Smart Mobility: Driver State Estimation and Advanced Driver-Vehicle Interfaces

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Abstract With increasingly complex user interfaces and advancing automation, measuring the state of the driver has never been more important. By using sensor fusion techniques we combine information from multiple sources to accurately and robustly measure the driver's state—drowsiness and attention, workload and cognitive load, pleasure and anxiety. Only by integrating and synchronizing all the data streams can we properly understand the interaction of the driver and the vehicle.

Keywords Driver · Behavior · Human factors · Simulator · Eye-tracking · Multi-modal data integration

1 Introduction

With the trend towards automated vehicles, the role of the driver is changing. This means that all sorts of new questions arise with respect to studying driver-vehicle interaction. How can the driver keep alert enough to intervene at the moment he or she needs to override the automatic system? What is the experience of the driver and passengers in an advanced car—do they feel safe, trusting the automation, or helpless and nervous? Measuring the state of the driver has never been more important, and this has led to a demand for new methods and tools. At the same time, it has become clear that to fully understand the driver's state, it is not sufficient to rely on a single measure, but use of sensor fusion techniques combining multiple modalities is necessary. In the Netherlands, several public-private partnerships have been formed between knowledge institutes and corporations to address these challenges in a wide variety of settings, from driving simulators to instrumented cars, to fully autonomous self-driving vehicles on the public road. In those cases we and our partners have developed tools to measure the driver's state by combining state-of-the art measurements including eye tracking, physiology

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(heart rate, skin conductance), facial expression and behavior of the vehicle/simulator. Without integration and synchronization, these data are much less useful. For instance, if a driver looks at a point on the display of a simulator and the simulator displays a person at that point, it is only by combining the data that you can know that that the driver has seen the pedestrian. These techniques have proved so promising that they have been incorporated into commercial products currently being released onto the market. Besides driver studies, these techniques are applied to a variety of other domains, such as consumer behavior in virtual supermarkets.

2 Why Measure Driver Behavior in a Simulated Environment?

Measuring driver behavior in a virtual (simulated) environment has a number of advantages over similar measurements in an actual car:

- It is possible to run exactly the same scenario for multiple subjects (for example precisely the same traffic on the road).
- You can include scenarios which would otherwise be too dangerous (for example a pedestrian stepping out in front of the car).
- It is possible to test scenarios which normally only rarely occur (such as failure of a component of the car).
- You can more cheaply and easily test scenarios for which you want to test several variants (e.g. several UI designs).
- It can also be easier to instrument a simulator with measurement devices such as physiological sensors and eye trackers than a real car.

However, if data from those sensors are not integrated and synchronized with the simulator data, then interpretation is limited and difficult. In this paper we present an integrated system, named DriveLab, which has been designed to overcome precisely that issue.

3 DriveLab System Description

DriveLab [1, 2] has been developed in the ADVICE project (see Acknowledgments). It is built with a modular architecture around an integration and synchronization platform. There are a number of core components, fundamental to the system, and a variety of optional components which have been tested for compatibility with DriveLab, but are not required for its operation. It is an open system, so that other modules can be added as required (Fig. 1).

Fig. 1 DriveLab in operation

3.1 Core Components

3.1.1 Driving Simulator

A core component of a DriveLab setup is the driving simulator. The first DriveLab implementation is based on a Green Dino simulator. Green Dino BV is a Dutch developer of driving simulators for both instructional and research purposes. The driver is seated with a physical steering wheel and controls such as pedals and hand brake, and both the instrument display of the car and the external view (windscreen, side windows and mirrors) are created virtually. The simulator is programmed with a number of predefined routes and events, which can be modified by the user, and all data generated by the simulator is available to the rest of the DriveLab system.

3.1.2 Eye Tracker

The Swedish company Smart Eye AB produces high-end 3D remote eye trackers. These have a number of features which make them especially suitable for automotive applications. They can use multiple cameras, so that a wide field of view (up to 360°) can be encompassed, giving the test subject complete freedom of head rotation. In the DriveLab system we use an eye tracker with three cameras. 3D depth is correctly interpreted (e.g. the system knows if the driver is looking at the dashboard or out of the car and there is no parallax effect). The eye tracker gives data output for both the head, left and right eye with over 145 parameter values including gaze tracking, head tracking (6DOF), eyelid tracking, pupil tracking, raw and filtered gaze, blinks, fixations, and saccades.

3.1.3 Audio-Video Recording and Behavioral Annotation

The driver's body posture and gestures are captured with a scene camera, mounted behind the driver and looking forward over his shoulders. The video stream is recorded with Noldus' Media Recorder software, and this is fed into Noldus' The Observer XT software, where it can (optionally) be annotated by the researcher to log specific behavioral events. The scene video is shown with a gaze overlay superimposed from the eye tracking data.

3.1.4 Integration and Synchronization

A key development in the ADVICE project was a communication protocol between all the various components, named N-Linx. N-Linx enables data from all the different components to be streamed real-time. It uses the RabbitMQ messaging framework as a platform for sending and receiving messages. RabbitMQ was selected as it is open source software supporting all major operating systems and most development environments (see Fig. 2). It is also scalable (more servers can be added) and can deal with lost connections without losing data.

An example of the use of N-Linx is the automated tracking of the driver's visual fixation on moving objects. The driver's point of gaze coordinates, recorded by the eye tracker, are sent (using N-Linx) to the simulator, which returns the identity of the virtual object being displayed at that specific position. Thus, the system can track which objects (UI items, road signs, cyclists, etc.) the driver looks at. The combined data is then sent back via N-Linx and then, together with the rest of the

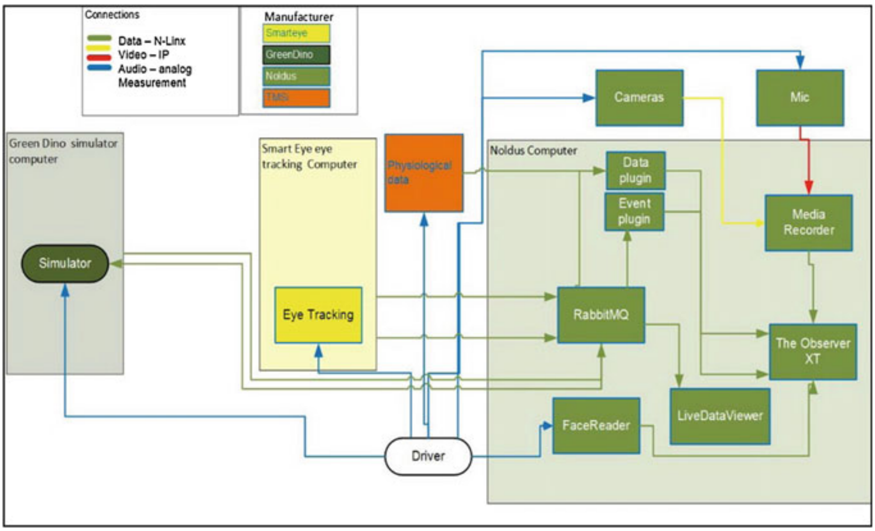

Fig. 2 Schematic diagram of the communication and architecture of DriveLab

data streams (facial expressions, physiological data, etc.), sent to The Observer XT. The Observer XT is Noldus' software for behavioral coding, which also serves as a data integration platform [3].

3.1.5 Data Analysis

In The Observer XT all the data can be analyzed. In particular, a selection can be made of particular persons, behaviors, and time slices relevant to study; for instance the eye blink rate whilst carrying out a particular task or the speed of the car when the simulator presented a road sign that was not observed (for instance if the driver was looking at the dashboard).

3.2 Optional Components

3.2.1 Physiology

Measures such as driver alertness, workload and stress can most effectively be measured by combining physiological data with other measures (such as pupil diameter and blink rate). DriveLab uses The Observer XT to integrate and synchronize the physiological data with the other data streams. This means that the system can work with virtually all commercial physiological data acquisition systems. In the ADVICE project, a TMSi Porti (www.tmsi.com) was used. A similar setup has also been tested with Near Infra-Red Spectroscopy (NIRS) equipment manufactured by Artinis Medical Systems (www.artinis.com). Both TMSi and Artinis support the N-Linx protocol.

3.2.2 Emotion

The emotional state of the driver can be measured by video analysis of their facial expressions with Noldus' FaceReader software. This software measures the six basic emotions (happiness, sadness, surprise, fear, disgust and anger) as well as neutral [4]. In addition it gives a measure of both the valance (balance of positive and negative emotions) and arousal as well as other measures such as the opening or closing of eyes or mouth, raising of eye brows, and facial action units [5] (which indicate more subtle emotions, which could be relevant in this context).

3.2.3 Live Data Viewer

Noldus also developed special software (named Live Data Viewer) for customizable live visualization of all data streams (Fig. 3). This has a two purposes. Firstly,

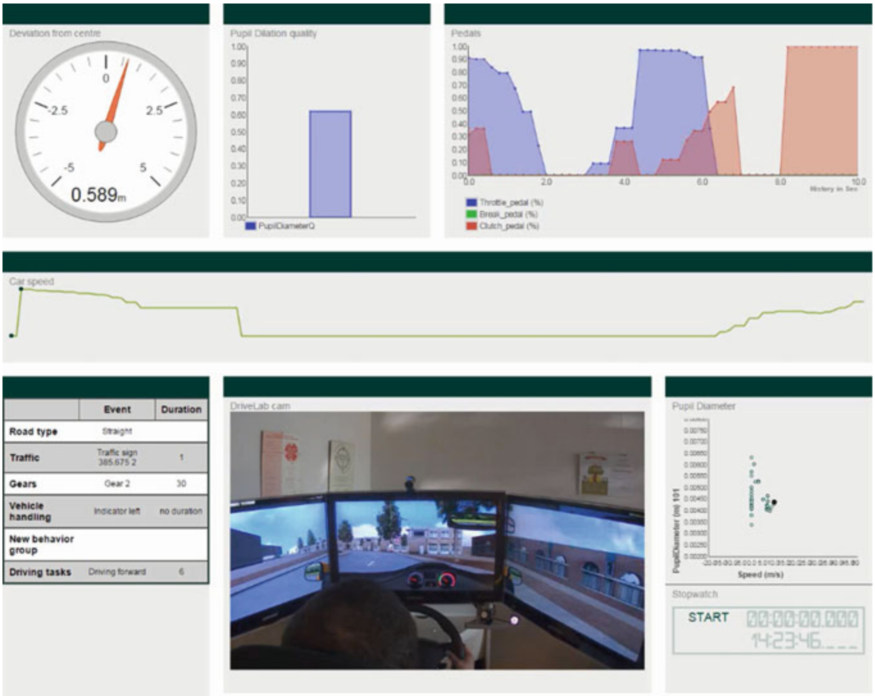

Fig. 3 DriveLab live data viewer showing data from three sources (simulator, eye tracker and video camera) with a variety of different visualizations

to enable the researchers to monitor the measurements, for instance to check that all the instrumentation is working correctly. Secondly so that the test leader can react appropriately to specific events in real-time, for example to give feedback to a trainee or to alter the experimental conditions accordingly. The Live Data Viewer can be configured so that the user can define which data sources he or she wants to see, and also which visualization of the data is most relevant, as well as setting a number of parameters such as the maximum and minimum data values. The Live Data Viewer runs in a browser on PCs, notebooks, tablets or smartphones, allowing researchers to monitor DriveLab sessions in the lab or from a remote location.

4 Conclusions and Future Developments

The methods presented in this paper demonstrate the possibility and the added value of measurements which do not just measure one aspect of a person's behavior, but integrate several different channels (sensor fusion) to give a more robust and more complete behavior. The upcoming Internet of Things and associated increasing availability of relatively cheap and abundant sensors gives many possibilities in this respect. The partners in ADVICE are also working in other projects on applying the same technology to different domains, for instance we are studying consumer behavior in a virtual shop [6] with the addition of EEG and NIRS [7] measurements.

Within the project the main focus now is to further develop it so that DriveLab also works in an actual car as well as a simulator [8]. Although simulators have a number of advantages, there are also disadvantages such as simulator sickness [9] and validity [10]. We have also shown the validity of DriveLab or its components in several practical use-cases [11].

Acknowledgments DriveLab has been developed in the project ADVICE (Advanced Driver Vehicle Interface in a Complex Environment) [12], which is funded by the Dutch Ministry of Economic Affairs and will finish in December 2015. The partners in the project are: HAN University of Applied Sciences (www.han.nl/international/english/), Delft University of Technology (www.tudelft.nl/en/), Noldus Information Technology (www.noldus.com), TNO (www.tno.nl/en/), and TomTom (www.tomtom.com).

References

1. DriveLab website (2015). Retrieved 16 June 2015 from http://www.noldus.com/innovationworks/products/drivelab.
2. Tobias Heffelaar, Jorrit Kuipers, Jonas Andersson, Leon Wiertz & Lucas Noldus (2014). Easy to Use Driving Behavior Analysis Using DriveLab. HCI International 2014 - Posters' Extended Abstracts. Springer International Publishing. Pp 330–334.
3. Patrick H. Zimmerman, Liesbeth Bolhuis, Albert Willemsen, Erik S. Meyer, and Lucas P.J.J. Noldus (2010). The Observer XT: a tool for the integration and synchronization of multimodal signals. Proceedings of Measuring Behavior 2008 (Maastricht, The Netherlands, August 26–29, 2008). Eds. A.J. Spink, M.R. Ballintijn, N.D. Bogers, F. Grieco, L.W.S. Loijens, L.P.J.J. Noldus, G. Smit, and P.H. Zimmerman. Pp 125-126.
4. Lewinski, P.; den Uyl, T.M.; Butler, C. (2014). Automated facial coding: validation of basic emotions and facs aus in FaceReader. *Journal of Neuroscience, Psychology and Economics*, 7 (4), 227–236.
5. P. Ekman and W. Friesen. *Facial Action Coding System: A Technique for the Measurement of Facial Movement*. Consulting Psychologists Press, Palo Alto, 1978.
6. FOCOM website. Retrieved 16 June 2015 from: http://www.noldus.com/projects/focom-food-and-cognition-model-systems.
7. Villringer, J. Planck, C. Hock, L. Schleinkofer, U. Dirnagl (1993), Near infrared spectroscopy (NIRS): A new tool to study hemodynamic changes during activation of brain function in human adults. *Neuroscience Letters*, 154 (1–2), 101–104.
8. Tobias Heffelaar, Renske B. Landman, Menno Merts, Jasper Michiel van Hemert, Arjan Stuiver, Lucas Noldus (2014). Driver state estimation: from simulation to the real world. Proceedings of Measuring Behavior 2014, (Wageningen, The Netherlands, August 27–29, 2014). Eds: A. Spink, L. Loijens, M. Woloszynowska-Fraser & L Noldus.
9. Brooks, J.O., Goodenough, R.R., Crisler, M.C., Klein, N.D., Alley, R.L., Koon, B.L., & Wills, R.F. (2010). Simulator sickness during driving simulation studies. *Accident Analysis & Prevention*, 42(3), 788–796.

10. Bédard, M.B., Parkkari, M., Weaver, B., Riendeau, J., Dahlquist, M. (2010). Assessment of driving performance using a simulator protocol: Validity and reproducibility. *American Journal of Occupational Therapy,* 64, 336–340.
11. Kuipers, J. (2014). Automation of training and assessment with DATA Centred Design (DCD). Proceedings of Measuring Behavior 2014, (Wageningen, The Netherlands, August 27–29, 2014). Eds: A. Spink, L. Loijens, M. Woloszynowska-Fraser & L Noldus.
12. ADVICE project (2015). Retrieved on 16 June 2015 from http://www.noldus.com/projects/advice.
13. Kuipers, J. (2014). Multi variable strategy reduces symptoms of simulator sickness. Proceedings of Measuring Behavior 2014, (Wageningen, The Netherlands, August 27–29, 2014). Eds: A. Spink, L. Loijens, M. Woloszynowska-Fraser & L Noldus.