Intelligent Collision Avoidance and Manoeuvring System with the Use of Augmented Reality and Artificial Intelligence

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Abstract. The efficiency of collision-avoidance abrupt braking or manoeuvring is primarily based on a driver's response time. The latter is affected by the driver's spatial and situational awareness, which in turn is heavily depended on the driver's cognitive workload. Attention taxing, infotainment systems could dramatically reduce the driver's ability to respond effectively in an imminent collision situation. Current attempts to reduce this negative impact on driver's performance had limited success. To improve the driver's ability to perform a successful collision avoidance braking or manoeuvring, this paper presents the design considerations of a prototype system that employs Augmented Reality (AR) to overlay guidance information in the real-life environment. The proposed system will be further supported by an Artificial Intelligence (AI) system that will act as a co-driver, offering in real-time alternative options to the driver. Prior work for the development of a similar system for Emergency Services' (ES) vehicles sparked the idea to transfer and investigate the acceptance of this technology on a civilian vehicle domain. In conclusion, the paper presents the preliminary design for the development of the civilian version of the AR/AI system based on the feedback and suggestions of twenty drivers.

Keywords: Augmented Reality, Intelligent Transportation, HCI, AI, Collision Avoidance, Head-Up Display

1 Introduction

The typical vehicular interiors can be described as highly physically mutable environments with fluctuating noise, light levels and space availability. The external environment also presents variable levels of visual and auditory cues and subsequently, lead to increased cognitive loads reducing driver's ability to perform successfully the primary task of driving. Consequently, these conditions leave limited available attention resources for secondary tasks (i.e. infotainment, passenger discussions and navigation guidance amongst other) while driving.

Smart devices such as phones, tablets and wearables have created a new culture of constant provision and craving of information by the users. This contemporary trend has infiltrated and became a necessity also in the vehicular interiors. In turn, the vehicular environments responding to this user's requirement has been increasingly accomodating various infotainment devices that announce, project and otherwise call driver's attention to various pieces of information [1,2]. An imminent consequence of these attention-seeking devices is the driver's distraction and increased probability of collisions [3,4].

Despite legislative means of controlling the use of smart devices or other in-vehicle infotainment systems whilst driving having been introduced, it is expected that the profusion of such devices and their dangerous use will continue with a projected potential increase predicted in the following years [5].

As such, the proposed work examines the potential ways of fulfilling the prominent infotainment needs of modern drivers without jeopardising the safety of the driving process following previous studies examples [6-8]. In particular, this research is focusing on the safe guidance of the driver through traffic and the provision of safe manoeuvring options that will utilise better the road network and minimise abrupt lane changes that could result in a collision situation.

To achieve this, the proposed work employs emerging technologies such as Augmented Reality (AR) and Artificial Intelligence (AI). The latter will provide collisions avoidance guidance and manoeuvring options in the form of an AI co-driver suggesting in real-time the optimal speed and manoeuvring options that will enable the driver to avoid any potential collision incidents. This crucial information will be superimposed directly on the external environment and driver's field of view.

This AR representation of simplified options will utilise a full-windshield, prototype Head-Up Display (HUD) interface, avoiding any additional dashboard related screens. It was previously observed that the AR representation of data with the use of HUD conduits has resulted in faster driver responses and reduced accidents in various weather and traffic conditions [9-12].

Overall, the paper will present the initial design rationale and development process of the proposed AR/AI interface. In turn, the design aspects of the proposed interface will be contrasted against current systems through a comparative, qualitative study with twenty drivers. Their feedback will be presented and discussed in detail as it provides an understanding of the potential use of such emerging technologies in passenger vehicles. Finally, the paper will provide a tentative plan of future work which will explore further the interface development and the proposed technology acceptance from the drivers.

2 Current Navigation and Maneuvering Issues

As aforementioned, the stream of incoming infotainment information and the interaction requirements with these devices have already reduced dramatically driver's attention. Additionally, variable traffic conditions, particularly in a motorway environment and unexpected fluctuation in the traffic flow could surprise the driver and result in a potential collision.

During these situations, the driver's decision-making process is slow, due to increased cognitive load. The driver's inattention to the road magnifies the difficulty to choose appropriate action. In milliseconds the driver has to identify potential options of braking and/or evading manoeuvres [13]. However, in such a demanding condition, the driver's spatial and situational awareness might be impeded and the choice of speed, lane, or braking might be obscured or inappropriate.

Typical navigation systems offered in the majority of passenger vehicles are offering very limited information regarding the potential collision hazards lying ahead on the vehicle's path. Also, the generic traffic flow information provided, lack any visual linking to the external environment as typically are presented in a small-sized, dashboard screen.

Previous attempts to offer a real-time provision of crucial information to the driver for collision avoidance produced encouraging results [14-16]. These AR-HUD systems warned the driver for potential collision hazards related to the neighbouring vehicles and/or the road infrastructure as illustrated below (see Fig.) [12]. However, they did not provide the optimal route or action (i.e. manoeuvring, braking) options for successful collision avoidance and a step by step guidance to avoid the accident.

Fig. 1. Previous collision avoidance systems which incorporated AR projection of data through a full-windshield HUD [12].

3 Proposed Solution

Following concurrent research in the development of intelligent collision avoidance and manoeuvring systems for Emergency Services' (ES) vehicles, it was observed that the bespoke system characteristics for collision avoidance could be adapted and transferred in the civilian vehicles [17, 18].

The feedback of the ES drivers was also in support of offering a simplified version for the passenger vehicles [19]. As such, instead of considering a more spartan infotainment environment or complete exclusion of smart devices (embedded or not on the vehicle), the current research is investigating the optimal way to control the incoming information whilst supporting in real-time the driver's decision making process. The proposed solution follows a two-fold approach with regards to the utilization of emerging technologies as described below.

3.1 Augmented Reality (AR – HUD)

The provision of crucial information to the driver in a timely and efficient manner is a challenging task. Current systems and applications require from the driver to divert his/her gaze from the road and interact with various devices and screens positioned typically in the dashboard area namely Head-Down Display (HDD) section of the vehicular cockpit. This contributes further to the time that the driver gazes away from the road and interacts with additional infotainment means [6, 10]. To counteract the above issue, this work follows previous studies which employed various types of HUD interfaces to present the required information directly to the driver's field of view [12, 15, 20-24].

The overall interface is an adaptation of the ES version, which maintains the primary functionality of real-time superimposed information for safe guidance. However, the civilian version complies fully with the speed and traffic regulations and does not offer unconventional manoeuvring options that apply only for emergency vehicles. The system will provide the best possible manoeuvre option given the vehicle's speed and proximity to the immobile obstacle (see Fig. 2). Yet if the collision is imminent the system will provide the best option to avoid or minimise the impact. This ultimate attempt will utilise every possible alternative to reduce the severity of the collision.

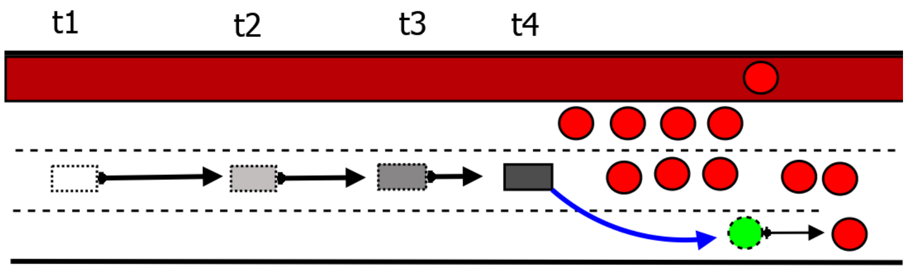

Fig. 2. Sudden braking scenario and manoeuvring options in an imminent collision case.

In a zoom-in, top view of the driving simulation, the red-vehicle driver is guided step by step towards the direction that will provide additional space for safer abrupt braking or escape route (see Fig. 3).

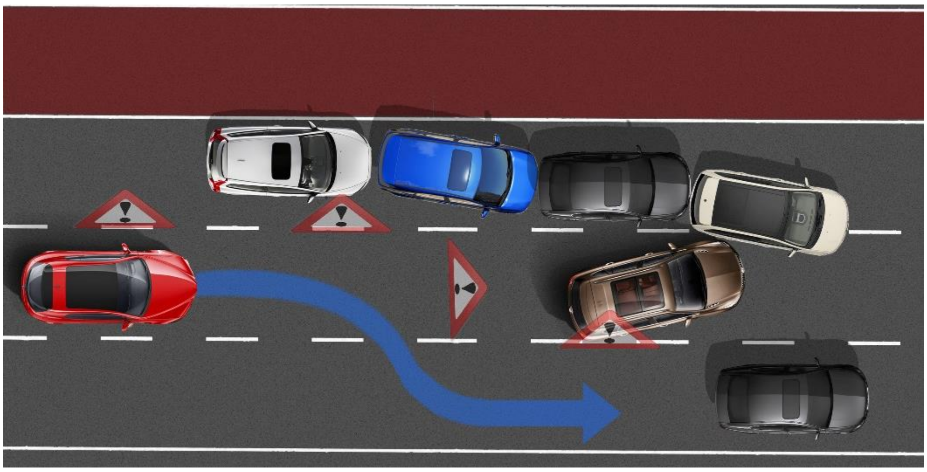

Fig. 3. Guided collision avoidance with the use of the AR/AI HUD.

Although on a top view, this option seems logical and obvious, in a real-life situation, the panic response of the driver typically results in a collision [6, 9]. The system's intervention is presented in a driving simulation environment (see Fig. 4).

Fig. 4. Suggested manoeuvre and speed by AR/AI HUD in a driving simulation environment.

3.2 Prototype Interface Design

Conveying the information to the user relies primarily on the type of information, interface design and conduit of presentation [12, 15, 20]. Simple and easy to follow multimodal interfaces reduce the cognitive load and the time of the decision-making process [12]. As this interface is intended to be activated before a potential collision, the information provided must be presented to the driver is a simplistic manner that enables to user to understand and respond instantly.

As such, the interface presents the guidance to the driver directly, superimposed in real-scale on the road ahead, as illustrated in the VR driving Simulator screenshot above (see Fig.). This approach imitates the naturalistic human hand directions provided typically by a co-driver. In this manner, the AI co-driver described below is materialized virtually with the use of the directional arrows instead of hands. The visual interface is complemented by a voice-over highlighting the directions and the actions. The interface follows a typical colour coding approach of red, amber, green and blue, stating the risk level of the manoeuvring option with red being the riskier in contrast to blue which is the less urgent and easier to perform.

3.3 AI Co-Driver

The effective operation of the AR HUD interface is based on the correct and timely information provision. This is a task that has been allocated to the second element of the proposed system namely Artificial Intelligence Co-Driver. The system under development aims to acquire information from the vehicles' sensors, the Vehicular Ad-hoc Networks, and the road infrastructure [12, 25, 26].

Additionally, the AI Co-Driver will be trained by previous accident data and through VR simulations performed by drivers in the VR Driving Simulator [27-30]. Initial feedback from focus groups has suggested that the AI Co-Driver should not be intrusive and offer only crucial information in challenging situations [18-19].

The particular system design requirements will prevent the system's misuse (i.e. unsafe manoeuvring). As such the AR/AI HUD will strive to enable the driver to perform a necessary manoeuver safely and maintain the control of the vehicle in a challenging situation.

4 Preliminary Evaluation and Feedback by 20 Drivers

A preliminary evaluation of a demo system was deemed essential for the further development and customisation of the proposed AR/AI for passenger vehicles.

4.1 Survey Rationale and Structure

This survey followed a similar structure to the ES drivers' survey to receive comparable information. As such the twenty drivers completed a pre-demo questionnaire aiming to acquire the demographic information of the group and their current experience and beliefs related to navigation and guidance systems.

In turn, the demonstration AR/AI HUD interface was presented to twenty drivers and contrasted to a default navigation system. A typical rear-collision scenario was employed to depict the conditions of the potential accident [12]. The provision of information with and without the AR/AI HUD was discussed. Finally, a post-demo survey was designed to obtain drivers' subjective feedback that could inform the future development and required adaptations of the proposed system for civilian, everyday use presented in Table 1. Also, this part of the survey aimed to identify the view of the typical driver on the technology. The second questionnaire served also as a public gauging for the use of emerging technologies to improve ES vehicles' performance for improving the speed and level of support to the public.

Table 1. Table captions should be placed above the tables.

Post-Questionnaire
Q11. Did you find the *interface design simple and clear*? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 (1 Very Simple – 5 Very Difficult)
Q12. Do you think that *interface design and colour coding* would be useful to convey the manoeuvring information? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 (1 Very Useful – 5 Not Useful at all)
Q13. Do you think that it would be useful to have ***AR*** *navigation/guidance system in the* ***ES vehicle***? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 (1 Very Interested – 5 Not Interested at all)
Q14. Do you think that it would be useful to have ***AI*** *navigation/guidance system in the* ***ES vehicle***? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 (1 Very Interested – 5 Not Interested at all)
Q15. Would you be interested to have ***AR*** *navigation/guidance system in the* ***civilian vehicles***? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 (1 Very Interested – 5 Not Interested at all)
Q16. Would you be interested to have ***AI*** *navigation/guidance system in the* ***civilian vehicles***? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 (1 Very Interested – 5 Not Interested at all)
Q17. Would you be interested to have *real-time guidance suggestions by an AI/AR system*? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 (1 Very Interested – 5 Not Interested at all)
Q18. Do you think that the *AR/AI proposed system could replace other guidance systems*? ☐ Yes ☐ No
Q19. Do you think it would be a helpful system (AI/AR) to *integrate into future ES vehicles*? ☐ Yes ☐ No
Q20. Do you think it would be a helpful system (AI/AR) to *integrate into future civilian vehicles?* ☐ Yes ☐ No
Q21. Do you have *any other suggestions, comments or thoughts* regarding the proposed AR/AI system? If yes please use the space below to write your comments. ☐ Yes ☐ No

4.2 Participants

The evaluation was performed by twenty users (5 female, 15 male) which held a valid driving licence and they were aged between 20 and 58 years of age. The participants were volunteers with variable driving experience, occupations, computing experience and nationalities.

5 Data Analysis and Discussion

An indicative appraisal of the system was provided through the post questionnaire results presented below (see Fig. 5). Overall the responses at this stage were in favour of a system. The minimalistic approach of the interface design was well perceived as 70% of the users considered it very simple and 20% simple enough to follow as presented in Question 11.

Similarly, the intended colour coding also received the users' approval with 90% in favour of the chosen scheme as presented from the results in Question 12. The system was deemed also logical and potentially very useful for ES vehicles for reducing potential collisions and the Estimated Time of Arrival (ETA) to the events as presented in the results of Question 13. However, the drivers raised some concerns regarding the potential intrusion of the AI Co-driver in an already challenging ES vehicle environment as seen from the responses in Question 14.

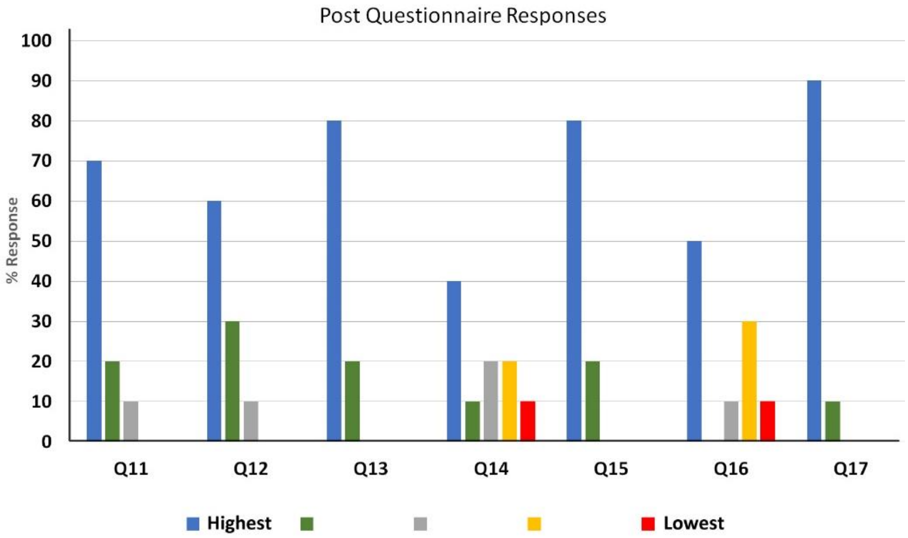

Fig. 5. Participants feedback and post-questionnaire results for questions 11-17.

For the civilian use and in the particular example of the rear collision scenario, the drivers felt that such a system could have a major positive contribution in the safe manoeuvring and navigation through adverse traffic situations as illustrated by Question 15.

Question 16 results presented similar concerns to Question 14, as the drivers were unsure on the level of intrusion of the AI Co-Driver to the overall driving experience. The concerns on both questions stemmed from the experience of voice navigation systems and interfaces on contemporary vehicles. However, the combined approach of AI and AR HUD system scored 100% (see Fig. 5).

The remaining Questions (18,19,20) received also positive responses with 90%, 70% and 100% respectively highlighting the future expectations of the drivers.

7 Conclusions

This paper presented a prototype AR/AI system that aims to support the driver's decision-making process in challenging situations such as imminent collision scenarios. The system was designed to superimpose guidance information in a real-life environment and real-scale with the use of a full windshield HUD device. This work stemmed from a concurrent project related to the development of a similar AR/AI HUD system for the emergency response services. The proposed version capitalizes on the main design framework for the ES, yet it is customized to support the everyday driving of a typical civilian user.

Additionally, the paper described a preliminary of the prototype systems' functionalities by twenty drivers. Their feedback was in par to the previous studies aiming to identify the potential usability of such a system for ES vehicles. The derived results from the preliminary evaluation were analysed and presented offering an informative appraisal of the system's capabilities and users' expectations of the final output. The drivers' feedback and suggestions highlighted also some concerns particularly for the AI component of the system that need to be addressed in the future versions. Furthermore, the future plans for this project entail the evaluation of a fully functional version, by a large cohort of users, in our immersive VR driving simulation facility to achieve finer granularity of the results.

References

1. Morris A., Reed S., Welsh R., Brown L., Birrell S.: Distraction effects of navigation and green-driving systems – results from field operational tests (FOTs) in the UK, European Transportation Research Review, Springer Berlin Heidelberg, vol.7, no. 26, (2015).
2. Simons S.M., Hicks A., Caird J. K.: Safety-critical event risk associated with cell phone tasks as measured in naturalistic driving studies: A systematic review and meta-analysis", Accident Analysis and Prevention Journal, Elsevier, vol. 87, pp. 161-169, (2016).
3. Liao Y., Li G., Eben S., Cheng B., and Green P.: Understanding Driver Response Patterns to Mental Workload Increase in Typical Driving Scenarios, *in* IEEE Access, vol 6, pp. 35890-35900, (2018).
4. Regan M.A., Hallett C., Gordon C.P.: Driver distraction and driver inattention: definition, relationship and taxonomy, Accident Analysis & Prevention, vol.43, no. 5, pp.1771-1781, (2011).
5. Simons S.M., Hicks A., and Caird J. K.: Safety-critical event risk associated with cell phone tasks as measured in naturalistic driving studies: A systematic review and meta-analysis", Accident Analysis and Prevention Journal, Elsevier, vol. 87, pp. 161-169, (2016).
6. Charissis, V., Papanastasiou, S.: Human-Machine Collaboration Through Vehicle Head-Up Display Interface, International Journal of Cognition, Technology and Work, P. C. Cacciabue and E. Hollangel (eds.) Springer London Ltd Volume 12, Number 1, pp 41-50, DOI: 10.1007/s10111-008-0117, (2010).

7. Okumura, H., Hotta, A., Sasaki, T., Horiuchi, K., Okada, N.: Wide field of view optical combiner for augmented reality head-up displays, 2018 IEEE International Conference on Consumer Electronics (IEEE ICCE), (2018).
8. Charissis, V., Papanastasiou, S., Vlachos G.: Interface Development for Early Notification Warning System: Full Windshield Head-Up Display Case Study. In: Jacko J.A. (eds) Human-Computer Interaction. Interacting in Various Application Domains. HCI International 2009. Lecture Notes in Computer Science, vol 5613. Springer, Berlin, Heidelberg, (2009).
9. Lagoo, R., Charissis, V., Harrison, D.K.: Mitigating Driver's Distraction: Automotive Head-Up Display and Gesture Recognition System, IEEE Consumer Electronics Magazine, vol8, no 5, pp 79-85, DOI: 10.1109/MCE.2019.2923896, (2019).
10. Beck D., Park W.: Perceived Importance of Automotive HUD Information Items: a Study With Experienced HUD Users, IEEE Access, vol. 6, pp. 21901 - 21909, (2018).
11. Hyungil K., Xuefang W., Gabbard J. L., Polys N. F., Exploring head-up augmented reality interfaces for crash warning systems, 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, ACM Automotive UI '13, pp. 224-227, ACM, (2013).
12. Charissis V., Papanastasiou S., Chan W., and Peytchev E.: Evolution of a full-windshield HUD designed for current VANET communication standards, IEEE Intelligent Transportation Systems International Conference (IEEE ITS), The Hague, Netherlands, pp. 1637-1643, DOI: 10.1109/ITSC.2013.6728464, (2013).
13. Smith, D. L., Najm, W. G., Lam, A. H.: Analysis of Braking and Steering Performance in Car-Following Scenarios, in Proceedings of the Society of Automotive Engineers World Congress (SAE 2003), Paper 2003-01-0283, Detroit, MI, USA, (2003).
14. Weinberg G., Harsham B., Medenica Z.: Evaluating the usability of a head-up display for selection from choice lists in cars, 3rd ACM International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Automotive UI '11, pp. 39–46, ACM, (2011).
15. Okumura H., Sasaki T., Hotta A., and Shinohara K., Monocular hyperrealistic virtual and augmented reality display, 2014 IEEE Fourth International Conference on Consumer Electronics (ICCE-Berlin), Berlin, Germany, pp.19 – 23, (2014).
16. Charissis, V., Papanastasiou, S., Mackenzie, L.: Evaluation of collision avoidance prototype head-up display interface for older drivers, Lecture Notes in Computer Science. 14th International Conference on Human-Computer Interaction, HCI International 2011, Orlando, 9-14 July 2011, vol. 6763 pp. 367-375, Springer, Berlin, Heidelberg, (2011).
17. Smith, N.: A National Perspective on Ambulance Crashes and Safety: Guidance from the National Highway Traffic Safety Administration on ambulance safety for patients and providers, NHTSA Report, EMS World, pp. 91-94, (2015).
18. Bram-Larbi K.F., Charissis V., Khan S., Lagoo R., Harrison D.K., Drikakis D.: Collision Avoidance Head-Up Display: Design Considerations for Emergency Services' Vehicles, In IEEE International Conference on Consumer Electronics (ICCE), Las Vegas, USA, (2020).
19. Bram-Larbi K.F., Charissis V., Khan S., Harrison D.K., Drikakis D.: Improving Emergency Vehicles' Response Times with the Use of Augmented Reality and Artificial Intelligence, In Lecture Notes in Computer Science, (2020).
20. Zhang Y., Yang T., Zhang X., Zhang Y., Sun Y. (2020) Driver's Visual Attention Analysis in Smart Car with FHUD. In: Stanton N. (eds) Advances in Human Aspects of Transportation. AHFE 2020. Advances in Intelligent Systems and Computing, vol 1212. Springer, Cham. https://doi.org/10.1007/978-3-030-50943-9_9, (2020).

21. Beck D., Jung J., Park J., Park W.: A Study on User Experience of Automotive HUD Systems: Contexts of Information Use and User-Perceived Design Improvement Points, International Journal of Human–Computer Interaction, 35:20, 1936-1946, DOI: 10.1080/10447318.2019.1587857, (2019).
22. Lagoo R., Charissis V., Chan W., Khan S., Harrison D.: Prototype gesture recognition interface for vehicular Head-Up Display system", In IEEE International Conference on Consumer Electronics, Las Vegas, USA, pp.1-6, (2018).
23. Wang S., Charissis V., Harrison D.K.: Augmented Reality Prototype HUD for Passenger Infotainment in a Vehicular Environment", in Advances in Science, Technology and Engineering Systems Journal, Vol. 2, No. 3, 634-641 (2017).
24. Charissis V., Naef M.: Evaluation of Prototype Automotive Head-Up Display Interface: Testing Driver's Focusing Ability through a VR Simulation, In IEEE Intelligent Vehicle Symposium, (IV '07), Istanbul, Turkey, (2007).
25. Kianfar R. et al.: Design and Experimental Validation of a Cooperative Driving System in the Grand Cooperative Driving Challenge, In IEEE Transactions on Intelligent Transportation Systems, vol. 13, no. 3, pp. 994-1007, doi: 10.1109/TITS.2012.2186513, (2012).
26. Flanagan S.K., He J. and Peng X.: Improving Emergency Collision Avoidance with Vehicle to Vehicle Communications, In 2018 IEEE 20th International Conference on High-Performance Computing and Communications; IEEE 16th International Conference on Smart City; IEEE 4th International Conference on Data Science and Systems (HPCC/SmartCity/DSS), Exeter, United Kingdom, 2018, pp. 1322-1329, doi: 10.1109/HPCC/SmartCity/DSS.2018.00220, (2018).
27. Vazquez, D.; Meyer, L.A.; Marın, J.; Ponsa, D.; Geronimo, D. Virtual and Real World Adaptation for Pedestrian Detection. IEEE Trans. Pattern Anal. Mach. Intell. 2014, 36, 797–809, (2014).
28. Frank, M., Drikakis, D., Charissis, V.: Machine Learning Methods for Computational Science and Engineering, Computation (Journal), Computational Engineering Section, MDPI, 8(1), 15; https://doi.org/10.3390/computation8010015, ISSN 2079-3197, pp 1-36, (2020).
29. Charissis V., Papanastasiou S.: Artificial Intelligence Rationale for Autonomous Vehicle Agents Behaviour in Driving Simulation Environment, book chapter in the "Robotics, Automation and Control" Aramburo J. and Trevino, A., R., (Eds), I-Tech Education and Publishing KG, Vienna, Austria, EU, pp314-332, ISBN 953761916-8I (2008).
30. Li, J., Cheng, H., Guo, H. et al.: Survey on Artificial Intelligence for Vehicles. Automot. Innov. 1, 2–14, https://doi.org/10.1007/s42154-018-0009-9, (2018).