The ConTRe (Continuous Tracking and Reaction) Task: A Flexible Approach for Assessing Driver Cognitive Workload with High Sensitivity

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ABSTRACT

The importance of understanding cognitive load in driving scenarios cannot be stressed enough. With a better management of cognitive resources, many accidents could be avoided, hence it is one of the most critical variables that user experiments attempt to investigate when new in-car systems are introduced. Since there is currently no way to measure it directly, it is often estimated via its impact on primary task performance.

Driver assistance systems have traditionally sported rather simple and uni-modal HMIs, but the recent increase in variety of in-vehicle information systems (IVIS) suggests that a more distinguished look at measurement tasks may be needed. Our research indicates that the few established tasks may not be suitable for estimating distraction in all cases, which consequently makes them an unreliable predictor for cognitive load. For the specific conditions we require in our investigation (e.g. continuity, controllable difficulty etc.), we propose the *ConTRe* (Continuous Tracking and Reaction) Task, which complements the de-facto standard lane change test in order to provide more insight in these cases.

Categories and Subject Descriptors

I.6.m. [**SIMULATION AND MODELING**]: Miscellaneous

General Terms

Measurement, Documentation, Performance, Design, Reliability, Experimentation, Human Factors.

Keywords

cognitive load, workload, driver distraction, driving task, driving simulator

1. INTRODUCTION

During the last decades numerous new in-vehicle information systems (IVIS) have been introduced into modern cars (e.g. navigation systems, media players, travel information, vehicle communication systems, driver convenience services). As most of them can be controlled while driving, it is important to consider possible effects of system usage on driving performance. Prior to bringing these systems onto the road for customers, their influence on driving performance is measured in test-track and on-road studies. Moreover, even before using real cars, because of safety and liability issues new systems need to be tested in driving simulators to investigate effects on cognitive workload and potentially driving performance. A further advantage of simulator studies is the controllability of tracks, situations and exact conditions leading to fewer confound and therefore more efficient evaluation e.g. if you want to find out about differences between systems or interindividual differences. While the importance of simulator studies in general is undisputed, it is an entirely different question how the task should ideally look like for a given system evaluation (e.g. lane change task, vehicle platooning task, wayfinding according to navigation instructions) and which out of numerous metrics (e.g. brake reaction times, lane exceedences, steering angles, glance durations) should be chosen. In the following, we present some common driver distraction measurement approaches and driving simulation solutions, followed by a short summary of our open source driving simulator *OpenDS*. Next, we introduce the *Continuous Tracking and Reaction (ConTRe)* Task and discuss its characteristic advantages for driving performance assessment and inferences with regard to cognitive load. Finally, we will provide first results achieved with the *ConTRe* Task in a recent user study.

2. BACKGROUND

So far, there exist common performance metrics used in driving simulations, as for example vehicle following, lane keeping, or event detection [8]. This variety of metrics can be recorded with the help of rather expensive and complex commercial driving simulators (e.g. [3]). Alternatively, there are some low-cost approaches available for measuring driver distraction. For example, [7] have used the racing simulator *rFactor*, which was originally developed for the entertainment market with a focus on physically believable racing experience. *rFactor* provides the feature of developing and using additional plug-ins. However, the developer is very restricted when creating them: It might be possible to create new racing tracks, but it is not possible to create a complex street system, which would be needed to construct urban areas. Other cars controlled by the computer can be inserted and their general driving style can be modified, but the driving path of these cars or the time they start moving cannot be controlled. Another low-cost driving simulation solution is the *Configurable Automotive Research Simulator (CARS)*, which has been developed and made available as an open-source project [2]. This latter aspect leads to a more flexible solution for researchers, as the source code of *CARS* can be accessed and modified, if necessary. However, *CARS* has two major limitations, which are rooted in its architecture. On the one hand, the map editor, which is contained in the *CARS* software package, severely restricts the size of the maps that can be created. Another disadvantage is the fact that the *CARS* map editor employs a proprietary map format and does not incorporate a standard compliant data format for neither import nor export. The driving simulator itself is also constrained to this map format.

In addition to the aforementioned driving simulation solutions, there exist surrogate driver distraction measurement techniques, like the ISO-standardized lane change test (LCT) [4, 6], which was especially developed for low-cost driving simulators. The LCT is a valuable approach for evaluating the impact of a secondary task on driving performance (i.e. lane keeping, detection of instructional signs and lane changing). Advantages from classic reaction time measurement approaches are integrated into a cost-efficient simulation tool, which provides reliable and valid evaluation results [5]. This has lead to a widespread usage of this task within the research community. However, the LCT has some major drawbacks, which might make it unusable for specific research questions and encourage the design of a novel task. First of all, in the LCT it is not possible to compare interface tasks interrelated with the actual driving situation (e.g. it cannot be used to test new interfaces for navigation systems), as the tracks, the signs and the task are fixed and the 3D model cannot easily be extended. But even if that is not an issue, a researcher might still want to change parameters like task difficulty in order to investigate influences in easy driving conditions opposed to more challenging ones. Another requirement might be a more fine-grained evaluation of driver distraction in terms of temporal resolution. For the task in LCT, drivers only need to change the lanes once in a while by conducting a rather abrupt maneuver combined with simple lane keeping on a straight road in between. But real driving mostly demands rather a continuous adjustment of steering angle and speed without knowing when the next incident will occur. This would require a task which bears more resemblance in interaction to e.g. a car following task. Furthermore, the performance metric is based on a generated, normative model as the ideal line used in the LCT rather than an absolute ground truth of perfect behavior.

The *ConTRe* Task introduced in this paper was created to overcome some of the limitations of the aforementioned approaches. As such, it should be sufficiently controlled to eliminate major subject failures, like going in circles or colliding with objects by mistake, which would interfere with the automatic performance evaluation. Track length and duration should moreover be adjustable according to secondary task demands. Another intended advantage of the *ConTRe* Task over the LCT and also many other standard tasks is the possibility to explicitly address mental demand via a central or peripheral detection task. Effects of cognitive load should be revealed above all by the achieved reaction times. This additional discrete task should be accomplished in addition to the continuous adjustment of steering wheel angles for lateral control, and therefore was implemented as longitudinal control (gas and brake). Each of these two tasks or their combination will provide in general a very sensitive and controlled tool that can, for example, be used for system comparison in early design lifecycle evaluations.

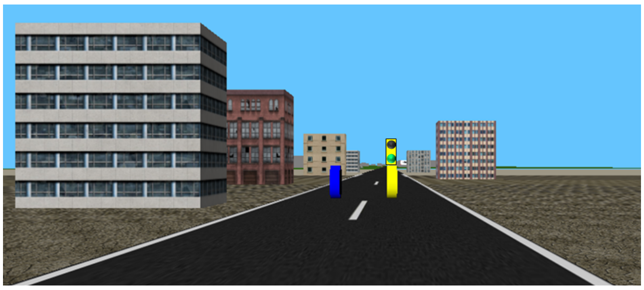

Figure 1: A screenshot of the *ConTRe*. The driver controls the movements of the blue cylinder while the yellow cylinder moves autonomously.

Summing up, we present a new extremely flexible and sensitive task for measuring driver distraction. To facilitate optimal customizability, the task was implemented as part of our modular open-source driving simulation *OpenDS* and can be extended by any programmer of the community. The development of the software is fostered by the EU-project *GetHomeSafe*[1]. The simulation provides an accurate physical environment with realistic forces, lighting, and road conditions. Objects and events can be placed, and traffic can be simulated. A driving task editor can be used to design a task suited for a given experiment, while the simulator runtime provides extensive logging of the subject's driving, and evaluation tools allow both computation and visualization of various metrics, such as deviation from a reference drive.

3. CONTRE TASK DESCRIPTION

The driver's primary task in the simulator is comprised of actions required for normal driving: operating the brake and acceleration pedals, as well as turning the steering wheel. System feedback, however, differs from normal driving. In the *ConTRe* task, the car moves autonomously with a constant speed through a predefined route on a unidirectional straight road consisting of two lanes. Neither operating the acceleration or brake pedal, nor changing the direction of the steering wheel does have an effect on speed or direction of the vehicle. Accordingly, motion rather feels like a video clip. Steering, braking and using the gas pedal do not actually control the car, but instead manipulate a moving cylinder which is rendered in front of the car. On the road ahead, the driver perceives two such cylinders, which continuously move at a constant longitudinal distance (20 meters) in front of the car. The two cylinders differ only in color: one is blue and the other one is yellow. The latter is called the reference cylinder, as it moves autonomously ac-

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[1] http://www.gethomesafe-fp7.eu

cording to an algorithm. The movement direction and the movement speed of the reference cylinder are neither controlled nor predictable by the user, except that the cylinder never exceeds the roadsides. In contrast, the driver controls the lateral position of the blue cylinder with the help of the steering wheel, trying to keep it overlapping with the reference cylinder as well as possible. As the user turns the steering wheel, the controllable cylinder moves to the left or to the right, depending on the direction of the steering wheel and its angular velocity (i.e. the steering wheel controls the cylinder's lateral acceleration). Effectively, this corresponds to a task where the user has to follow a curvy road or the exact lateral position of a lead vehicle, although it is more strictly controlled and thus with less user-dependent variability. Furthermore, there is a traffic light placed on top of the reference cylinder containing two lights: The lower one can be lighted green, whereas the top light shines red when it is switched on. Either none or only one of these lights appears at a time. The red light requires an immediate brake reaction with the brake pedal, whereas green indicates that an immediate acceleration with the gas pedal is expected. As soon as the driver reacts correctly, the light is turned off (see Figure 1).

This task set-up can be adjusted to meet the requirements of a particular experiment by means of modifying certain control variables. This includes the displacement behavior of the reference cylinder and the frequency of the brake and acceleration situations, which can be set before beginning the driving task. The displacement behavior in turn is affected by the displacement velocity, acceleration, and rate of changes. By manipulating these factors, the difficulty level of the driving task can be changed. The driving task can be very challenging when the reference cylinder moves with high speed and the driver has to brake or accelerate frequently due to the condition of the traffic light.

Using this simulator setup, different measurements can be obtained. One value of interest is the distance metric between the reference cylinder and the controllable cylinder. This distance measurement is internally calculated in meters. However, as the width of the street is a fixed value (8 meters), it is transformed into a value relative to the width of the street, where 100% deviation corresponds to the width of a full lane in this two-lane scenario. This way, the resolution of the simulator display will not affect the measurements, as they are calculated relative to the street width. Other relevant values are the reaction times of operating the acceleration or brake pedal, and number of errors (wrong usages of these two pedals) or omissions.

4. EXPERIMENTAL DATA

Since the proposed task has not been published before, no large-scale experience could be obtained with it yet. Instead, our goal with this paper is to give an impression of results that can be achieved with this task and to underpin the internal validity of the method, i.e. to give a proof of concept. For this reason, we present some results of a driver distraction experiment (to be published separately) that was conducted in our lab and that was part of the original motivation for suggesting this task. The goal of the study was to investigate user and context adaptation of interaction concepts for IVIS with respect to driver distraction, secondary task performance, and user acceptance. We assume that an intelligent, adaptive IVIS would be able to provide better safety and value by taking the current context into account [1]. This lead to the more concrete hypothesis that different contexts (e.g. driving difficulty: easy vs. hard) would moderate driving performance for two different feedback modalities (visual vs. audio feedback). One varying driving context is the traffic situation, which – for simplicity – was divided into the two categories *easy* and *hard* in the experiment. Using the *ConTRe* Task's ability to control tracking bar movement speed, the two categories were mapped to two difficulties, reflecting the need for increased correction movements during fast driving or in heavy traffic. The IVIS (secondary task) was a basic POI selection app, and the interaction concepts available to the system were visual and audio feedback. While doing the *ConTRe* Task, participants were asked to find POIs of a certain type on a map shown on an auxiliary screen, which could only be done by selecting POIs (using a touchscreen) and then reading or listening to the details provided by the system. The interaction in this task is not connected to the driving context, hence this precondition for using *ConTRe* is satisfied.

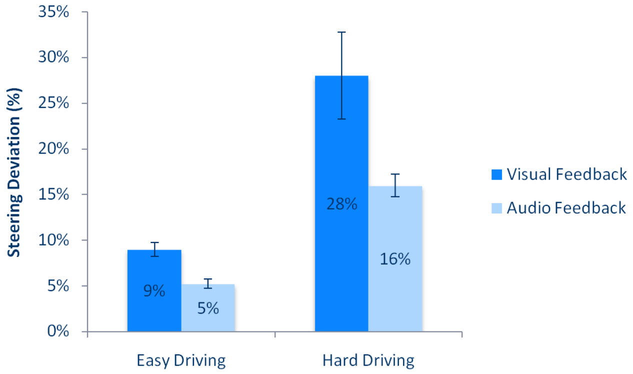

Figure 2: Average steering deviation (in percent, y-axis) and standard error in two driving scenarios (easy and hard, x-axis) and using two output modalities (visual and audio) recorded from 24 participants performing the *ConTRe* Task.

Figure 2 shows the average steering deviation recorded from the subjects in all four combinations. Several reasonable hypotheses are plausibly confirmed by these figures: First, the easy driving condition always causes lower deviation than the hard driving condition ($F(1, 23) = 49.2; p < .001$). This implies high content validity for measuring the driving difficulty levels. Second, for the individual driving difficulty levels the visual modality causes a higher distraction than the (eyes-free) audio modality showing quite a high sensitivity of the method ($F(1, 23) = 12.51; p < .01$). Third, the difference between modalities is stronger in the hard driving condition ($t(23) = 2.78; p < .05$), leading to the conclusion that sensitivity is even high enough to determine quantitative differences between conditions. In addition to this metric, using *ConTRe* as the primary task, further observations were made: The number of completed tasks within a track of constant length is also lower in the hard driving condition, although this effect is not cross-modal ($t(23) = 3.33; p < .01$ for visual and $t(23) = 3.11; p < .01$ for audio). On the other hand, the number of completed tasks is always higher in the visual condition ($F(1,23) = 25.95; p < .001$). For most of the other experiments conducted as part of the study, the hypotheses could likewise be confirmed. Apart from their implications on the experiment goal, the means and standard errors reflected in these figures suggest that the proposed task does indeed provide a solid basis for experimental investigation of fine-grained effects on driver distraction.

5. CONCLUSION

The *ConTRe* Task introduced in this paper extends the assortment of solutions available for measuring driver distraction in simulator environments. It was created to compensate certain potentially weak points of other driving tasks. We expect that user experiments with similar characteristics, as the study of adaptive IVIS described in the previous section, will benefit from the continuity and clean design of the task. A more sensitive task reveals more subtle effects, as significance tests benefit from less experimental data noise and from having a reliable ground truth available. This will again enhance the investigation of cognitive workload, as a more fine-grained evaluation of driving performance will better reveal even a slight decrease in performance induced by higher - or too low - cognitive load. Furthermore, flexibility in driving task difficulty is retained through various configurable parameters. Varying or adjusting current driving task difficulty during a track might be a valuable extension for cognitive workload assessment in the future. While the user study has served successfully as a first application of our new method, additional experience as well as a more formal comparison of different methods are part of future work that is needed to establish the *ConTRe* Task as a permanent constant in the driving task ecosystem.

In this paper, we have presented a high-level description of the implementation. Since the task is written as a driving task “plug-in” for the new extensible open source driving simulation platform *OpenDS*, it will be made freely available in conjunction with the latter within a narrow time frame. Likewise, we will be further enriching the framework with different driving tasks, including some that are more linked to specific and realistic driving conditions, to reach an even broader coverage of test scenarios for driver distraction related to modern in-car systems.

6. FUTURE WORK

Estimating cognitive load will remain a challenge for the next years. Driving tasks such as *ConTRe* bring us one step closer to our goal of reliable and expressive metrics, if we assume a correlation between distraction and load. In a more general sense, we believe that we will not discover a way to measure workload directly in the near future, if at all. Instead, the truth can be approximated by approaching the problem from two perspectives: an observating and a generative strategy, which we both recommend to be equally pursued by future research.

The former category, to which all driving tasks belong, attempts to estimate the current workload by observing and evaluating the subject’s state and reactions. An advantage of this method is that it can be applied without knowledge of the subject’s context and other tasks. The second category, the generative methods, attempt to analyze the factors influencing the subject’s cognitive load, such as context factors (e.g. density of traffic, driving time etc.) or secondary tasks (complexity of the HMI presentation or interactions performed by the driver). This requires a more extensive amount of knowledge, but has the advantage of being able to also predict changes to workload incurred by a certain system behavior. These aspects are part of a separate line of future work that we are looking into and should also take a prominent place on the community’s roadmap.

A third line of work should deal with the relation of the production and measurement side of cognitive load, which are both joined by a cognitive load model. Being able to extend the *ConTRe* Task towards a dynamically and individually adaptable scenario will highly support this line of research. Once we have found and empirically confirmed such a relationship between cognitive workload generation and measurement, this can be seen as strong evidence that the underlying model and formulas are close to the actual processes, hence we consider this a long-term goal of cognitive load modeling.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] R. F. T. Brouwer, M. Hoedemaeker, and M. A. Neerincx. Adaptive interfaces in driving. In *Foundations of Augmented Cognition. Neuroergonomics and Operational Neuroscience*, volume 5638 of *LNCS*, pages 13–19. Springer, 2009.

[2] D. Kern and S. Schneegaß. CARS – Configurable Automotive Research Simulator. *i-com Zeitschrift für interaktive und kooperative Medien*, 8(2):30–33, 2009.

[3] H.-P. Krueger, M. Grein, A. Kaussner, and C. Mark. SILAB - A task-oriented driving simulation. In *Proceedings of the Driving Simulator Conference (DSC) North America*, page 9, Orlando, Florida, 2005.

[4] S. Mattes. *The Lane-Change-Task as a Tool for Driver Distraction Evaluation*, chapter Quality of Work and Products in Enterprises of the Future, pages 57–60. ergonomia Verlag, Stuttgart, 2003.

[5] S. Mattes and A. Hallén. *Driver distraction: Theory, Effects and Mitigation*, chapter Surrogate Distraction Measurement Techniques: The Lane Change Test, pages 107–122. CRC Press, 2009.

[6] I. O. of Standardization. ISO-26022: Road vehicles: Ergonomic aspects of transport information and control systems – simulated lane change test to assess in-vehicle secondary task demand. Technical report, ISO, 2010.

[7] G. Weinberg and B. Harsham. Developing a low-cost driving simulator for the evaluation of in-vehicle technologies. In *AutomotiveUI*, pages 51–54, 2009.

[8] K. L. Young, M. A. Regan, and J. D. Lee. *Driver distraction: Theory, Effects and Mitigation*, chapter 7: Measuring the Effects of Driver Distraction: Direct Driving Performance Methods and Measures, pages 85–105. CRC Press, Florida, 2009.