Toward Next Generation of Driver Assistance Systems: A Multimodal Sensor-Based Platform

Mahdi Rezaei
Department of Computer Engineering
Qazvin Islamic Azad University
Qazvin, Iran
rezaei@qiau.ac.ir

Mohammadreza Sarshar
Department of Computer Engineering
Islamic Azad University, SR Branch
Tehran, Iran
sarshar@kiau.ac.ir

M. Mehdi Sanaatiyan
Faculty of Computer
Mazandaran Inst. of Technology
Babol, Iran
m.sanaatiyan@mit.ac.ir

***Abstract*—Achieving secure vehicles equipped with accident prevention systems is one of the greatest passions of researchers in automotive laboratories. This article provides a detail description on the state of the art techniques for road situation monitoring and driver's behavior analysis (human factors). The focus would be to gain a practical multifaceted approach in order to simultaneous analysis of driver's distraction, and potential road hazards to make an emergency intervention in case of dangerous driving situations. In this regard, a diversity of information via Iris/Pupil status monitoring and EEG spectrum has been gathered and then fused with out-vehicle sensors such as RADAR, LIDAR, Ultrasonic and Vision. In order to cope with computational complexities due to multiple sensors, a heuristic method of multi sensory data fusion and fuzzy solutions has been developed. All discussions are based on real sensors. The method could be applied on various driver assistance systems such as cruise control, overtaking and lane keeping systems.**

Keywords- Advanced Driver Assistance Systems; Intelligent Transportation Systems; Human Factors; Iris/Pupil Monitoring; RADAR; LASER; EEG Spectrom; Sensor Fusion

I. INTRODUCTION

Regarded though have several companies offered modern cars equipped with safety systems e.g. automatic cruise control, car parking sensor, airbag, night vision and improved breaking systems, there are still some dominant concerns that threats the life of car passengers.

Recent researches by NHTSA (National Highway Traffic Safety Administration) show that 16,626 people are died in US traffic crashes, just in the first half of 2009! [4]. Another research by FARS (Fatality Analysis Reporting System) shows that although "*injury*" and "*property damages only*" decreased during 2004-2008, the fatal rate due to distraction has a continues increasing trend from about 10% in 2004 to more than 16% by the year 2008 (Figure 1). These prove that today's driver are becoming more distracted, may be due to variety of social, economical and behavioral disorders.

In addition, speeding is another contributing factor in 31 percent of all fatal crashes; In 2000 and just in USA, the cost of speeding-related crashes was estimated to be $40.4 billion — $76,865 per minute or $1,281 per second.

Considering above mentioned statistics, 47% of all fatal crashes are because of *"distraction"* or "*speeding*".

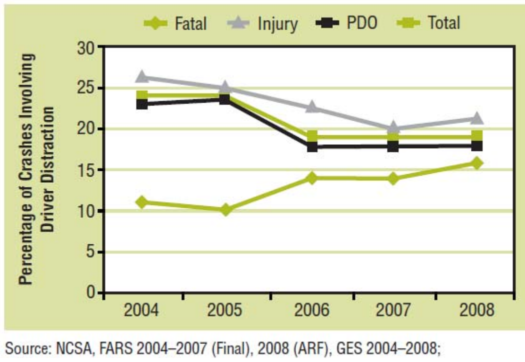


Figure 1. Crashes involving driver distraction by crash severity

The remained 53% is due to un-standardized road, wrong driver's decision, weather condition, limited view and failures in steering or electromechanical system. These signal one important point: The driver assistance systems are still in infancy. We have lot to do to gain some Advanced Driver Assistance Systems (ADAS) that emphasize on driver's vigilance and speed control.

II. RELATED WORKS

Although the initial developments in the field of Driver Assistance Systems intended to increase the drivers' comfort, starting with park assisting systems and cruise control, Recent Research for ADAS is being aimed to increasing the level of the safety for both driver and pedestrians [1]. Among research in the field, a very few of them considered synchronous assess of road situation and driver's vigilance. Here, first we introduce different aspects of driver assisting system and the studies done for driver's distraction analysis and out vehicle monitoring. Then, we present a new assessment techniques, has not been introduced yet. In addition, we try to develop a robust technique of multi sensor data fusion to evolve a multimodal-pervasive ADAS.

978-1-4244-5586-7/10/$26.00

A. Driver's Vigilance Detection

M.H. Sigari has provided a hypo-vigilance detection system based on eyelid behavior and eye-region processing [8]. He used a combination method to measure eye-lid distance and eye closure rate. This method suffers from a high degree of computational complexity and need to be improved.

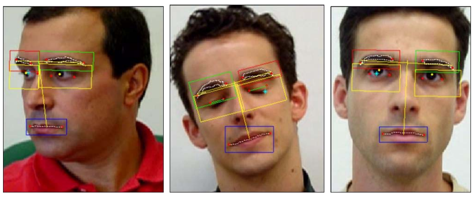


Figure 2. Eye gesture detection to detect normal and distracted driver [9]

J. Batista offers a solution to track eyelid and head movement [9]. The method tries to detect the most important facial feature areas including mouth, eyes and eyebrows. Performing statistical approaches to detect mouth and eye closure has reduced the computational time; however, the focus is to detect elliptical face modeling and fully closed eyes. That is, semi closed eye detection and lapse detection are omitted (Figure 2).

M. Miyaji et al provided a means to detect eye and head movement [10]. These movements were tracked via standard deviation and categorized features for pattern recognition; however, this method is applied in a simulation and the results for real world are not available.

Doshi and Trivedi [11] worked on contextual information via study on head and gaze data dynamics. They tried to use driver behavioral cues to manifest some useful information to predict ongoing events. The method is nicely evaluated; however, it is still far more to be implemented practically.

B. Out- Vehicle Monitoring

In a typical scenario, a vehicle faces a various driving conditions such as driving straight, turning, overtaking and meeting pedestrians. So, the ADAS need to be equipped with different sensors depend on current driving condition.

R. Danescu and S. Vedevschi [12] offered a probabilistic lane tracking system using a stereo vision and gray scale image processing system. Using particle filtering framework, their method seem robust; however various weather condition and pure illuminations may cause some limited views so limited accuracy.

W. S. Wijesoma et al. [14] Tried to detect road curbs using LADAR in comparison to millimeter wave radar. They applied extended Kalman filtering to speed up tracking curbs tracking. The method is fast enough and does not suffer of video limitation; but their method needs at least 25 mm height curb and it is not so accurate for unusual roads.

Wen Wu et al., proposed a detection method for text and road signs [15]; they are integrated 2D image features with 3D geometric structures extracted from video sequences. The detection rate is 88.9% with a 9.2% false hit rate; that it, 81.6% in overall which is not good enough for real-world applications.

III. Methodology

All above evaluations have their own benefits. Anyway, here we try to complement other's labors by developing a novel hybrid method. The main feature of proposed research is focus on providing a hybrid steering and assistance system that could be divided in three sub systems. Firstly, to detect driver's level of alertness by face monitoring and human factor recognitions. Secondly, to understand the environment immediately around the vehicle, via some forms of sensors (e.g. Laser, Vision, etc.) and data fusion techniques; and thirdly to design an appropriate decision making system to steer the vehicle in dangerous traffic conditions (Figure 3).

A. Driver's Consciousness Analysis

Considering advantages and drawbacks of current state-of-the-art sensors available on the market plus recent clinical researches in field of human factors, here we describe the first part of our methodology divided in two sub-sections: face monitoring and EEG signal measurement.

1) Face Monitoring

Although many aspects of face monitoring have been regarded through stereo visions, there are still some major uncertainties that cannot be covered just by video. Since alertness is a complex phenomenon, a multimodal approach needs to be used. In our approach, a new technique of fusion for eye gaze monitoring and EEG power spectrums as a real time human factor would help us to cope with the mentioned limitations as well as remedying must of uncertainties [2].

Studying Eye Anatomy (Figure 4) and using current methods of image processing, eye closure rate, pupil status and vertical/horizontal size of iris are assessable as a reliable measures to determine driver's level of vigilance.

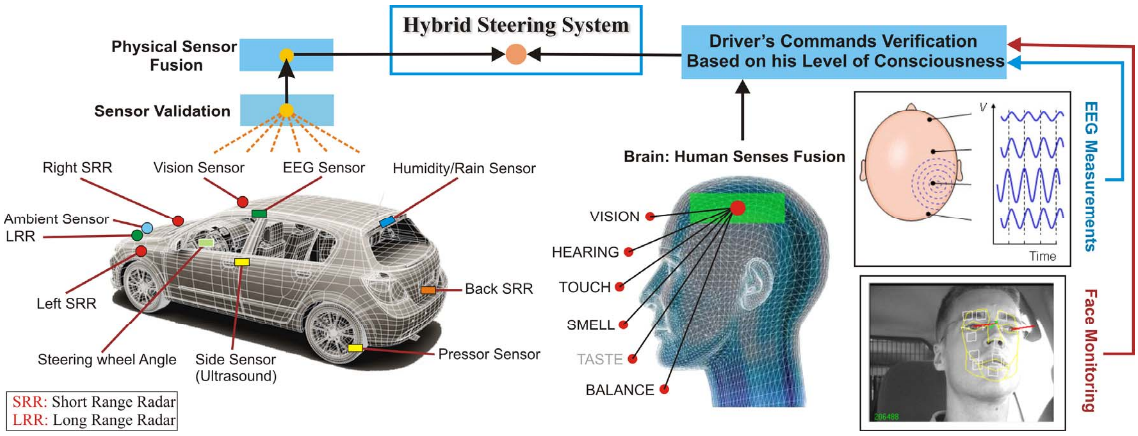


Figure 3. Multimodal Driver Assistance System based on "Physical Sensor Fusion", "Human Senses Fusion" and "Driver's Cconsciousness Monitoring"

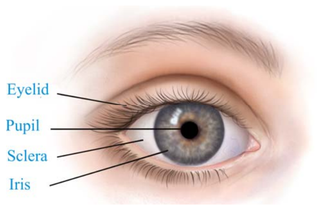


Figure 4. Eye Anatomy

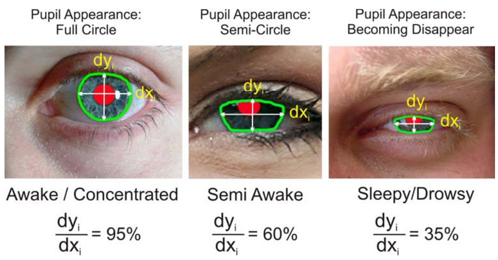


Figure 5. Iris-Pupil Based Distraction Evaluation

If the mean rate for eyelid closure has a decreasing trend so the driver's status is changing to a sleepy status; similarly, if the roundness of Iris is becoming smaller or is changing to a semicircle with a large gap between dx_i and dy_i size, we can say the driver is falling asleep (Figure 5).

According to clinical studies and as can be seen in figure 5, when the driver is fully aware so the horizontal and vertical diameter of Iris is almost equal ($dx_i \approx dy_i$); In addition, the pupil is fully visible and looks like a full circle. In contrast, when the driver becomes sleepy the vertical size of Iris becomes smaller ($dx_i / dy_i < 0.7$) and the pupil looks a semi circle and sometimes becomes disappear. Such a fashion could be applied on other face elements to detect more detail on driver's behavior (Observant, sleepy, drowsy, aggressive, using cell phone, etc.). Measuring these factors could be considered as a "Fundamental" but "Not firm" measure for driver's vigilance analysis. Therefore, below the other complementary method is discussed.

2) Electroencephalogram (EEG) Measurement

Actually, the EEG pulses, bioelectric impressed current density associated with neuronal activation, produce an electric field which can be measured on the surface of the driver's head or directly on his brain tissue. From the EEG signal it is possible to differentiate alpha (α), beta (β), delta (δ), and theta (θ) waves as well as spikes associated with epilepsy. The EEG signal is closely related to the level of consciousness of the driver and as the activity increases, the EEG shifts to higher dominating frequency and lower amplitude [5]. As depicted in figure 6, the alpha, beta, delta and theta waves have the frequency spectrum range of 8-13Hz, 13- 30Hz, 0.4-4Hz and 4-8Hz, respectively. α signals can be measured from the occipital region in an awake person when his/her eyes are shut, βs are detectable over the parietal and frontal lobes, δ signals are measureable in infants and sleeping adults and the theta waves could be obtained from children and sleeping adults. Typically the resting voltage is around -70 mV, and the peak of the action potential is positive and about 100 mV.

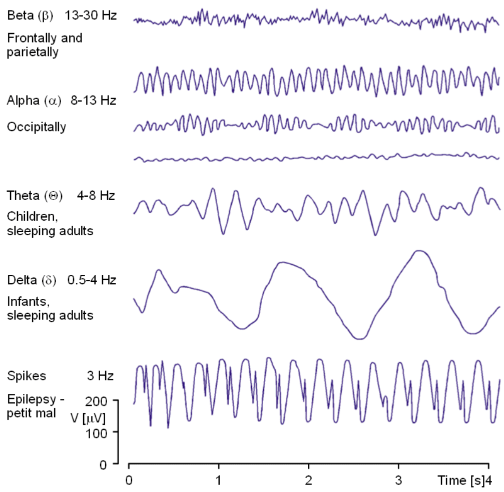


Figure 6. Some samples of EEG signals - image source [6].

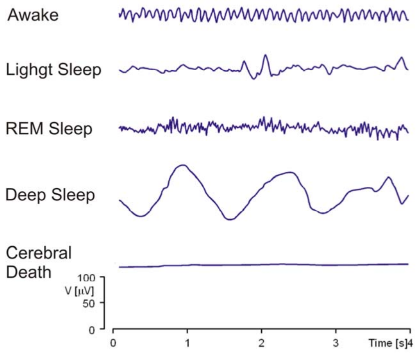


Figure 7. EEG frequency/amplitude, according to level of Consciousness[6].

B. Vehicle Soround Monitoring

As the second part of our methodology, we are going to formulate and simulate the selection of object-detecting sensors. With respect to various driving situations, the sensors should be capable of evaluating *Driver commands* (steer angle, backing, lane changing, turning and overtaking a vehicle), *Relative Vehicle's Velocity* and *Traffic Flow* (low or dense). The combination of these parameters will be used to reflect a proper diving situation encountered by the driver. So we need an optimal sensor selection to monitor all these three factors [13]. But, which sensors are better and optimal? "*IMAGE SENSORS"* have some drawbacks, such as low ability of sensing depth and advantage of higher ability of discrimination than LIDAR and RADAR. Besides, the data may be corrupted by noise and distortions. Such corruptions come from variations such as weather, shading, lighting, magnetic fields and electrical noise, movements, bad calibrations, motion blur and compression artifacts after image capture. Given these daunting challenges, we need to utilize some complementary sensors to obtain additional contextual knowledge to cope with limitations imposed on visual sensors. *"RADAR"* shows limited lateral spatial information because it is not available at all, the field of view is narrow, or the resolution is reduced at large distances. *"LIDAR"* has a wider view field that solves part of the previous problems; however, there are other problems such as low ability of discrimination, clustering error, and recognition latency. Therefore, prior to sensor fusion, decision on selecting a proper set of object-detecting sensors should be made based on the capability of available sensors and real-time driving condition [17].

C. Hybrid Steering System (HSS) and Contextual Knowledge Fusion

In HSS, the third part of our methodology, the driver's commands as the output of driver's *natural senses fusion* are compared with raw data from out-vehicle *physical sensor fusion*. Besides, driver vigilance is considered as an importance factor for the next step decision. As an example, if the driver forces the pedal to increase the speed of vehicle (according to his brain decision), the HSS checks the driver's command with auxiliary mounted sensors data in order to have a safe action. It means, if the sensors report a dense traffic or the in-vehicle sensors report the driver *"distracted"*, so the HSS will intervene actuators and the output commands might be something different to the initial driver's command. All these should be done through a fusion methodology. In order to reduce CPU usage and relevant complexities, we strongly recommend doing what a human does- fuzzy fusion method. In this method everything interpreted as some linguistic membership functions plus some basic arithmetic-logical concepts. Below are two sample conceptual membership functions:

IF the driver command is "overtaking" AND
The driver is "fully aware" AND
The distance to the front vehicle is "safe" THEN
Keep left and speed up

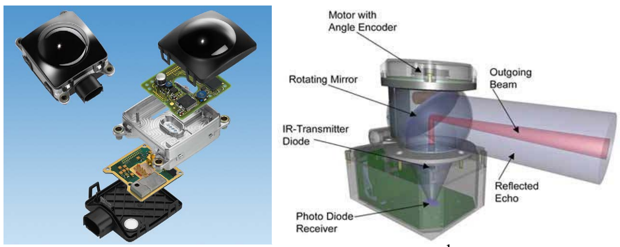
IF the distance is "low" AND
The driver is "semi aware" AND
The speed is "increasing" THEN
Perform Emergency Breaking and turn right

IV. RELEVANT SENSORS

In this section we introduce some current on the market sensors used in this article.

Steer Angle Sensor: Figure 8 shows a Steering Wheel Angle sensor by BOSCH GmbH. This sensor is developed as vehicle dynamic sensor, measures the current actual angle and its rotation. Thanks to integrated calibration system and a special self-diagnosis function, this steering wheel-angle sensor would be highly suitable for safe driving applications.

Figure 8. Steering Wheel Angle Sensor



a b

Figure 9. a) Bosch 2nd Generation Long Range Radar Sensor. b) ALASCA XT, the last Laser scanner from IBEO Automobile Sensor GmbH

LASER and RADAR: These Sensors are ideal to measure distance from any moving and static object around the vehicle. The RADAR sensors (Fig. 9.a) are available in two types according to its frequency (long and short range radar). Laser scanner has a wider viewing angle (Fig. 9.b).

But, they are highly degraded by weather conditions such as dirt, snow or mud on the back of the target vehicle.

RADAR main technical characteristics:

- Frequency: 76-77 GHz
- Range: 1-150 m
- Search Area: 12°
- Speed measurement precision: < 0.2 km/h
- Angular Precision: < 0.3°

LASER main technical characteristics:

- Broad range and wide viewing angle
- Scan Frequency: 12.5 Hz or 25 Hz
- Horizontal Viewing angle: up to 240° field of view
- Effective Distance range: up to 40 m
- Standard deviation distance: +/- 5 cm
- Eye-safe laser (laser class 1)

V. FINAL FRAMEWOR

Integrating all provided elements, the final desired framework take a forms; the whole system will either assists the driver in vehicle operations (driver assistance) or intervene the control of vehicle (automation), according to degree of driver's vigilance [16]. Such a system will enable the driver-vehicle system to operate more effectively and more safely. In this framework, onboard sensors such as EEG spectrum, facial video, short and long range radar, laser, camera, infrared and vehicle dynamic sensors provide real-time information about driver, traffic environment, and vehicle [7]. Such a multi-modal multi-sensor approach imposes challenges for online data interpretation that while serving the overall robustness we can reduce its ambiguity by performing techniques such as: correlation evaluation, regression modeling and innovative Neural-fuzzy methods.

Looking through the framework illustrated in Figure 10, we focus on not only the current situation of vehicle and driver, but also the future situation by predicting the potential collision probability distribution. How to configure sensors is closely related to the application domain. For example, in a multi-sensor Adaptive Cruise Control (ACC) system, radar and camera often suffice, but for driver's carefulness monitoring, video, EEG power spectrum and driver's commands analysis are required [3].

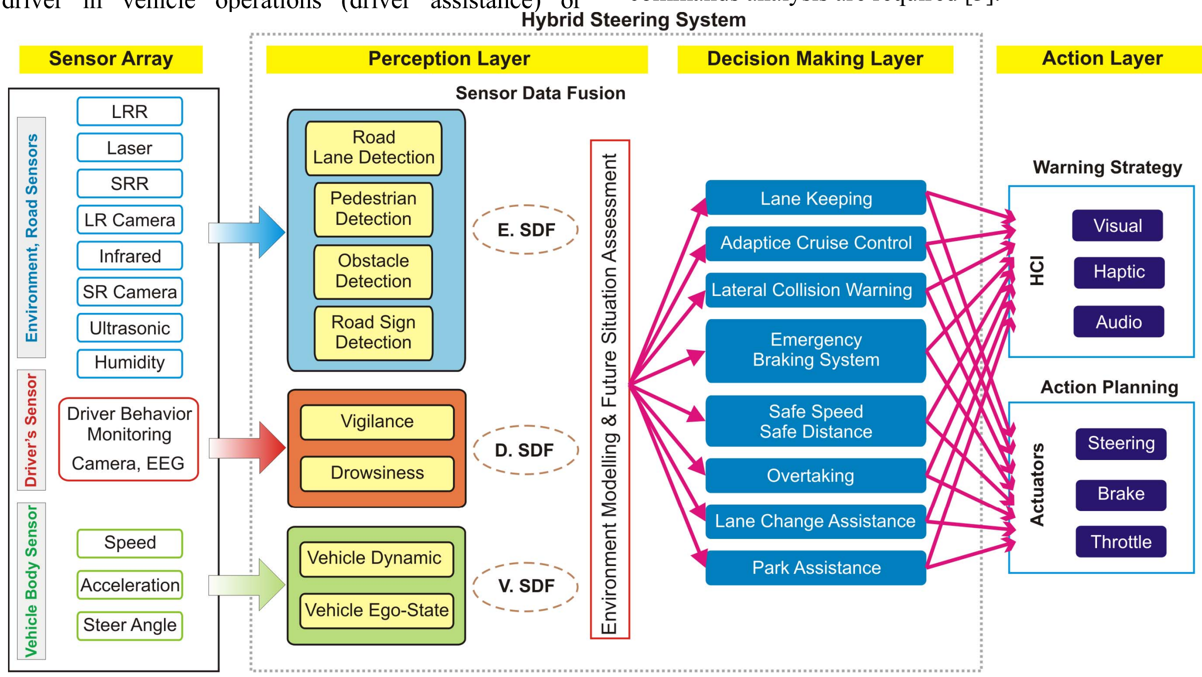


Figure 10. Overall architecture of driver assistance system based on sensor data fusion

VI. CONCLUSION

In this article we had a brief review on current technologies of advanced driver assistance systems. Our proposed method offered a concurrent assess of driver's vigilance via Iris/pupil, and electroencephalogram (EEG) analysis along with road situation monitoring. We discussed about diversity of real world sensors, their advantages and drawbacks. Finally, considering above terms and items we developed a feasible platform to design the next generation of driver assistance systems. The platform covered all real-world needed modules including sensor array (as inputs), Perception layer and decision making layer (as the artificial steering system) and Action layer (as outputs). For future works we could add some experimental results as a benchmark comparable with other research endeavors.

REFERENCES

[1] Bishop, R.," Intelligent Vehicle Technology and Trends". Artech House, Norwood, MA, USA,2005

[2] M.T.R. Peiris, R.D. Jones, P.R. Davidson, and P.J. Bones, "*Detecting Behavioral Microsleeps from EEG Power Spectra*", EMBAS 2006. pp. 5723-5725, Aug 30-Sept 3, New York City, USA, 2006

[3] H. Cheng, N. Zheng, X. Zhang, J. Qin, H. Wetering, *"Interactive Road Situation Analysis for Driver Assistance and Safety Warning Systems: Framework and Algorithms"*, IEEE Transactions on Intelligent Transportation Systems, Vol. 8, No. 1, March 2007

[4] NHTSA 2009, [online], http://www.nhtsa.dot.gov/

[5] A. Heitmann, et al., "Technologies for the monitoring and prevention of driver fatigue", First International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design, 2004

[6] J. Malmivuo, R. Plonsey, "Bioelectromagnetism, *Principles and Applications of Bioelectric and Biomagnetic Fields*", New York , Oxford, Oxford University Press, 1995

[7] P. Marchal, et al. *"SAVE-U: An innovative sensor platform for Vulnerable Road User protection",* Intelligent Transport Systems and Services, 16-20 November 2003, Madrid, Spain

[8] M.H. Sigari, *"Driver Hypo-Vigilance Detection based on Eyelid Behavior"*, Seventh International Conference on Advances in Pattern Recognition, pp.426-429, 2009

[9] J. Batista, *"A Drowsiness and Point of Attention Monitoring System for Driver Vigilance"*, IEEE Intelligent Transportation Systems Conference, Seattle, WA, USA, pp702-708, 2007

[10] M. Miyaji et al. , *"Driver's Cognitive Distraction Detection using AdaBoost on Pattern Recognition Basis"*, IEEE International Conference on Vehicular Electronics and Safety, USA. 2008

[11] A. Doshi and M. M. Trivedi, "Head and Gaze Dynamics in Visual Attention and Context Learning", IEEE CVPR Joint Workshop for Visual and Contextual Learning and Visual Scene Understanding, pp77-84, Miami, FL, USA , June 2009

[12] Danescu R., Nedevschi S., "Probabilistic Lane Tracking in Difficult Road Scenarios Using Stereovision", IEEE Transactions on Intelligent Transportation Systems, Vol. 10, No. 2, pp 272-282, 2009

[13] Kaempchen, N. & Dietmayer, K., "Data synchronization strategies for multi-sensor fusion, *World Congress on Intelligent Transportation Systems*, Issued No. 2250, November 2003, Madrid, Spain

[14] W. Wijesoma, K. Kodagoda, and P. Balasuriya, *"Road-Boundary Detection and Tracking Using Ladar Sensing"*, IEEE Transactions on Robotics and Automation Vol. 20, No. 3, pp. 456- 464, June 2004

[15] Wu W., Chen X. and Yang J., "Detection of Text on Road Signs From Video", IEEE Transactions on Intelligent Transportation Systems, Vol. 6, No.4, pp. 378-390, December 2005

[16] L. Fletcher, G. Loy, N. Barnes, A. Zelinsky, "Correlating driver gaze with the road scene for driver assistance systems", Transaction of Robotics and Autonomous Systems, Elsevier, May 2005

[17] M. Rezaei and Sabzevari.*"Multisensor Data Fusion Strategies for Advanced Driver Assistance Systems"*, Book: Sensor Data Fusion, In-Teh Publishing KG, p. 141-166, ISBN 978-3-902613-52-3, 2009