The theater-system technique: Agile designing and testing of system behavior and interaction, applied to highly automated vehicles

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ABSTRACT

In this paper, the theater-system technique, a method for agile designing and testing of system behavior and interaction concepts is described. The technique is based on the Wizard-of-Oz approach, originally used for emulating automated speech recognition, and is extended towards an interactive, user-centered design technique. The paper describes the design process using the theater-system technique, the technical build-up of the theater-system, and an application of the technique: the design of a haptic-multimodal interaction strategy for highly automated vehicles. The use of the theater-system in the design process is manifold: It is used for the concrete design work of the design team, for the assessment of user expectations as well as for early usability assessments, extending the principles of user-centered design towards a dynamically balanced design.

Categories and Subject Descriptors

D.2.2 [Software Engineering]: Design tools and techniques.

General Terms

Design, Human Factors.

Keywords

Theater-system technique, Wizard-of-Oz technique, highly automated vehicles, haptic interaction, design process, user-centered design, balanced design.

1. AGILE DESIGNING AND TESTING UNDER RESOURCE CONSTRAINTS IN GENERAL

Human-machine systems are shaped by technological progress and a natural selection in the market place: Good products earn enough money to be further developed, less adequate products disappear. As the number of design alternatives can be large and the development costs for a certain product high, it can make sense to boost the "natural" selection of the market place with an accelerated selection in an agile development and assessment process. Efficiency to explore larger portions of the design space is crucial for agile design and testing techniques [1]. Many times, the user is the one who will decide, or contribute to the decision for or against a new technical system. It can therefore be beneficial to let the user actively participate early enough in the design process (see the principles of user-centered and participatory design [2].

One method for agile designing and testing of interface and interaction concepts is the theater-system technique that allows the involvement of users from the beginning of the design process in a very tangible way [3]. The following paper addresses how the theater-system technique works in general and takes the technological development in the vehicle domain as an application example to show how the technique is used for agile designing and testing of haptic-multimodal interaction for highly automated vehicles.

2. APPLICATION DOMAIN: HIGHLY AUTOMATED VEHICLES AND HAPTIC-MULTIMODAL INTERACTION

The current trend in the vehicle industry is to bring more and more assistance systems and automation on board of the vehicles like Adaptive Cruise Control (ACC) or Lane Keeping Systems (LKS). This results in so-called highly automated vehicles [4]. From the perspective of a human-machine interface designer, the increasing automation in the vehicles comes along with the need of an adequate interaction design that allows the driver as well as the automation to guide the vehicle in a cooperative way (Figure 1). Both, the driver and the automation build up intentions and act on the vehicle guidance.

The requirements for the interaction design for such highly automated vehicles are mainly to keep the driver in the loop, to ensure he is aware of the current automation mode and to support the driving in different automation levels as well as the transitions between these levels. One approach to meet these requirements is the use of a haptic interaction strategy that is enriched with visual and auditory elements – a haptic-multimodal interaction.

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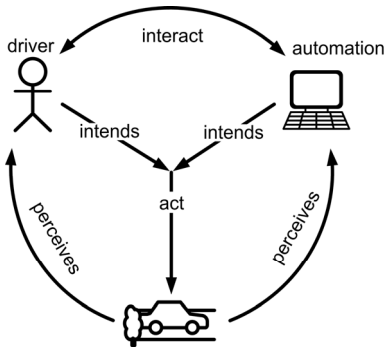

Figure 1: Interplay between the driver and the automation guiding the vehicle by cooperative control

Haptic interaction with a highly automated vehicle mainly happens via force feedback devices. Force feedback devices allow to display a variety of haptic signals, such as continuous forces, vibrations or discrete signals like double ticks for example on the steering wheel or the accelerator pedal [5]. With the help of the haptic feedback the driver can always be provided with information about the current actions and intentions of the vehicle automation, for example via steering wheel movements or forces on the pedals. However, the flow of information is not only directed from the automation towards the driver but also vice versa from the driver to the automation. For example, the driver could have the option to activate and command maneuvers by applying tics or forces on the steering wheel.

For the design of such haptic-multimodal interaction for highly automated vehicles we use the theater-system technique in all different stages of the design process.

3. THE THEATER-SYSTEM TECHNIQUE IN GENERAL

The theater-system technique is based on the idea to do a rapid prototyping of system behavior and haptic-multimodal interaction long before the complex software for such a prototype is build up. The theater-system technique is based on the Wizard-of-Oz technique (WoOz), where a human "wizard" hidden behind a curtain is emulating the functionality of a machine [6]. Originally, the technique was used for automatic speech or gesture recognition and picked up in other domains.

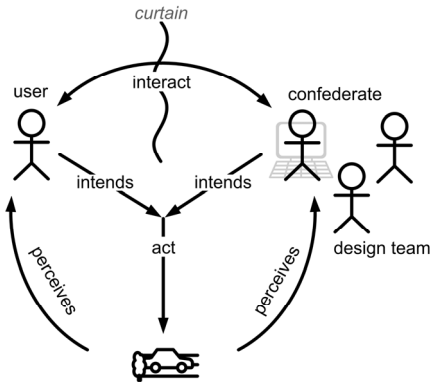

Figure 2: Interplay between the user, the confederate as member of the design team and the task (here a vehicle guidance task)

The theater-system technique extends the WoOz technique in a way that there is no longer a hidden wizard but that the curtain between the user and a member of the design team (confederate) can also be open, and both user and confederate can play through different use cases as if they would play a role in a theater (Figure 2). Whereas the WoOz technique is used for the evaluation of functionality, the theater-system can be used both for evaluation and design.

A typical design process with the theater-system is shown in Figure 3. Based on the initial ideas and an early analysis of the design challenge, an appropriate infrastructure has to be set up or adapted. This includes the adaptation of the theater-system itself for the emulation of the automation behavior and interaction in the chosen scenarios and tasks.

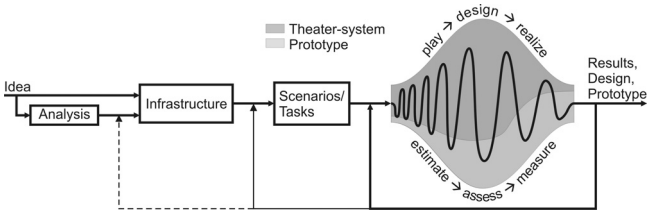

Figure 3: Schematic depiction of the design process using the theater-system in early and software prototypes in later stages of the iterative process

During the iterative design process, prototypes played by the confederate in the theater-system and software prototypes work as complement: Starting with a more open play with design variables and estimation of their effects with the confederate, design options are designed in detail and their effects assessed, until the design can be condensed, realized in software and its effect measured. This loop of infrastructure & scenario adaption, play, detail design, selection and realization can be iterated as often as necessary.

4. APPLICATION EXAMPLE: THE THEATER-SYSTEM TECHNIQUE FOR HIGHLY AUTOMATED VEHICLES

The technique is used so far for designing interaction for vehicles (DLR, TU Munich) and cockpit interaction for aircrafts and helicopters in simulation environments (NASA, DLR). In addition, one aspect of the WoOz/ theater-system technique, here the emulation of the behaviour of the assistance and automation functions, has already been applied to a real car for driving tests on public roads [7].

At the Institute of Transportation Systems at DLR Braunschweig (DLR-TS), the work with the theater-system focuses on haptic-multimodal interaction for highly automated vehicles [8]. The technique is used during the early design work by the design team and for discussion with external partners like vehicle manufactures and users, for the assessment of user expectation as well as for first usability assessments of the interaction design for highly automated vehicles.

4.1 Technical setup of the theater-system at DLR-TS

The theater-system at DLR-TS consists of two static low fidelity simulators located next to each other in a distance of about two meters. Both simulators include force feedback control devices coupled with each other mechanically or electronically as a redundant set of controls. In a current implementation of the theater-system two electronically coupled force feedback side-sticks, and two mechanically coupled force feedback steering wheels as well as two force feedback pedals which are also coupled mechanically, are realized (Figure 4).

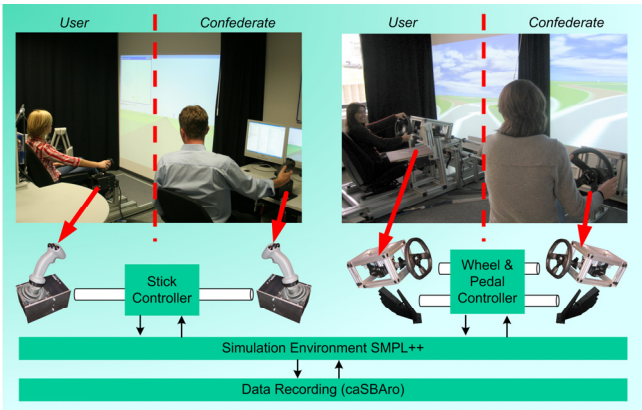

Figure 4: Implementation of the theater-system with coupled inceptors at DLR-TS

For the work with the theater-system one member of the design teams plays the confederate. The confederate is, similar to the wizard, responsible for emulating the vehicle behavior and interaction. The coupled inceptors allow the confederate, who is sitting in the right simulator of the theater-system, at any time to feel the tactile and haptic input of the user, sitting in the left simulator of the theater-system.

Another important feature of the theater-system is indicated by the vertical dashed line in figure 4. The line of sight between the user and the confederate can be obstructed by a curtain (similar to WoOz). In addition, the curtain can be open. Then, the confederate and the user can directly communicate and interact with each other. This enables an open dialogue between the confederate and the user. In this dialogue, expectancies on the behavior of highly automated vehicles or concrete design ideas can be queried by the confederate (see section 4.3).

By closing the curtain the theater-system can be used similar to the WoOz technique for exploration or testing of haptic-multimodal design elements that are not yet implemented in software. Therefore, prototypes of interaction designs are simulated either completely by the confederate or by a combination of confederate inputs and already implemented software parts of the automation (see section 4.4).

4.2 Design work in the theater-system

For the design work, the members of the design team use the theater-system for the generation and test of design ideas. Several design options are played through and documented with video records, data records and in text and pictures. In general, the haptic interaction follows a design scheme that was developed during the work for several projects: Continuous signals like forces are used to display the current behavior of the automation. Vibrations are used for warnings and alerts. Discrete signals like tics are used for communicating intentions of the automation or to trigger maneuvers. These haptic signals can be combined to more complex interaction patterns. For example, the so called “virtual gravel pit” is a combination of forces and vibrations that is displayed in case of an unintentional lane departure. The haptic feeling is similar to a real gravel pit; the vehicle is jounced and slowed down. For urgent warnings and for the communication of future events or intentions of the automation the haptic interaction is enriched with visual and acoustic signals.

4.3 Assessment of user expectations

After collecting first ideas of the design within the design team, the theater-system can be used for assessments of user expectations. For this, the curtain of the theater-system is open. During the expectation assessment the confederate does not simulate any predefined system behaviour but asks the user about his expectations. The assessment is conducted in form of a semi-structured interview during which the confederate leads the user through a sequence of predefined traffic scenarios. The user can express his expectations verbally, but of even more importance for the design process, the user can use the theater-system to directly show the confederate which kind of haptic interaction he or she expects in the given scenario. For example, the following dialog could be heard when discussing the design of a haptic interaction when exceeding the speed limit:

Confederate: “What would you expect if you exceed the current speed limit?”
User: “Maybe a force on the accelerator pedal that pushes me back, followed by a vibration if I do not react.”
Confederate: “How would that feel? Like this?” (Conf. demonstrates a soft force threshold on the pedal) “Or more like this?” (Conf. demonstrates a hard force)
User: “I’d prefer it a little stronger force, more like this…” (User demonstrates directly on the coupled pedal what he expects).

The user expectancy assessment allows to get some insights either in the naive expectations that drivers have about the general functionality of vehicle automation and the way this automation interacts with the driver, or in the expectation which users derive from a design metaphor [3].

The advantages of this approach are:

- The confederate directly grasps what kind of haptic interaction the user expects and how it feels like.
- He directly perceives in how far the user expectations differ from the primarily intended design.
- He directly experiences new, possible design variations that the design team did not think of.

4.4 Usability assessment in the theater-system

Besides the user expectancy assessment, the theater-system is used for usability assessments of interaction designs before implementing the design into software prototypes. For the usability assessment approach, the theater-system is used similar to the WoOz technique. The confederate is intensively trained to emulate a specific haptic interaction. During the usability assessment, the curtain of the theater-system is closed and the

confederate wears ear plugs to avoid vocal communication. The confederate emulates the automation behavior and interaction while the user drives through different scenarios. Depending on the predefined design this could be for example a slight lane keeping force or in case of lane departure tics or vibrations on the steering wheel. During the runs driving and interaction data, acceptance ratings and thinking aloud protocols are assessed for further analysis. Even though, the confederate can not reproduce the system behavior as standardized and consistent as a software prototype, the approach has one important advantage regarding the understanding of different user behavior: Before analysing any data, the confederate gets a first, intuitive impression of the interaction of the user with the system and potential conflicts by feeling the input of the user on the steering devices.

Based on the outcomes of the expectation assessment and the usability assessment the design is improved and modified. This modified design is then transferred into first software prototypes.

4.5 Confederate = Human-machine interface designer

For the implementation into software, the confederate who has internalized the complex behavior of the prototype in every situation ideally does or leads the implementation of the software prototype. That way, every small part of the prototype, any "feelage" of haptic interaction, can be replicated almost as originally designed. As the confederate may not be a computer scientist, it is therefore necessary that the programming framework is easy to use and easy to understand. DLR-TS uses the Straightforward Modular Prototyping Library in C++ (SMPL++) for this purpose, which is developed by DLR, NASA Langley and several university partners since 2001 [1]. SMPL++ as a rapid prototyping framework already includes several tools for the agile development of prototypes: E.g. SMPLcaSBAro (Computer Aided Situation Behaviour Analysis Replay/Online) serves as a recording tool with capabilities of monitoring recorded data from an overview perspective as well as from a very detailed perspective down to each record entry. This feature, based on the "Pointillistic Analysis" [9] enables the confederate to directly check the behavior of the software prototype. Another valuable tool is the SMPLControlPanel. It can be used for monitoring as well as for changing each variable of the software prototype during runtime, so it is an ideal tool for fine-tuning. Altogether, the complete SMPL++ toolbox combined with the haptic memory of the confederate enables the rapid prototyping of high quality prototypes.

5. DISCUSSION AND OUTLOOK

The theater-system technique is currently used successfully in several projects like H-Mode, IMOST, HAVEit and CityMobil that focus on assistance and automation for vehicles for urban and highway applications. For example, in the project IMOST a haptic-multimodal interaction strategy for a system that assists drivers on highway entries is developed with the help of the technique.

As the DLR-TS theater-system uses only a low fidelity simulation and does not provide, e.g. any vehicle movements, the prototypes are further tested in more realistic environments like the DLR-TS motion-based simulator or the research vehicle FASCar.

Altogether, the technique has a high potential to bridge different domains and perspectives, e.g. a user-centered and a technical perspective. We will continue to use and improve this technique as integral part of an ergonomic tool and technique portfolio that is a basic prerequisite for a better, well-balanced design of human- machine systems.

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