The automated vehicle in the loop - A test platform for future driving

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ABSTRACT

Realistic vehicle dynamics can exert a non-trivial influence on how we interact with vehicles as well as behave within them. This pertains to the burgeoning field of automated vehicles too. In this paper, we present a novel test platform that allows human factors research to be evaluated under controlled settings that, nonetheless, supports the presentation of realistic vehicle dynamics. Specifically, we present an automated vehicle-in-the-loop (AN-VIL). AN-VIL is a real automobile that is able to present a virtual visualization of a driving scenario that corresponds to how the vehicle is being handled. This is achieved by mapping the vehicle movements through the scenario with a test track. In this paper, we present the capabilities of this vehicle and its underlying software and hardware implementation. We conclude by discussing the potential of this system and how its unique role, relative to laboratory simulators or experimental vehicles for field testing.

CCS CONCEPTS

• **Human-centered computing** → **User models** • **Humancentered computing**.

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KEYWORDS

Automated vehicles; Autonomous vehicles; (semi-)autonomous vehicles; Distraction; Interruptions; In-car activities; Mobile Office

INTRODUCTION

Recent years have witnessed a dramatic upsurge in research on the use of automated vehicles [6]. This topic presents uncharted territory for several reasons. First, it is unclear how using automated vehicles might modify existing driving capabilities or, in fact, the skills that users ought to possess [7, 11]. Hence, it remains uncertain which in-vehicle activities can be safely performed under realistic settings. Besides this, the aims of delivering a safe experience can sometimes be antagonistic to those of a satisfactory experience.

The uncertainty of what users want and ought to be allowed to do brings about an ill-specification of automated vehicle capabilities and their user interfaces. The interior of automated vehicles will undoubtedly undergo a radical redesign with the uptake of automated driving. This is because vehicle handling will simply cease to be the primary cockpit task. With vehicle automation, driving will be the new distraction and the prominence of the steering wheel and foot pedals will steadily give way to other interfaces that more effectively support what users might desire to do, instead of driving. Thus, novel design spaces for individual productivity and entertainment are of growing importance [6]. In summary, interior design of automated vehicles needs great attention to meet the user requirements and challenges in human interactions with automated vehicles.

On the one hand, design evaluations of safe and satisfactory an in-vehicle non-driving experience will require highly controlled settings that are not easily manipulable with field testing vehicles. On the other hand, recent research has also demonstrated that vehicle dynamics exert a non-trivial influence on human interactions with automated vehicles [8, 10]. Thus, both field testing as well as fixed-base driving simulators [1] are limited in evaluating human interactions with automated vehicles. This raises a need for a new test platform for evaluating automated driving environments.

To overcome these challenges, we implemented an automated interconnected vehicle-in-the-loop (AN-VIL) that is capable of presenting the same scenario repeatedly, in terms of event visualization as well as vehicle dynamics.

TECHNICAL IMPLEMENTATION

The vehicle-in-the-loop (VIL) is a real car that is operated on a mapped test track. The VIL provides kinaesthetic, vestibular, and in parts, auditory feedback of a real car with a simulated visual view [2]. The visualization display of the driver's view can be a head-mounted display [2] or monitors and a projection screen Figure 1 [9]. In summary, drivers experience the real interaction with the

Figure 1: Front and side view of the VIL

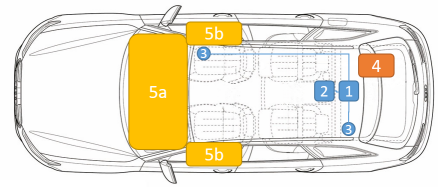

Figure 2: Schematic setup of the VIL (1) IMU, (2) GNNS-antenna, (3) HF-antenna, (4) consumer computer

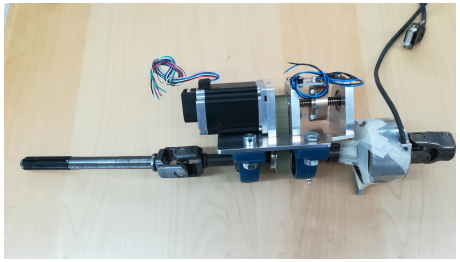

Figure 3: steering actuator

car while seeing a virtual environment. This gives researchers the possibility to conduct highly controlled experiments with real vehicle dynamics and, thus, the evaluation of human interactions with automated vehicles.

The VIL solves two challenges, (1) the mapping of the car onto a test track and (2) the visualization of a simulated environment mapped onto the test track. The mapping of the vehicle is done by an inertial measurement unit (IMU) (Figure 2 (1)) and based on a differential GNSS (dGNSS)-signal received by the GNSS- and HF-antennas (Figure 2 (2) and (3)). To obtain highly accurate position data, a dGNSS-station on a known coordinate is needed. These components provide an accurate mapping of the vehicle on a test track. The visualization is done by constructing virtual environments (currently implemented in VIRES [12]) that are also mapped to the test track. The fusion of the vehicle position and simulation is done by a consumer computer (Figure 2 (4)). The front view is projected with a near field projector onto a screen directly at the windscreen (1980x1080) (Figure 2 (5a)). Both side views use 29 inches monitors (1980x1080) (Figure 2 (5b)) [4, 9]. In summary, the VIL combines the strength of driving simulation (e.g. virtual environment visualization) with real vehicle dynamics.

The integration of autonomous capabilities is the last missing part to implement a test platform for autonomous vehicles, which enables experiments in which the driver is disengaged from vehicle control. Automation of the VIL required, on the one hand, the actuation of steering, acceleration, and deceleration. On the other hand, control algorithms are implemented to drive on a pre-planned path like a GNSS path or conduct online path planning [3]. The actuation of the steering is done by a stepper motor integrated into the steering column (Figure 3). The stepper motor enables a maximum actuation of the steering wheel of 180deg/sec depending on driving conditions. The vehicle acceleration is controlled via electrical signals. Deceleration will be realized by a special mechanical modification attached to the brake pedal. The separation of all three components provides a high level of safety in the case of one system failure. Three safety mechanism handle system failures: (1) a central power off button (Figure 4), (2) a hands-on detection in the steering wheel and (3) a safety driver.

The GNSS path following is done by a model predictive control strategy for online steering and speed control [3]. The algorithm takes care of speed and path optimization at the same time. The integration of these four components allows the AN-VIL to automatedly drive along a path.

OPPORTUNITIES

Figure 4: emergency stop button in the AN-VIL

[1]The Tesla autopilot mode did not recognize a light colored truck against a light sky. The system tried to handover to the driver, who did not respond. Neither the system nor the drive could handle the situation, which lead to a tragic accident [13].

The evaluation of automated cars requires a new test platform that combines highly controlled experiments like driving simulators but also features real vehicle dynamics. We introduced the AN-VIL which is an automated real vehicle with a virtual environmental visualization Figure 1.

The use of the AN-VIL allows replication of the same experimental procedure for all participants. This includes, on the one hand, traffic conditions that are reproducible and standardized for all participants. But also, vehicle dynamics like accelerations and decelerations can follow the same pattern. These dynamics are of critical importance in automated testing to get valid and reproducible results [8, 10]. A concern with driving simulation is simulator sickness. Even though first studies with the VIL showed a slight increase of simulator sickness, a recent study reported an enjoyable driving experience of the VIL [4]. The main concern of participants was the different resolution between front view and side view, which has been improved by introducing a new projector. Even though the VIL does not integrate auditory feedback of the virtual environment, participants in the study reported high immersion [4]. Participants have demonstrated satisfactory responses to radar traps and emergency braking.

A use case of the AN-VIL are tests of different interfaces that facilitate control transfer between automation and the user. In this context, multi-modal interfaces and adaptive systems could actively manipulate the driver's involvement across different tasks. Another topic is trust in automation. For the purpose of testing hand-over and trust, virtual situations and errors that are too dangerous in real traffic can be simulated. A possible situation could be the known Tesla accident[1]. Within this scenario influences on situational awareness can be manipulated and tested safely.

CONCLUSION

To summarize, this paper reports a novel test platform, AN-VIL, for evaluating user-centric aspects of automated driving. On the one hand, it allows for experiments that can be highly controlled for the timing and presentation of events (e.g., handover, path trajectory, collisions). On the other hand, it features realistic vehicle dynamics that recent research has shown to be a non-trivial mitigating factor on in-vehicle user behavior [8, 10]. Respectively, this combines the reasons for favoring the use of either an experimental driving simulator or an actual vehicle in the real world. Furthermore, this platform could allow us to verify the robustness of results obtained from highly-controlled environments, prior to assuming the costs and liabilities associated with real-vehicle testing.

Currently, our users report high levels of immersion. Nonetheless, we believe this could be further improved with the introduction of an auditory simulation, such as environmental sounds generated by other road users. The visual simulation is, to date, based on proprietary software (i.e., VIRES [12]), which allows it to be compatible with standardized simulations performed conventional driving simulators.

REFERENCES

[1] Bellem, H., Klüver, M., Schrauf, M., Schöner, H.-P., Hecht, H. and Krems, J.F. 2017. Can we study autonomous driving comfort in moving-base driving simulators? A validation study. *Human factors*. 59, 3 (2017), 442–456. DOI:https://doi.org/10.1177/0018720816682647.

[2] Berg, G., Nitsch, V. and Färber, B. 2016. Vehicle in the loop. *Handbook of driver assistance systems*. H. Winner, S. Hakuli, F. Lotz, and C. Singer, eds. Springer International Publishing. 199–210.

[3] Gerdts, M., Karrenberg, S., Müller-Bessler, B. and Stock, G. 2009. Generating optimal trajectories for an automatically driven car. *Optimization and Engineering*. 10, 4 (2009), 439–463. DOI:https://doi.org/10.1007/s11081-008-9047-1.

[4] Graichen, M., Graichen, L., Rottmann, T. and Nitsch, V. 2018. Using the projection-based vehicle in the loop for the investigation of in-vehicle information systems: First insights. *Proceedings of the 4th international conference on vehicle technology and intelligent transport systems*. M. Helfert and O. Gusikhin, eds.

[5] Huber, A. and Gerdts, M. 2017. A dynamic programming mpc approach for automatic driving along tracks and its realization with online steering controllers * *this material is partly based upon work supported by the air force office of scientific research, air force materiel command, usaf, under award no, fa9550-14-11-0298. *IFAC-PapersOnLine*. 50, 1 (2017), 8686–8691. DOI:https://doi.org/10.1016/j.ifacol.2017.08.1529.

[6] Kun, A.L., Boll, S. and Schmidt, A. 2016. Shifting gears: User interfaces in the age of autonomous driving. *IEEE Pervasive Computing*. 15, 1 (2016), 32–38. DOI:https://doi.org/10.1109/MPRV.2016.14.

[7] Kyriakidis, M., Winter, J.C.F. de, Stanton, N., Bellet, T., van Arem, B., Brookhuis, K., Martens, M.H., Bengler, K., Andersson, J., Merat, N., Reed, N., Flament, M., Hagenzieker, M. and Happee, R. 2017. A human factors perspective on automated driving. *Theoretical Issues in Ergonomics Science*. 53, (2017), 1–27. DOI:https://doi.org/10.1080/1463922X.2017.1293187.

[8] Mayer, S., Le, H.V., Nesti, A., Henze, N., Bülthoff, H.H. and Chuang, L.L. 2018. The effect of road bumps on touch interaction in cars. *Proceedings of the 10th international conference on automotive user interfaces and interactive vehicular applications - automotiveui '18* (New York, New York, USA, 2018), 85–93.

[9] Riedl, B. and Färber, B. 2015. Evaluation of a new projection concept for the vehicle in the loop (vil) driving simulator. *Proceedings of dsc 2015 europe driving simulation conference & exhibition*. H.H. Bülthoff, A. Kemeny, and P. Pretto, eds. 225–226.

[10] Sadeghian Borojeni, S., Boll, S.C., Heuten, W., Bülthoff, H.H. and Chuang, L. 2018. Feel the movement: Real motion influences responses to take-over requests in highly automated vehicles. *CHI 2018* (New York, NY, 2018), 1–13.

[11] Stanton, N.A. and Marsden, P. 1996. From fly-by-wire to drive-by-wire: Safety implications of automation in vehicles. *Safety Science*. 24, 1 (1996), 35–49. DOI:https://doi.org/10.1016/S0925-7535(96)00067-7.

[12] VIRES Simulationtechnologie GmbH 2018. VTD: Vitual test drive. VIRES Simulationtechnologie GmbH.

[13] Yandron, D. and Tynan, D. Tesla driver dies in first fatal crash while using autopilot mode. *The Guardian*. 2016.