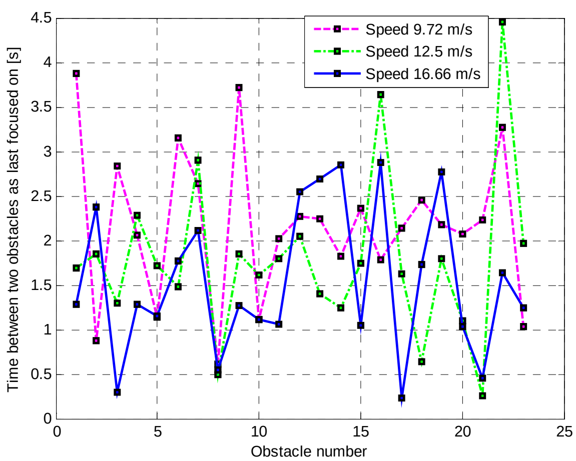


Figure 6. Travel time between obstacles (experienced user)

different speeds, after participating on a 15 minutes session of training with this virtual model. Three of them (license owners) can be considered experienced drivers, (users 1, 2 and 3) and the other three (user 4, 5 and 6) less experienced.

The blue cars in figure 3 are the representations of driver's running car, showed in different moments, along with driver's corresponding gaze orientation, all in a replay session of one driver evolution during one of the conducted tests.

In the implemented scenario we have adopted the idea of adjusting the maximum speed in each experiment, so that all users will drive their car with the same speed approximately, no matter if they are considering reducing it.

This measure was taken in order to prevent prudent subjects from going slower than the less prudent ones, so they will have

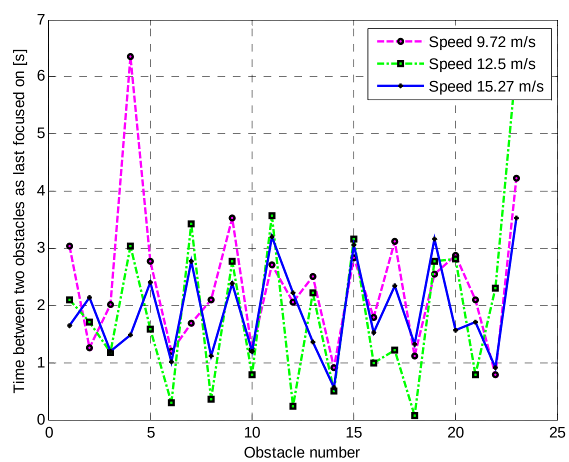


Figure 7. Travel time between obstacles (inexperienced user)

the same amount of time to focus on each car. We asked each of the six participating drivers to repeat the experiment four times, but we did not mention them that the car speed will be adjusted around four different speeds each time they will start a new track:

v_1 = 9.72 m/s (35km/h),
v_2 = 12.5 m/s (45km/h),
v_3 = 15.27 m/s (55km/h),
v_4 = 16.66 m/s (60 km/h).

The track was straight; the obstacles were presented in front at distances around 25±0...2m from the driver’s car and on sides at distances of ±0…3m from the road’s middle line, all in a randomly chosen manner. 25 such obstacle had to be avoided.

The first three speeds presented no problem for the user to go along the track without hitting any obstacle, but the last speed imposed by the computer program, rather than chosen by the subjects, was too difficult and several collisions appeared, so this case was not completely included in this study.

5 DISCUTIONS OF RESULTS

Although there is no need to focus on an obstacle in order to avoid it (concentrating on it does not involve necessarily to be in the centre of the gaze direction), in this application only cases when the users are fixing their gaze point were considered and evaluated. The position of the obstacles (other cars ahead) was known from the computer generated scene, the gaze direction was measured, correlated with the head movement, and the obstacles on which the users are focusing on were found in each frame of the simulation. Because the drivers were not able to reasonably approximate the location of cars further than three obstacles ahead, the gaze evaluation of the users involved in the experiments regarding on focusing on a specific car were limited to this number (although sometimes it was possible to see in the scene obstacles further than three cars ahead this is not influencing the decision of the driver in avoiding the next obstacle).

To evaluate the sequences of fixations corresponding to the position of obstacles we divided the entire recording to the number of obstacles and then evaluated the driver's decision starting from the position in front of one obstacle and ending near the next one. This approach limits the evaluation of the user's fixations sequence in avoiding one particular obstacle (from the moment of observation till it is completely passed by), but an obstacle can be considered as avoided if the user is not focusing anymore on it, so we have adopted the solution of dividing the entire recording at those moments in time when he is focusing on the obstacles for the last time (FLT – Focusing Last Time). In this way we have considered this moment when he is confident that the following obstacle ahead will be avoided and there is no need for checking its position again.

In figures 4 and 5 the distance between the driver's car and the next obstacle is shown, measured at the moment of the last time driver focus on it.

On these plots the values of distances below 25 (which is the average distance between obstacles), means that the user keeps on focusing on the nearest obstacle encountered until it is almost outrun and indicates that some additional measures to avoid it must be taken. The reason why he must concentrate longer on it is the obstacle that is somewhere near the path he must follow. Values above 25 indicate that the driver must not gather very precise information about the position of the nearest obstacle, meaning that the route to be followed is more distant from that obstacle. As it can be seen in figure 4 the number of distances closer to zero is bigger in the case of the highest speed plot. The conclusion is that for the driver it is important to gather more information about the next obstacle to be avoided when the speed is higher. When going faster around obstacles the time for executing the elusion is shorter so there will be more situations when the driver is not able to successfully execute the maneuvers, and possible collision with obstacles could occur. The distance to the nearest obstacle is thus a parameter the driver takes with priority into consideration when running with high speeds.

In table 1 the mean values and the standard deviations for the three different speeds considered are presented. It can be seen that the standard deviation is growing with the speed, because the drivers had to check several times their correct position. As the speed is going up this distance should not grow significantly, because the driver has less time to decide his action. If an inexperienced driver is affording too long time for one obstacle ahead, then the next one is hard to avoid so the experiment showed that several times he just ignored it. This is why the mean values are even smaller from these drivers, compared with the experienced ones.

This is an important parameter of the user's behavior evaluation, showing that the speed of the car is very important when the user has to make a decision: if he is satisfied with the current position, direction and velocity of the car, then he will focus his attention on obstacles lying further on the road.

Another measured parameter was the time necessary for the user to travel between two FLT points of consecutive obstacles.

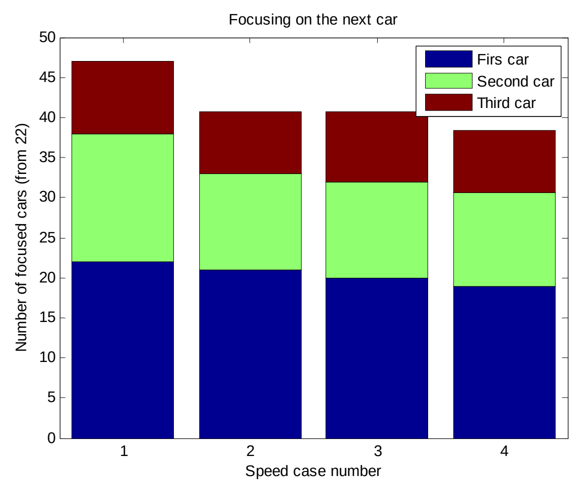
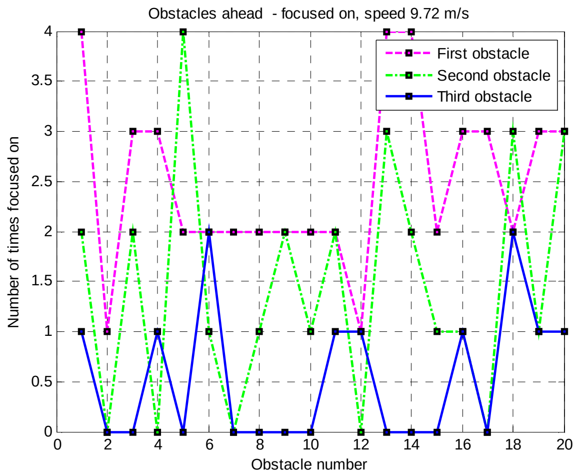


Figure 8. Number of focusing cases on cars ahead

Because the speed was almost the same in each case for the three users and the obstacles are also positioned at almost equal distance, the time between focusing the last time on two consecutive obstacles can be considered proportional with the distance between two consecutive FLT. In figure 6 and 7 such a plot for two of the users is shown. It can be seen that the time is shorter as the speed is increasing for experienced drive, but at high speed, when it is not easy to make a decision, this value can sometimes increase significantly. In case of the inexperienced driver, even when the driving speed is



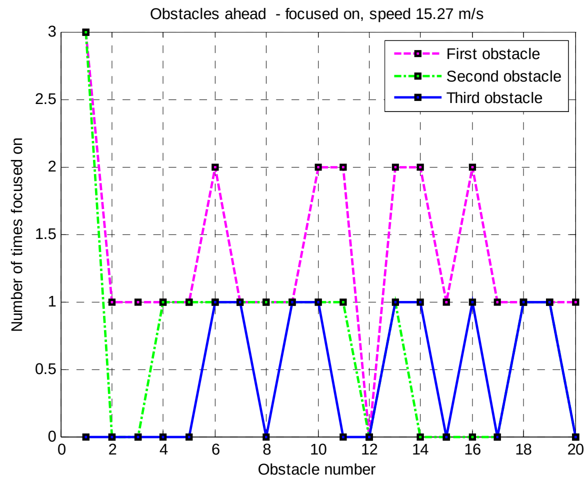


Figure 9. Obstacles ahead, when last time was focused (experienced driver)

involuntary increased by the computer, he is trying to slow down by making big turn around the obstacle; this is way the travel time between two FLT points is not getting smaller.

Table 1. Distance to next car

User	v_1 = 9.72 m/s		v_2 = 12.5 m/s		v_3 = 15.27 m/s	
	Mean value [m]	Standard deviation [m]	Mean value [m]	Standard deviation [m]	Mean value [m]	Standard deviation [m]
User 1	21.58	7.18	22.35	8.38	26.7	10.87
User 2	22.07	6.29	27.84	10.9	26.24	12.77
User 3	22.31	6.48	22.68	7.74	26.82	14.77
User 4	22.01	13.54	20.49	14.75	20.87	17.97
User 5	22.83	12.16	15.59	32.4	22.59	11.52
User 6	19.69	11.85	13.58	36.00	18.16	24.32

The driver showed alternating fixations between near and far obstacles on the road ahead. In figure 8 the average number of fixation on the obstacles ahead is shown, counted between two consecutive FLT. Only 22 out of the 25 obstacles were considered, the first and the last two were not included in the evaluation.

It can be seen that users are focusing at least once on the next obstacles ahead when they are driving in safe condition (reduced speed), but as the speed is going up more and more the next obstacles ahead are increasingly omitted. When the speed is reduced the driver has enough time to check the position of the second obstacle also, or even the third, but this is also reduced at high speed.

Table 2. Time focusing on the first obstacles

User	v_1 = 9.72 m/s		v_2 = 12.5 m/s		v_3 = 15.27 m/s	
	Mean value [s]	Standard deviation [s]	Mean value [s]	Standard deviation [s]	Mean value [s]	Standard deviation [s]
User 1	0.85	0.4	0.51	0.42	0.35	0.36
User 2	0.81	0.42	0.8	1.67	0.31	0.41
User 3	0.81	0.53	0.45	0.23	0.37	14.77
User 4	1.24	2.41	0.67	1.63	0.41	0.42
User 5	1.21	2.01	0.83	1.8	0.78	1.83
User 6	0.79	1.12	0.98	1.47	0.65	1.29

Differences in sequences of fixations were found when the users are driving the car at different speeds. In figure 9 and 10 the sequences of fixations at the lowest speed and highest safe speed are shown for one experienced (user 1) and one inexperienced drivers (user 4). These figures show how many times the users are focusing on the obstacles ahead between two FLT points. It can be seen that at low speeds the gaze point is coming back on the first obstacle ahead at least 2-3 times, but at high speeds the obstacle is checked only once or twice. The same case is for the second obstacle when the average is going from 2 to 1. No significant change can be seen at the third obstacle.

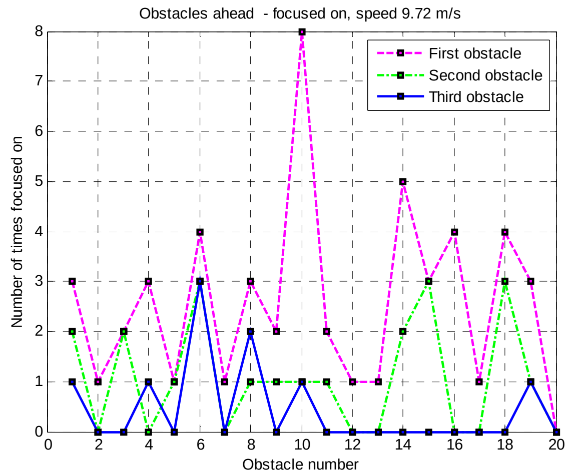


Figure 10. Obstacles ahead, when last time was focused (inexperienced driver)

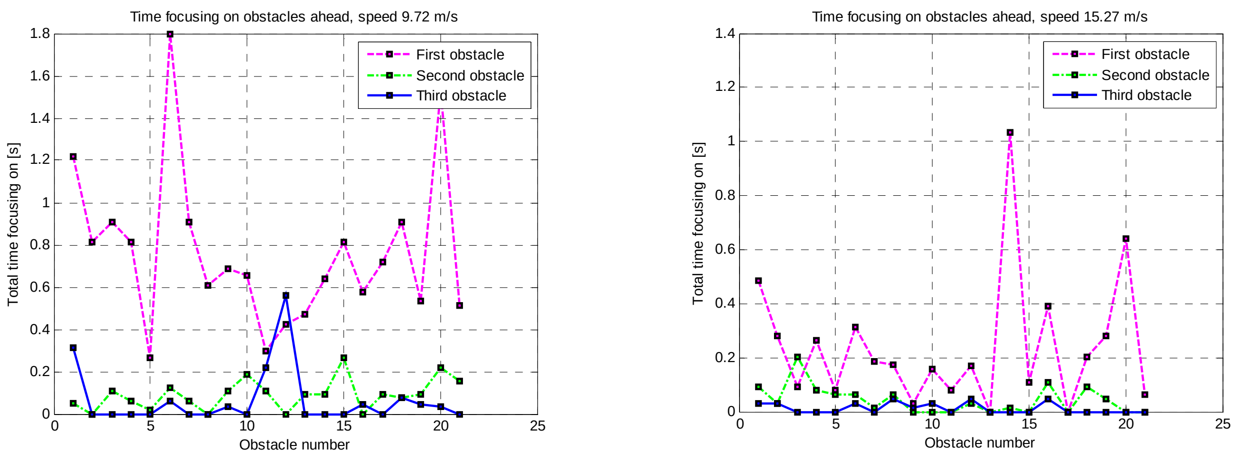
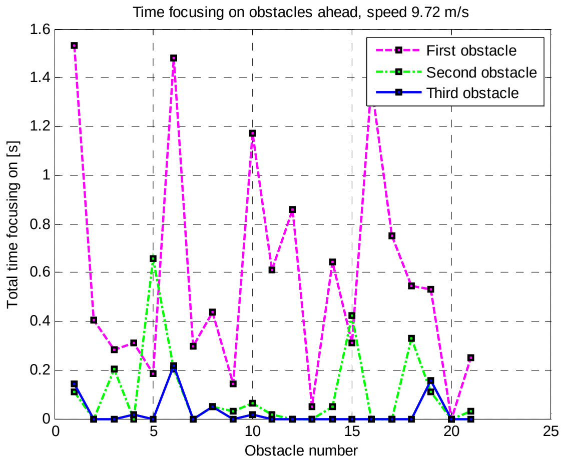


Figure 11. Time spent focusing on obstacles (experienced driver)

In real-life situation the position of an obstacle is not known, but the eye fixation pattern can give a clue about the location of an obstacles. In figures 11 and 12 the total time spent focusing on each obstacles is presented for the two types of users involved (experienced and inexperienced). The mean value and the standard deviation of the time the drivers are focusing on the first and the second obstacle ahead are presented in table 2 and 3. At the lowest speed the users are spending an average of 0.9s on each obstacle, but as speed increases this time is shorter and shorter. Once known that an obstacle is ahead, the location of the obstacle can be computed from the current velocity of the car and the eye fixation direction (in the 2D environment at least the direction on which the obstacle is laying).

Table 3. Time focusing on the second obstacles

User	v_1 = 9.72 m/s		v_2 = 12.5 m/s		v_3 = 15.27 m/s	
	Mean value [s]	Standard deviation [s]	Mean value [s]	Standard deviation [s]	Mean value [s]	Standard deviation [s]
User 1	0.07	0.07	0.07	0.07	0.04	0.05
User 2	0.08	0.07	0.036	0.05	0.041	0.05
User 3	0.11	0.11	0.034	0.042	0.0419	0.0726
User 4	0.06	0.102	0.07	0.108	0.03	0.037
User 5	0.057	0.094	0.119	0.31	0.076	0.117
User 6	0.11	0.169	0.135	0.36	0.079	0.21



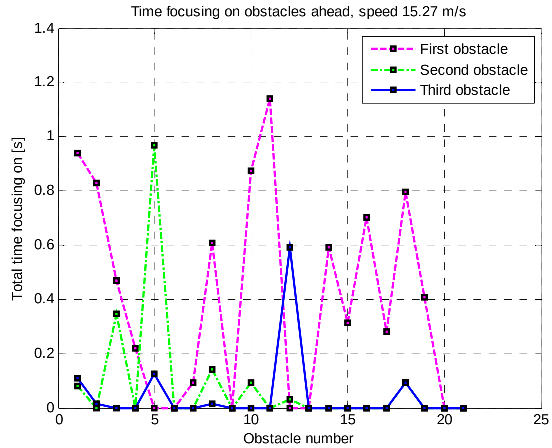


Figure 12. Time spent focusing on obstacles (inexperienced driver)

6 CONCLUSIONS AND FUTURE WORK

This paper presented the first results in the investigation of the correlation between eye fixation parameters on obstacles avoidance strategies. The main issue investigated was the influence of the speed and the distance to the next obstacle which is to be avoided. A user study was conducted and the recorded eye movement was analyzed correlated with the in-scene position of the car. The recorded maneuver of the driver was divided between frames in which the gaze wss fixed for the last time on the obstacle in front.

As a primary conclusion, it can be noted that the speed of the car plays a crucial role in the driver decision making process. Various strategies are used at various speeds for the same obstacle situations. In case of driving the car at a speed considered safe for the users, the possible location of the obstacle ahead can be computed from the fixation pattern.

Another expected conclusion is that as the speed increases the users afford fewer fixations on various visual targets, the cognitive load for the decision is higher and therefore the users tend to reduce speed according to the frequency of the obstacles to be treated.

The driving experiments have been conducted on a desktop computer system provided with only a conventional 2D display, while the scenes are rather simple involving only one type of entities i.e. obstacles. Nevertheless, our first experiments showed promising results in terms of reliability of the method, although, further refinements are needed to improve the precision, because the decision the user is making is a continuous output. The users' actions were recorded, so it is expected that good correlation can be found between user action and eye fixation to avoid dangerous situation in real life.

An important question is how the 3D visual perception, in particular perception of the depth within the computer generated environments influence the system precision. Therefore in the next step the computer simulated environment will be deployed in fully immersive stereoscopic virtual environment (a three-sided, back-projection, CAVE-like immersive system), so the user will perceive the scene in 3D and will be able to estimate the distance to the next obstacle correlated with the current speed of the car. At the same time, more complex scenes will be considered, with various types of obstacles (other cars, pedestrians, trees etc) in order to study various types of avoidance strategies as well as the user reactions in various types of driving situations and traffic events.

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