

Technical setup of a Wizard-of-Oz vehicle for on-road AI data collection

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Abstract

This paper presents an implementation of a new solution that improves data collection for artificial intelligence (AI) applications with a Wizard-of-Oz (WoZ) vehicle. It allows to immerse test participants in on-road studies into experiences of not yet existing systems. As measurement technology, the paper focusses on a stereo camera Advanced Occupant Monitoring System which detects driver activities in real time and further allows to collect AI training data for activity and driver state classification. Three application areas for data collection with this setup for automated driving are presented: Support for level compliant behaviour of drivers, identification, and influence of motion sickness on driving ability and improving proactive interaction of smart assistants with vehicle passengers. To constantly adjust and improve hard- and software to the data collection requirements of the different applications, the modular vehicle setup and data collection procedure can be adjusted in an iterative process.

Keywords: Wizard-of-Oz vehicle, Occupant Monitoring

Introduction

The field of Human-Computer Interaction still faces challenges in the design and development of human-centered AI applications in the car. Due to the complex and resource-intensive technology of AI systems and their complex outcome, it is challenging to easily create prototypes which include all possible ways the AI system can interact with the user (Yang et al., 2020). This leads to a lack of structured approaches for the design of adaptive AI systems and interfaces in human-AI interaction so far (Yang et al., 2020). Besides this, the availability of (labeled) real-world driving data, which are a prerequisite for the development of a corresponding application, is often a challenge because of time consuming semi-manual labeling approaches (Nieto et al., 2021).

In the past, most of the data for the development of AI-based systems were collected in driving simulator studies, which represent a well-controlled study environment with few noisy data. In comparison, real-world driving studies have the advantage of representing driving behaviour in real traffic, considering other transport users and pedestrians. This allows the collection of more realistic data of users' behaviour. Furthermore, the possibility of using an extensively equipped vehicle on the road gives better insights on driver distraction and users' behaviour in unpredictable situations in real time and therefore represents a good addition to the standard ways of data collection with self-reports and questionnaires before and after the ride (Carsten et al., 2013). Especially the simultaneous use of multiple sensors in the car allows a multimodal data collection of e.g., video data, physiological data, and vehicle-specific data (Li et al., 2013) and therefore provides various naturalistic data for the training of AI-based systems.

Different types of real-world driving studies are described in literature, including controlled on-road studies, field operational tests and naturalistic driving studies (Carsten et al., 2013). The selection of a suitable study design depends on the research question. If the user performance under certain circumstances on predefined routes should be examined, a controlled on-road study setup is best suited. This type of data collection lasts between minutes and hours. An automated data collection over several days, weeks or even months is best examined in an operational field test or naturalistic driving study (Carsten et al., 2013). Whereas the former is often used to study the impact of new driver assistance systems on driving, naturalistic driving studies are best suited for a better understanding and the identification of problematic traffic situations (Carsten et al., 2013). However, a major challenge for the development and evaluation of autonomous driving functions is the low availability of highly automated vehicles for research (Habibovic et al., 2016). A well-established technique for the conceptualization and evaluation of automated systems is the WoZ approach in which a human ("wizard") performs the tasks of the AI-based system, which gives the user the impression of interacting with a fully automated system (Fraser & Gilbert, 1991). The WoZ technique originates from the area of voice interface design but is also applied in the automotive sector, to simulate and evaluate HMI functions as well as user behaviour during partial or fully automated rides and transitions (Kiss et al., 2008). In case of using the WoZ approach during real-world driving, it allows the data collection and the investigation of more natural behaviour of the user during the ride.

The following paper is divided into two main parts. First, we present in detail the advanced architecture of the WoZ vehicle, based on the first description in Diederichs et al. (2021), as well as the integration of measurement technology and data synchronization. Next, the application of the WoZ vehicle in three different data collection scenarios for driver monitoring and AI-based applications is described. The first two focus on the influence of motion sickness on driving performance and take over ability, as well as on the classification of non-driving related tasks during different automation levels. The third scenario describes the use of the WoZ vehicle as a naturalistic environment to evaluate the interaction between the user and a speech assistant to identify opportune moments for proactive interactions with the user. The described applications are developed as part of the project KARLI with the aim to drive forward the transfer of results on intelligent interaction concepts in the vehicle from research to series vehicles (Diederichs et al., 2022).



Figure 1 - Exemplified setup of the measurement technology in the WoZ vehicle, including interior camera systems, eye tracking technology, microphones, physiological sensors, CAN bus interfaces as well as several hardware for data storage.

Research Vehicle

Advanced architecture

In the following, the technical setup of the WoZ vehicle of Fraunhofer IAO is described in more detail. The WoZ vehicle described in this paper is a right-hand-drive Volkswagen Caddy equipped with three seats; left and right front seat, as well as a separated driver cabin in the back of the vehicle. Each of them is equipped with its own steering wheel. Since the introduction of the functions and the setup of the WoZ vehicle in Diederichs et al. (2021), several adjustments were made. Thus, both front seats are now equipped with double pedals and mechanically connected steering wheels. Forces from the steering wheel at the back seat are transmitted by an electric motor, implemented by the space drive system developed by Paravan, which includes a steer by wire technology (Paravan, 2022). The takeover between manual and automated driving functions (transitions) can be performed during the ride by pressing a button between both front seats. To fulfil the WoZ approach and maintain the illusion of an automated vehicle, the back windows of the WoZ vehicle are tinted, and the back seat is separated from the front seats by a mirrored glass.

For user studies, this setup enables the following role allocation: the user, whose place is on the left front seat, a security driver on the right front seat and the wizard at the back seat. During the ride, the user can either drive on his own or is treated as a passenger in an automated vehicle, while the wizard is driving the vehicle. The security driver has to observe the current driving behaviour of either the user or the wizard and has to take over the control of the vehicle in dangerous situations (Diederichs et al., 2021), which is possible due to the mechanically connected steering wheels. The strength of this technical setup is that it allows the simulation of several types of SAE levels (SAE, 2014), in which the user can either drive on his own (SAE level 1-2) or the driving task is up to the wizard (SAE level 3-5), as well as transitions from manual to automated driving and vice versa.

Measurement technology & simulation tools

For the collection of multimodal data during the ride the front area of the WoZ vehicle is equipped with different measurement technology. Furthermore, several hardware for data storage as well as software for data synchronization is located at the back of the vehicle.

Due to the 240V power supply, the WoZ vehicle is capable to supply multiple industry- or car computers, laptops, and tablets, used as operator computers for data synchronization and storage of data collected by multiple sensors. All operating computers are located within the same network, allowing communication and data transfer between different sources. Figure 1 illustrates an example setup of multiple sensors in the WoZ vehicle, including an interior camera system for AI based body pose detection and driver monitoring, microphones for speech recognition and simulation of AI based voice interactions, an eye tracking system for investigating gaze behaviour or pupil dilation as well as physiological sensors for monitoring driver wellbeing. Furthermore, two CAN bus interfaces enable the extraction of vehicle specific data, like braking- and steering behaviour or acceleration.

Depending on the purpose of the study, the mentioned measurement technology, and the interior of the WoZ vehicle can be adjusted and extended. In the following, the measurement technology available in the vehicle, its functions and applications are described in more detail.

As illustrated in Figure 1, a stereo interior camera system is implemented at the front of the vehicle, which is used for body pose detection as well as driver and passenger activity classification. This Advanced Occupant Monitoring System (IOSB, 2022) is implemented by Fraunhofer IOSB and applies a deep learning pipeline to estimate all passengers' three-dimensional skeleton and predicts 35 of the most common activities during automated driving (Martin et al., 2019) (Figure 2). Besides the human skeleton, moveable (e.g., smartphone) and fix (e.g., driver seat) objects are used for the activity recognition system (Martin et al., 2020). The system shall also be used to provide specific planning to allocate activities to the adequate level of automation. Within KARLI, Fraunhofer IOSB focuses on activity recognition and driver state estimation. Therefore, a new camera hardware is developed and integrated into road vehicles. This KARLI occupant monitoring camera is the third generation of Fraunhofer IOSB in-cabin cameras after the In-Car-In project (InCarIn 2022, Martin et al., 2017) and the Pakos project (Martin et al., 2020). The new camera system is designed for 3D body pose data collection during daytime as well as at night. Therefore, a camera system consisting of a stereo camera pair with active IR lighting is designed. The camera system consists of two industrial NIR-cameras (IDS UI-3241LE-NIR-GL) with a S-mount 2.95 mm fisheye lens and an 850 nm continuous IR-LED ring light for each camera. The electric current of the IR-LED illumination is stabilized with a constant current source (MEAN WELL LDD 350L). In order to minimize this uncertainty, the cameras are triggered externally. For the trigger an Adafruit Trinket 3V microcontroller is used. All components were acquired on board level and installed in a specially developed 3D-printed case.

Besides the Advanced Occupant Monitoring System, an eye tracking system for investigating situation awareness, stress, workload, or cognitive distraction is installed in the car cockpit. Tracking gaze behaviour can give information about drivers' alertness and the current focus of attention (Khan & Lee, 2019), whereas changes in pupil size can give information about the current workload and stress level (Pedrotti et al., 2014). The WoZ vehicle is equipped with an eye tracking system (SmartEye Pro dx),

which is applicable in different lighting conditions and therefore well suited for real-world driving studies (SmartEye, 2022).

In addition to the pupil size, driver's wellbeing can be classified by using several physiological parameters like electrocardiogram (ECG) or electrodermal activity (EDA), to get insights into the current stress level, excitement, nervousness, or discomfort of the driver. In the context of collecting realistic data during a real-world driving study, it is important not to influence the natural behaviour of the driver by attached electrodes or cables. Therefore, the WoZ vehicle is equipped with a wearable (Empatica EmbracePlus), which is well suited for real word driving studies (Empatica, 2022).

To investigate novel speech interaction concepts adapting to different users and context parameters, a WoZ software application for the experimenter (Wizard) was implemented that runs on a tablet computer. It simulates a dialogue between a voice assistant with the user in the vehicle by using the car loudspeakers to broadcast the prompts to the user as well as a microphone in the car to record the user's messages. WoZ applications for speech assistants were previously developed (Brüggemeier & Lalone, 2019) with a focus on sending and receiving speech prompts to simulate the dialogue via a Graphical User Interface (GUI). In the developed software application, the GUI allows to prepare dialogues with different answer paths of the participant for personalized interactions by means of an integrated user profile that can be linked to specific dialogues. Speech prompts can be selected in real time by the experimenter, so that interactive dialogues with the user during different levels of automation are possible.

Besides data of human machine interaction and driver's wellbeing it is also interesting for many use cases to collect vehicle specific data like acceleration or steering and braking behaviour by using CAN bus interfaces. The data are used to draw conclusions regarding reaction time, situation awareness or lane keeping ability of the user.

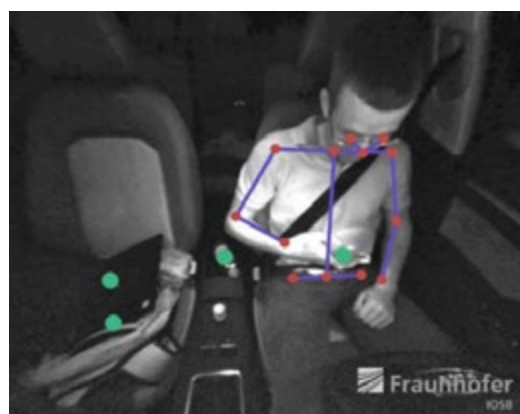


Figure 2 - Detection results of the Advanced Occupant Monitoring System. Body pose (red) and object (green) detections are marked with dots.

Data synchronization

A major challenge in multimodal data collection is the time synchronization. In order to draw conclusions from the collected data it is important to define a time synchronization concept. In the WoZ vehicle this is implemented with a software (Blickshift Recorder) developed by Blickshift GmbH, which allows the simultaneous start of the data recording from different sources, included by TCP/IP protocols, and assigns timestamps from the operator computer to the data files in predefined time intervals (Blickshift, 2022). For the spatial synchronization of interior camera systems, Fraunhofer IOSB provides a common coordinate system for all integrated cameras in the vehicle.

Data collection scenarios

To get a better understanding of the application areas of the presented WoZ vehicle for on road data collection, three use cases from the KARLI project and their corresponding data collection scenarios are described in the following chapter in more detail. They include among others the application areas of internal HMI, simulation of automation levels and transitions, as well as non-driving related activities and driver monitoring (Diederichs et al., 2021).

Motion Sickness

One of the biggest advantages and at the same time one of the biggest challenges in automated vehicles is the shift from the pure driver to a co-driver or even pure passenger. This allows among others working or watching videos in the car, which can lead to motion sickness (Dam & Jeon, 2021). Motion sickness describes the effect of sensory mismatch due to conflicting visual and vestibular information, resulting in either mild symptoms of sweating or headache up to severe symptoms of nausea or vomiting (Diels & Bos, 2016). Previous research, primarily conducted in driving simulators and investigating the effect of motion sickness on performance, showed that already mild symptoms of motion sickness influence the performance (Smyth et al., 2018). Given still few research on motion sickness during real-world driving and on the effect of motion sickness on driving ability and take over performance, this is an interesting use case to be investigated in a WoZ study. Using the WoZ vehicle allows the simulation of different levels of automation and transitions between the wizard and the user. During the ride, the severity of motion sickness occurring in different non-driving related tasks in different levels of automation can be investigated. To evoke motion sickness symptoms the condition of the driven route (curves, stop and go etc.) as well as the non-driving related task (reading, working etc.) the user performs during the automated ride is important. To get ground truth labels, the subjective motion sickness severity can be asked in predefined time intervals by using the misery scale (MISC), an 11-point discomfort rating scale (Bos et al., 2005), by either the security driver or an automated software. Furthermore, eye-tracking data can be collected to analyse the viewing direction and physiological data from the Empatica wearable can give insights to heart rate variability or skin conductance as a measure of wellbeing. Additionally, the Fraunhofer IOSB Advanced Occupant Monitoring System can be used to detect and classify non-driving related activities. In combination with vehicle specific data, extracted from the CAN bus interfaces, and route information Motion Sickness mitigation systems can be developed.

Level compliant behaviour

The development from SAE level 3 systems towards SAE level 4 or even SAE level 5 systems allow the driver to shift the vehicle control to the system for predefined routes or even during the whole ride. This allows the user to spend more time on non-driving related tasks, like working, reading, or even sleeping during the ride (Shi et al., 2020). Depending on the automation level of the vehicle, the users' attention must be more or less focused on the road. Due to intransparent specifications of permitted and non-permitted behaviour in a certain automation level, it is difficult for the user to behave properly, especially during partially automated rides. Driver's state is especially relevant before, during and after transitions (Diederichs et al., 2020, Erikson et al., 2017, Lu & de Winter, 2015). To evaluate a level compliant behaviour, the current driver state has to be classified and compared with the requirements of the current automation level (Diederichs et al., 2022). With the development of AI-based technologies, the current driver state as well as the current non-driving related activities can be recognized to inform the user about possible non level compliant behaviour and give recommendations about the correct behaviour to the user. AI-based recognition of user activities requires a huge amount of realistic training data to ensure correct classifications of non-driving related tasks. Therefore, the collection of realistic training data is one of the goals when conducting real-world driving studies with the WoZ vehicle. The previously described Advanced Occupant Monitoring System for AI based body pose detection can be used during real world drives to collect realistic data, reflecting the natural behaviour of the user. Therefore, it is up to the user when and in which order to perform several non-driving related tasks like reading, texting, or grasping a bottle to drink. Furthermore, information about gaze direction and the users' focus of attention as well as the current drowsiness level are provided by eye tracking data. A high variance in the data, regarding differences in weather, light and traffic conditions can be ensured by an iterative study design. This includes several rides performed by the same user at different timepoints. A study setup using the WoZ vehicle also allows, beside the pure data collection, the examination of transition scenarios and user behaviour before and after transitions, as well as the relationship between different non-driving related tasks and takeover readiness of the user.

Voice interaction

Speech assistants offer an intuitive modality for users to interact with AI-based technology. Even though not yet commercially available, different concept cars have presented the vision of intelligent assistants in the vehicle as companions (Lugano, 2017). To prototype, test and evaluate new interaction concepts, the WoZ research vehicle is used as a realistic environment to confront users during the ride iteratively with a voice assistant concept. Of particular interest for a more intelligent interaction in the vehicle is the question how speech assistants can behave proactively, i.e., interacting with the user by offering suitable services to enhance the ride experience (Lugano, 2017). Identifying opportune moments for a proactive voice assistant to interact with the user is however still an open research question (Nothdurft et al., 2014), especially in the context of automated driving. To investigate this question, different hypotheses for opportune moments of proactive interaction were derived from previous research. The previously presented WoZ software application can be used to

prepare different dialogues to be triggered during a pre-selected route. Following each speech prompt, participants are asked to rate the appropriateness of the moment for the system behaviour. While the user is instructed to behave naturally and traffic as well as environment conditions can change dynamically, the Wizard can document notable influencing factors. These insights feed into the conceptualization and development of an AI-based speech assistant for the car.

Results & Discussion

The WoZ approach in the context of automated driving incorporates some important benefits but also downsides. Automated driving in all levels can be demonstrated to end users without a specific technological readiness level and participants do not need a special driving license. The immersion of participants provides behavioural data from a context that is not yet available. Hence it allows us to define user requirements for such systems early in the development process. Downsides of the approach are the handling of a complex vehicle and processes to assure safe driving on roads. The wizard drivers need practice to drive the vehicle and to appropriately simulate an automated system in different levels of automation.

The advanced architecture of the Fraunhofer IAO WoZ vehicle, which allows among others the simulation of a fully automated vehicle and transitions during the ride, allows the investigation of various use cases in the field of human-machine interaction. To develop AI-based driver monitoring and assistance systems, it allows the collection of a variety of realistic data in a more natural study environment as if using a driving simulator. Data collection in realistic situations is a key contributor to developing AI functions. State-of-the-art driver monitoring datasets (Martin et al., 2019; Ortega et al., 2020) collected data in a parked car and simulator. In contrast to these datasets, the WoZ vehicle enables data collection of drivers performing secondary tasks in a real driving car. Hence, data collected in the WoZ vehicle is expected to be very useful training, validation and testing data for AI driver monitoring systems, such as the Fraunhofer IOSB Advanced Occupant Monitoring System. In the vehicle new cameras and new illumination are used that will be tested and validated in on-road applications. The data collection with the WoZ vehicle on real roads will also provide a large variance of different images and situations, e.g., driving under different light conditions including night driving and drop shadows. The data collection of 3D videos is enriched with synchronized data from an eye tracking system, physiological data and CAN data. This will allow a multisensorial data fusion to estimate level compliant driver behaviour and to detect motion sickness. The activity recognition will be used in the design of proactive speech interactions with a voice assistant.

Conclusion & Outlook

The vehicle setup is developed within the scope of the KARLI project and aims at complying with the requirements of user testing for three use cases. The architecture and implementation of components will be validated in an iterative data collection process. This will allow adjustments and iterative improvements while already providing first data that can be used for quality check, designing the labeling protocol and for testing the performance of existing state-of-the-art algorithms.

The Advanced Occupant Monitoring System as a research tool provided by Fraunhofer IOSB is

integrated in its 3rd on-road implementation and the new hardware and software components, specifically the new tailored stereo and mono cameras and their improved illumination, will be validated in the KARLI on-road studies. Next steps within the KARLI project involve several on-road studies implementing the previous described data collection scenarios as well as the development of a labeling concept to further use the collected data as input for AI algorithms. Based on the collected data, new AI algorithms are investigated for detecting passenger and driver activities. The activities are then used to calculate correlations to motion sickness, their relevance to match activities to adequate trip sections and to create AI-interactions, which are adaptive to the user's state and activities.

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