A model for an innovative Lane Change Assistant HMI

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Abstract

Millions of people are killed every year in road accidents, caused mostly by human errors. Therefore, it is of paramount importance to support the driver by improving the interaction between humans and machines. This paper presents a research aimed at developing a Cooperative Lane Change Assistant Human Machine Interface (HMI). The system checks whether the adjacent lane is free: if positive, it will suggest the lane-change manoeuvre via a recommendation HMI; if negative, it will show a warning-based HMI. In addition, an acoustic warning will be provided if a critical event is detected. As preliminary test, 20 users carried out two sequences of 18 lane-changes on a static driving simulator: the first run served as a baseline while the second added a secondary cognitive task to induce distraction. Eye-tracking and vehicle data were collected throughout the test and will be used to develop a Driver Cognitive Distraction Model. This classifier will be included into the HMI strategy; further tests have been planned to evaluate the efficiency and the acceptability of this assistant HMI, which can be regarded as a co-driver for the driving lateral task. This work is in the interest of the ARTEMIS Joint Undertaking under the number 269336 (www.d3cos.eu).

Introduction

The lane change manoeuvre is considered one of the most difficult driving tasks and special attention is needed: it is estimated that crashes resulting from improper lane changes constitute almost 8% of all car crashes (Fitch & Hankey, 2012). A common kind of dangerous situation may occur if the driver underestimates the speed of an approaching vehicle or overlooks it at all. It has been shown that drivers' perception of inter-vehicle distances are often insecure, especially at high velocities (Roelofsen et al., 2010). Lane Change Assistant (LCA) systems may help human drivers in avoiding severe accidents. A LCA monitors adjacent lanes and keeps the driver informed of the presence of other vehicles nearby. Typically, these systems don't perform any automated action to prevent a lane change, though such a feature is expected in the future (Visvikis et al., 2008).

Furthermore, in the event of conflicting resources (i.e. a section of a lane aimed by two vehicles) a cooperative LCA could considerably improve the handling of

In D. de Waard, K. Brookhuis, R. Wiczorek, F. di Nocera, R. Brouwer, P. Barham, C. Weikert, A. Kluge, W. Gerbino, & A. Toffetti (Eds.) (2014). Proceedings of the Human Factors and Ergonomics Society Europe Chapter 2013 Annual Conference. ISSN 2333-4959 (online). Available from http://hfes-europe.org

resources, boosting a beneficial collaboration between drivers (Heesen et al., 2012). Such cooperation could be achieved via a Vehicle-to-Vehicle (V2V) communication, which would allow an exchange of information between involved vehicles or also between their assistance systems. Moreover, cooperation among road users should also be associated with an efficient cooperation between the LCA system and the human driver (Flemisch et al., 2008), meaning that a proper HMI needs to be built. The system could also provide additional support if it was able to improve the involved drivers' situation awareness (Endsley, 1996). Many experiments with driving simulators assess the impact of cognitive distraction on the driving performance. Strayer and Johnston (2001) found that drivers engaged in phone conversations were more likely to miss road signs, plus their reaction time was superior with respect to the ones that weren't on the phone. Reported effects are similar whether mobile phones were held in hand or in hands-free configuration (speakerphone): this indicates that the decrease in the driving performance wasn't due to a physical limitation, but rather to a different cognitive load induced by a phone conversation. Then, the field of research was extended to the larger domain of the in-vehicle interfaces: Lee et al. (2001) reported a 300 ms delay in the braking of the vehicle for drivers who were using a voice-based email system while performing a primary driving task on a simulator. Recently, the growing number of In Vehicle Information Systems (IVIS) on the market, such as radios, GPS navigation systems etc., threatens to increase dangerously the sources of distraction. Therefore, to allow the drivers to take advantage of the IVIS without reducing safety becomes a critical topic (see also Liang et al., 2007).

In this paper, an innovative Cooperative-LCA HMI is presented: it embeds elements to support the driver in performing the lane change manoeuvre as well as a cognitive distraction model to infer a possible state of distraction. The key elements of the proposed system are:

- A cooperative driver model, a set of cooperation algorithms for collision avoidance
- A warning/recommender HMI, a multichannel interface which delivers the information to the driver in the most suitable way
- A Driver Cognitive Distraction Model (DCDM), a binary classifier which infers the cognitive state of the driver

This research is performed within the project D3CoS (Designing Dynamic Distributed Cooperative Human-Machine Systems), whose objective is to develop methods, techniques and tools (MTTs) for system engineers and to embed them in industrial system development processes, to support affordable development of highly innovative cooperative human-machine systems.

Background

Cognitive distraction and Machine Learning approach

As aforementioned in the introduction, despite the complexities of the driving task, it is not unusual to see drivers engaged in various other activities while driving, including talking to passengers or by a cellular-phone, listening to the radio and even reading. Concerns with the use of the IVIS while driving are also becoming increasingly common. All in all, any activity that distracts the drivers or competes for their attention with the driving primary task has the potential to degrade performance and have serious consequences for road safety. In this context, one of the main goals of this research is to support drivers by means of cooperation algorithms for collision avoidance, integrated with classifiers of users' state and in particular of cognitive distraction. Hence, the following research questions are investigated:

- Is it possible to develop appropriate driver's distraction classifiers, which are then used together with D3COS cooperative applications, in order to support users and to make such systems even "smarter"?
- Which techniques and algorithms can be regarded as the most "appropriate" (meaning enough accurate, precise, reliable and feasible)?
- With respect to the current state of the art, how can we improve the methodology and the results possibly achievable?

In order to deal with these topics, many methods have been proposed to evaluate and classify driver's distraction (Tango & Botta, 2009; Mattes, 2003; Young et al., 2003). In particular, Machine Learning (ML) techniques seem to be very appropriated for this type of classification problem. In fact, ML is the technology of searching large volumes of data for unknown patterns. It has been successfully applied in business, health care and other domains (Tan et al., 2005; Baldi & Brunak, 2001). So, the rationale to use ML techniques copes with two aspects:

- From a more "philosophical" point of view, one of the most ambitious goals of automatic learning systems is to mimic the learning capability of humans and their capability of driving is widely based on experience, particularly on the possibility to learn from it.
- From a more technical point of view, collected data about vehicle dynamics and external environment are definitely non-linear. Several studies have proved that in such situations ML approaches can outperform the traditional analytical methods. Moreover, also human's driver mental and physical behaviour is non-deterministic. So, since mental state of the drivers is not observable, no simple measure can index visual and cognitive distractions precisely (Zhang et al., 2004; Liang et al., 2007).

Hence, these types of technology can be applied to build a discrimination model able to capture the differences between drivers' normal and distracted behaviour. This phase is currently under development in the D3COS project, where the different distraction models are prepared and then implemented in the C-LCA application.

Lane Change Assistant systems

Designing a proper interface for a LCA system should comprise two different tasks: how the proper suggestion is presented to the driver and how the state of the system is communicated (Visvikis et al., 2008). Standards recommend that warnings are used to tell which side of the surrounding area is already occupied by another vehicle. Moreover, visual warnings should be clearly distinguishable from any other in-vehicle signal and should be positioned so that the driver is prompted to use mirrors.

LCA systems usually provide a two-level warning: the first level is reserved to cautionary warnings, when the likelihood of a collision is relatively low. The second level is instead a more imminent kind of warning, when dangerous situations are more likely to occur (Visvikis et al., 2008). Visual, acoustic or haptic channels may be used, but visual warnings are mostly suitable for a low priority information since they rely on the fact that the driver is looking at the display. On the other hand, acoustic warnings can draw the attention of the driver regardless of where he/she is looking and are therefore more appropriate for urgent warnings.

Furthermore, the driver might assume that the LCA system is always active throughout the journey. It is possible, tough, that the system is occasionally inactive, for example if the driver forgot to activate a manual system or if the criteria for an automatic activation were not met. Therefore, the driver should be constantly kept aware of the state of activation of the system in order to prevent any misinterpretation; likewise, it is also important to notify the driver if the system is temporarily unavailable, for example in case a sensor is covered with dust or snow.

Concept

The system presented in this paper is an innovative Cooperative Lane Change Assistant HMI, aimed at providing the driver with a twofold information: on one hand the system will give a warning if it detects a dangerous situation or a state of distraction of the driver; on the other hand it will suggest a lane change manoeuvre if a gap on a more suitable lane is available, according to a cooperative driver model. The driver model is built on the bases of a highly cooperative approach utilizing methods from the field of distributed artificial intelligence and multi-agent systems. This model enables to plan the trajectory of the vehicles moving on a highway and cooperatively checks them for conflicts: if a collision was detected, the trajectories of the vehicles would be adjusted to be conflict-free. A detailed description of this model is beyond the scope of this paper and can be found in Vokrinek et al. (2013).

The development of the HMI logic and images was driven by the research background reported in the previous section and was supported by pilot tests on a driving simulator, which are described in the next sections. The visual interface is integrated in the simulator dashboard, between the speedometer and the RPM needles, in order to minimize the deviation of driver’s gaze from the road. The acoustic interface is played by the simulator speakers.

Figure 1. Sample pictures of the visual HMI: a) "lane change" recommendation; b) "keep your lane" warning; c) LCA inactive.

In case the driver is proceeding on the lane suggested by the system only a white straight arrow is displayed, whereas a red box is added in case the indicator is turned on (fig. 1b) in order to alert the driver that he/she is about to perform an unsafe lane change; it is important, in fact, to prevent needless or distracting warnings during normal driving (Visvikis et al., 2008), so for those cases a minimum warning level was chosen. If instead the system is recommending a lane change, a green box will highlight a free gap onto the suggested lane (fig. 1a): this particular recommendation doesn't need any trigger or input from the driver (proactive behaviour).

The acoustic channel is instead launched if one of the following conditions becomes true:

- Two vehicles are about to collide (mostly because one of the drivers isn't following the shared plan, for example by attempting a lane change towards an occupied lane)
- A state of distraction is detected, in which case a sound is emitted with the purpose of alerting the driver

In particular, the state of cognitive distraction will be inferred by the classifier which is being developed by means of ML techniques: whenever a "TRUE" condition is detected, the HMI strategy is consequently adapted, emitting a sound specifically designed to warn a driver e.g. on a wide frequency range in order to be easily audible and clearly distinguishable from background noise.

The cooperative model constantly computes an updated plan and, at the minimum, the visual channel is always active so that the driver has at any moment the possibility to check his/her lane positioning. However, if necessary input data are not available, then an HMI-OFF image is displayed (fig. 1c) in order to keep the driver aware of the status of the system.

Experimental design

Description of the simulator

The experiments whose setup is presented in this paper were carried out using a static driving simulator owned by Reggio Emilia Innovazione (http://www.reinnova.it/en) and equipped with a SCANeR™ simulation engine (http://www.scaner2.com). The system is a fixed based simulator that comprises a mock-up of a car with real driving controls, specifically a seat, steering wheel, pedals, gear, handbrake and a digital simulated dashboard displaying a traditional instrumental panel, with RPM, speedometer and vehicle subsystem lamps. The scenario is projected on a frontal screen at the driver point of view, together with the rear mirror displayed on the top of the field of view and the wing mirrors on the sides. Environmental sounds, such as the engine rumble, are provided through the loudspeakers.

Distraction Model

A set of experiments on the driving simulator was carried out, involving 20 users in the age between 20 and 40 (Mean = 28.9, SD = 3.8 years). Participants were 14 males and 6 females, with a minimum driving experience of two years and at least 10,000 Km per year of travelling. The simulated scenario represented a highway and, after a five minutes warm-up period to let the user acquire confidence with the simulator, participants were instructed to:

- keep a fixed speed (130 Km/h)
- stay on starting lane, whenever possible

For the primary driving task, the reference test protocol is the Lane Change Task by Mattes (2003). With respect to this protocol a modification of the triggering event has been applied, corresponding to the introduction of one vehicle that appears in front of the Ego vehicle instead of a sequence of road signs suggesting a lane change. The reason of this adjustment was to ensure consistency with the scenario that will be used to test the C-LCA. A secondary task was then introduced to induce cognitive distraction: while driving, participants were asked to count backwards by 7 starting from a given number, suggested by the interviewer (e.g. 100, 93, 86, 79…). Every participant performed two driving session, each consisting of 18 LC manoeuvres:

- Run 1 (A1): LC without secondary task, serving as baseline for the driver cognitive distraction model
- Run 2 (A2): LC with secondary task

The time interval between two subsequent LC manoeuvres (15-40 s) was randomized between the participants according to 8 different combinations of the 18 manoeuvres, both for A1 and A2. Each participant had a different combination in A1 and A2. Randomization was aimed to minimize learning and interaction effects among the different sessions.

Figure 2. The driving simulator used for the experiments.

Throughout the test, vehicle data (such as speed, lateral position, steering wheel…) were collected by the Recorder module of the simulation software at a sample rate of 20 Hz. In addition, users were equipped with a Tobii® Glasses eye-tracker system (http://www.tobii.com) to collect gaze position and in particular three different Areas Of Interest (AOI) were defined: dashboard, rear mirror, central area (fig. 3).

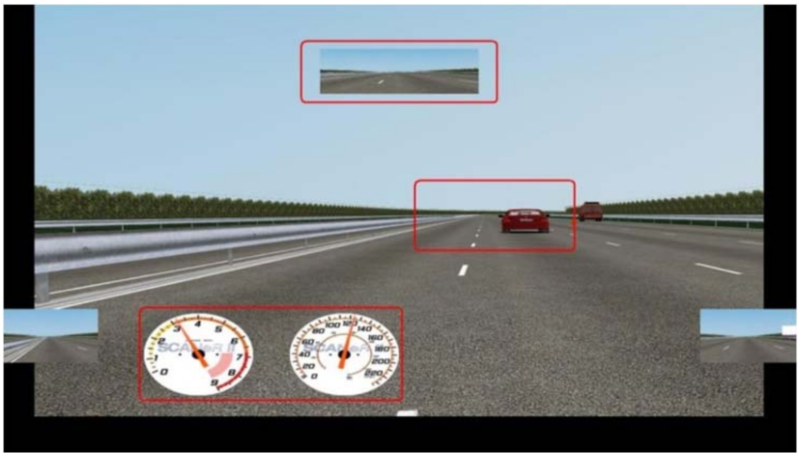

Figure 3. Screenshot of a lane change manoeuvre illustrating the AOI under investigation.

The distraction classifiers of users are being developed by using ML techniques (such as ANN, SVM, etc.). When the DCDM will be fully developed, its output will be included as an input for the LCA system: this way, different HMI strategies can be chosen depending on the distraction state of the driver.

Cooperative HMI

With the purpose of collecting valuable feedbacks for the development of the HMI, 10 participants (mean age = 34.3, SD = 6.7) were involved in a set of pilot tests. As preliminary task, the users were asked to fill out some questionnaires to evaluate Sensation Seeking (Arnett, 1994) and Locus of Control (Montag & Comrey, 1987), and also a socio-anagraphic form to assess users' driving experience and confidence with IVIS (such as radio or GPS). Then the interviewer briefly explained the operation and purpose of the LCA system under investigation, also by showing the screenshots of the visual interface; five minutes of free driving were then used as warm-up before the beginning of the test.

The scenario represented a 3 lanes highway and the users were instructed to drive on the central lane, following a lead vehicle at a distance that they considered safe. After a time interval of 5 to 40 s (randomized between the manoeuvres) of car following, the lead vehicle slowed down: other cars were in transit around the Ego vehicle and the user had to choose between changing lane or slowing down in turn. This manoeuvre was repeated 9 times for each of the two arranged driving sessions, the first of which was carried out without the LCA system, serving as baseline. Finally, participants were asked to fill out a questionnaire to evaluate their confidence and acceptance of the system.

Pilots evaluation

The main purpose of the pilots was to have a halfway evaluation from the users on the HMI, especially on the suitability of the graphics and of the acoustic warning. Besides, pilots also provided useful suggestions on the rationale and on the operating parameters of the system, which were taken into account for the following cycle of development. Participants' response to usability questionnaires regarding the Visual Interface (VI) and the Acoustic Interface (AI) is showed in figure 4, on a scale from 1 to 7.

Users were asked to evaluate the appropriateness (whether or not the interface fit its purpose) and the clarity (whether or not the intended message was clearly received) of the VI (fig. 4a) and the AI (fig. 4b). In particular, the evaluation of the AI suggested a replacement of the warning sound with a more alerting one, which will be implemented in the next version of the system.

Participants also gave some free-comments regarding their perceived confidence in the system and in particular the proactive behaviour previously described was appreciated by the users. As final question, 8 out of 10 participants answered that they would prefer to drive using this C-LCA system with respect to the baseline situation.

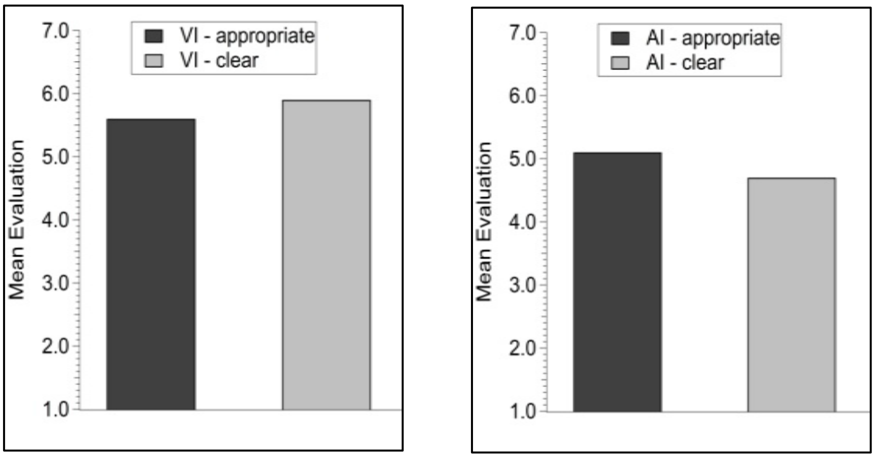

Figure 4. Mean evaluation: left: Visual Interface; right: Acoustic Interface, on a scale from 1 to 7.

Conclusions

This paper presents the concept of an innovative C-LCA HMI and outlines an experimental strategy having the purpose of supporting and validating the development process. Vehicle and eye-tracker data are being used to feed the distraction classifiers by means of different ML techniques in order to develop a DCDM: its output will then be included as an additional input to the HMI logic, so that different warning or recommending strategies may be chosen depending on driver's state. Pilot tests indicated that the users appreciate this kind of assistant systems: they are aware of the risks of highway traffic and they would rather have a LCA on their car. Comments by the pilots' participants will be taken into account to tune some parameters of the system, such as some threshold values, and their evaluation of the HMI indicated that the warning sound should be replaced with a more alerting one. Further experiments will be carried out as soon as the revised version of the C-LCA is fully developed: its effectiveness in improving the driving performance will be the main subject of the next investigations within the D3CoS project, as well as the user acceptance and trust.

Acknowledgement

This research has been funded by the ARTEMIS Joint Undertaking in the interest of the project D3CoS (http://www.d3cos.eu) – Grant Agreement 269336.

References

Arnett, J. (1994). Sensation seeking: a new conceptualization and a new scale. *Personality and Individual Differences, 16*, 289-296.

Baldi, P. & Brunak, S. (2001). *Bioinformatics: The Machine Learning Approach, 2nd edition*. Cambridge, MA: The MIT Press.

Endsley, M.R. (1996). Automation and situation Awareness. In R. Parasuramann and M. Mouloua (Eds.) *Automation and Human Performance: Theory and Applications* (pp. 163-181). Mahwah, NJ: Lawrence Earlbaum.

Fitch, G.M. & Hankey, J.M. (2012). Investigating improper lane changes: driver performance contributing to lane change near-crashes. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting 2012* (pp. 2231-2235).

Flemisch, F., Kelsch, J., Löper, C., Schieben, A., Schindler, J. & Heesen, M. (2008). Cooperative control and active interfaces for vehicle assistance and automation. *ATZ – Automobiltechnische Zeitschrift*, 9.

Heesen, M., Baumann, M., Kelsch, J., Nause, D. & Friedrich, M. (2012), Investigation of Cooperative Driving Behaviour during Lane Change in a Multi-Driver Simulation Environment. In D. de Waard, K. Brookhuis, F. Dehais, C. Weikert, S. Röttger, D. Manzey, S. Biede, F. Reuzeau, and P. Terrier (Eds.) (2012), *Human Factors: a view from an integrative perspective. Proceedings HFES Europe Chapter Conference Toulouse 2012* (pp. 305-317).

Lee, J.D., Caven, B., Haake, S. & Brown, T.L. (2001). Speech-based interaction with in-vehicle computers: the effect of speech-based e-mail on drivers' attention to the roadway. *Human Factors, 43*, 631–640.

Liang, Y., Reyes, M.L. & Lee, J.D. (2007). Real-time detection of driver cognitive distraction using support vector machines. *IEEE Transactions on Intelligent Transportation Systems, 8*, 340–350.

Mattes, S. (2003). The lane change task as a tool for driver distraction evaluation. *IHRA-ITS Workshop on Driving Simulator Scenarios*, Dearborn, MI.

Montag, I. & Comrey A.L. (1987). Internality and externality as correlates of involvement in fatal driving accidents. *Journal of Applied Psychology,72*, 339-343.

Roelofsen, M., Bie, J., Jin, L. & van Arem, B. (2010). Assessment of safety levels and an innovative design for the Lane Change Assistant. In *Intelligent Vehicles Symposium (IV), 2010 IEEE* (pp. 83-88).

Strayer, D.L. & Johnston, W.A. (2001). Driven to Distraction: Dual-Task Studies of Simulated Driving and Conversing on a Cellular Telephone. *Psychological Science, 12,* 462-466.

Tan, P.-N., Steinbach, M. & Kumar, V. (2005). *Introduction to Data Mining*. Boston, USA: Pearson Addison Wesley.

Tango, F. & Botta, M. (2009). Evaluation of Distraction in a Driver-Vehicle-Environment Framework: an application of different Data-mining techniques. In P. Perner (Ed.), *Advances in Data Mining. Applications and Theoretical Aspects* (pp. 176-190). Berlin: Springer Berlin Heidelberg.

Visvikis, C., Smith, T.L., Pitcher, M. & Smith, R. (2008). *Study on lane departure warning and lane change assistant systems* (PPR 374). Wokingham, UK : Transport Research Laboratory.

Vokrinek, J., Janovsky, P., Faigl, J., Benda, P., Tango, F. & Pinotti, D. (2013). A cooperative driver model for traffic simulations. In *Industrial Informatics (INDIN), 2013 11th IEEE International Conference* (pp. 756-761).

Young, K., Regan, M. & Hammer, M. (2003). *Driver Distraction: a review of the Literature* (Technical Report No 206). Monash, AUS: Monash Injury Research Institute.

Zhang, Y., Owechko, Y. & Zhang, J. (2004). Driver cognitive workload estimation: a data-driven perspective. In *Intelligent Transportation Systems, 2004. Proceedings. The 7th International IEEE Conference* (pp. 642-647).