Towards User-Centred Development of Integrated Information, Warning, and Intervention Strategies for Multiple ADAS in the EU Project interactIVe

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Abstract. In the increasingly fast strive for new advanced driver assistance systems and a continuously higher automation of the driving task, it is essential not to lose sight of the most important factor: the driver. Therefore, we have to develop interaction strategies that center around the user perspective without loosing sight of the technological availability. Individual design for a certain assistance function must be balanced with the integrated and compatible design of multiple functions in several vehicles. This paper details the iterative interactIVe approach and details how the strategy space was structured to find possible common elements, derive generic interaction strategies universal to several or all systems, and identify the main research questions for the further course of the project.

Keywords: human-machine interaction, balanced design, user-centered design, interaction strategies, highly automated driving, active safety systems

1 Introduction

Today's road vehicles already offer the driver a significant amount of different assistance systems to increase comfort and enhance road safety. Yet the era of advanced driver assistance systems (ADAS) and highly automated driving just seems to be beginning, as available computer power and sensor technology is being further enhanced and the ensuing possibilities are explored for an ever increasing number of new safety and assistance systems and functionalities.

While the technological availability of such systems is a necessary prerequisite to the continued enhancement of road safety and further reduction of accidents and fatality rates, the driver remains the most essential actor also for the foreseeable future: The driver must be able to control the vehicle and understand and accept the assistance and automation offered by the various ADAS. Technical systems and drivers have to be compatible.

Therefore, it is crucial to carefully balance the technical capabilities with the characteristics of the driver. The driver and the driver's interaction with the assistance

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systems must be taken into account from early development stages on, in order to achieve a high compatibility between the technical systems and the driver. Compatibility can be decomposed into outer compatibility, e.g. via a human-machine interface compatible to the human physiology, and equally important inner compatibility between the driver and the technical system, e.g. concerning the structure, such that the driver intuitively understands the offered assistance, [1].

This compatibility issue extends also to the sum of all assistance systems in a vehicle, addressing the need to harmonize and integrate the different functionalities. Even further, compatibility between different vehicles is important, such that the driver is able to easily change from one vehicle to the next without having to relearn every interaction with the vehicle. This can be achieved by standardization and the development of common interaction strategies.

This paper describes the approach in interactIVe towards a user centred development of integrated IWI strategies for all ADAS in the different demonstrators. The paper further details how the strategy space was structured to find possible common elements, derive generic IWI strategies universal to several or all systems, and identify the main research questions for the further course of the project.

2 Interaction Design in the EU Project interactIVe

The EU project *interactIVe – Accident avoidance by active intervention for Intelligent Vehicles* covers a very wide range of functionalities from collision mitigation over accident avoidance by autonomous braking and steering to continuous support by warnings, interventions, and highly automated vehicle guidance. Seven demonstrator vehicles – six passenger cars of different vehicle classes and one truck – will be built up to develop, test, and evaluate the next generation safety systems.

In contrast to other projects in the past, interactIVe places a very high emphasis on the integration of the human-machine interaction (HMI) aspect. One of the seven subprojects (SP3-IWI Strategies) is exclusively dealing with information, warning, and intervention strategies for all systems and demonstrators. This allows the project to integrate the user-centred approach of designing and testing the most beneficial *information, warning, and intervention (IWI) strategies* for the HMI design. These IWI strategies can serve as guidelines or recommendations for the concrete HMI design of the individual demonstrators and cover more than just look-and feel aspects.

The development of the IWI strategies follows an iterative design-prototyping-testing cycle, displayed in Figure 2, to cope efficiently with the high degree of freedom and uncertainty, [2]. Starting with the definition of *use cases* based on target scenarios as detailed in Section 3, initial requirements are derived together with the vertical subprojects. Then an iterative cycle starts, where the developed *IWI strategies,* Section 4, and *IWI requirements*, Section 5, are iteratively tested and updated. For interactIVe three iterations are planned to balance convergence of the iterative process with the available time and resources. The final set of IWI strategies is complemented by a set of final requirements and specifications.

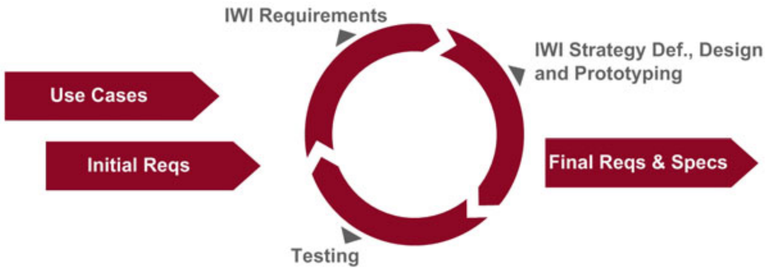

Fig. 1. Development process as iterative design-prototyping-testing cycle

This iterative design process focuses on the future user and involves both technical and human factors experts also from the other subprojects to ensure applicable solutions for the different demonstrators.

3 Use Cases

Based on existing work in [3, 4], a general methodology was developed to define use cases based on the actual problems to be solved, that is, accidents or other undesired outcomes such as traffic rule violations. These problems were defined as *target scenarios*. Since accident prevention is the main focus of InteractIVe, the focus lies on accident-related target scenarios (although the general methodology is equally applicable to other undesired outcomes). The first step was thus to define these problems in terms of the target scenarios addressed by interactive.

Target scenarios were defined on two levels. At Level 1, prototype accident scenarios were described in general terms, along with statistical data such as frequency, severity and typical contributing factors. By contrast, Level 2 scenarios provided further detail on kinematic conditions and causation factors. All target scenarios for passenger vehicles were based on data from the German GIDAS in-depth accident database, while target scenarios for trucks were based on the ETAC database [5]. At Level 1, the target scenarios were described based on simple pictograms illustrating the accident type, a general narrative (a short "story" describing a typical flow of events together with general statistics on the frequency and injury levels associated with the accident type. At Level 2, three complementary representations were used: (1) A narrative, (2) a sketch and (3) a sequence diagram. The narrative was a short story describing the general diagram, while the sketch provided a birds-eye view on the scenario configuration and how it developed. Finally, the sequence diagram defined the sequence of interactions between the involved actors (e.g. drivers and infrastructure elements) over time.

The use cases then defined *how* the problem stated in the target scenarios should be solved. That is, how an assistance or automation function is intended to prevent or mitigate the accidents in interaction with the user (e.g. function x prevents rear end collisions by informing or warning the driver or by intervening by doing y). Use case descriptions were directly based on Level 2 target scenarios and used the same representations (narrative, sketch and sequence diagram).

The definition of use cases was aided by the use of a *theatre system technique* where a human confederate emulated different potential ways to address the target scenarios in simulated driving (see Figure 3). In particular, the theatre system was used in a *use case workshop* where IWI- and demonstrator developers together could discuss different IWI concepts based on the emulated scenarios. A general user needs survey was also carried out as input to the use case definition.

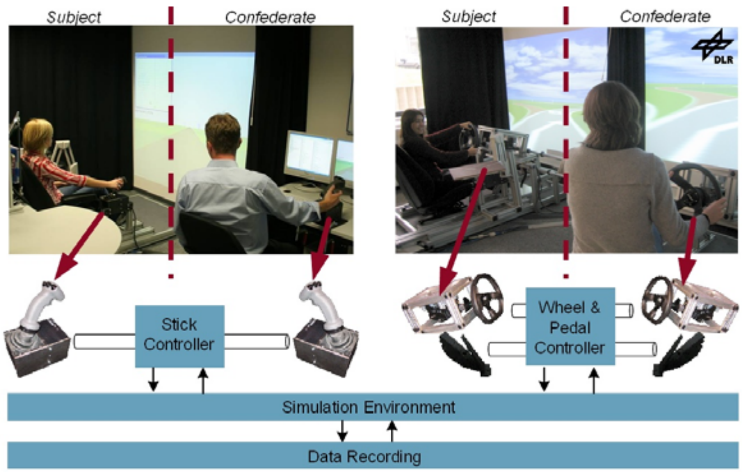

Fig. 2. Theatre system (Schieben et al., 2009)

The following provides an example of a use case narrative for a Rear-end Collision Avoidance (RECA) function addressing a related target scenario:

"*The host vehicle (HV) is driving behind a lead vehicle (LV) in a rural area at a speed v of about 50 kph at a time headway (thw) of about 2 s. Both vehicles are lightweight cars. The HV driver briefly looks towards an in-vehicle display. During the off-road glance, the LV brakes sharply to stop with deceleration a<-2 m/s^2 due to a traffic queue ahead. The RECA function detects the LV closing and issues a warning to the driver. If the RECAS determines that automatic braking alone will not be sufficient to prevent the crash and there is a sufficiently wide shoulder to the right, the system performs an automatic steering manoeuvre towards the shoulder. When stopped, the hazard lights of the HV are turned on.*"

Once defined, the use cases were categorised in terms of a taxonomy of unintended outcomes. The categories include a set of general accident types (e.g. rear-end collisions, head-collisions, lane change collisions etc.), but also non-accident related "problem" categories such as traffic rule violations. In addition, a number of use cases not directly related to target scenarios were included (e.g. related to fuel economy, activating functions, misuse, system limits, etc.). This constituted the use case catalogue that formed the basis for the further definition of initial requirements and the subsequent work on IWI strategies.

4 IWI Strategies

IWI strategies refer to how, when and where driver information, warnings, and interventions should be activated and represent a set of guidelines, recommendations, or options for the targeted demonstrator vehicles to achieve the goals of a compatibility and user centred design. The definition of IWI strategies is based on initial requirements that stem from the use cases, technical limitations and especially user inputs. Input from potential users is acquired by the means of a user needs analysis, and a user expectation assessment to involve the future user in the design process, [6]. As described in the iterative design-prototyping-testing cycle, the requirements and strategies are updated based on test results and a close cooperation with the function developing and implementing subprojects

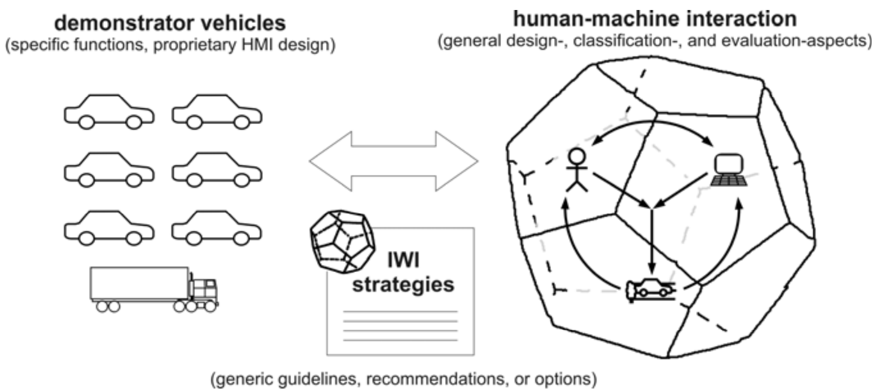

Fig. 3. IWI Strategies for different aspects as facets of the human-machine interaction

Based on the concepts of problem space and design space [7], the concept of *strategy space* was established. First the space of human-machine interaction was structured into a number of *aspects* which represent different dimensions, perspectives, or facets, see Figure 4. These aspects organize the discussions about possible IWI strategies into *strategy aspects* and thereby facilitate the comparison or harmonization of human-machine interactions in the different interactIVe demonstrators, the identification of the important open research questions, and later evaluations of prototypes. The aspects do not have to be neither disjunct nor all on the same level of detail or hierarchically structured. This maintains a great flexibility while still providing the aspired structural backbone.

The development of IWI strategies and its structuring in strategy aspects is performed in interplay between the analysis of possible human-machine interaction for specific demonstrators and assistance functions and their synthesis and generalisation (bottom-up) on the one hand, and a top down approach of formulating meaningful IWI strategies based on the before mentioned inputs and existing knowledge on human-machine interaction e.g. from standards, previous projects, or other scientific literature. In the course of the interactIVe project the IWI strategies are therefore also going to be iterated in interplay with the function-developing subprojects.

The following strategy aspects have been identified so far.

System purpose: Which general goals does the system (technical system and human driver together) have? Towards what end do the assistance functions support the driver?

Layer of Driving Task: On which layer (navigation, guidance, stabilization) of driving task is the driver supported by the technical system?

Level of Assistance and Automation: How much assistance and automation is offered to the driver for which phase in the recognize-act-cycle (perception, response selection, response execution)?

Range of Operation and Availability: What meaningful range(s) of operation should the technical systems and their assistance functions have?

Modes and Mode Transitions: Which modes shall exist for the overall system? Which is the default mode after the ignition cycle? Which transitions are there and who triggers them how?

Communicate System Status: What information about the current system status (mode, availability, dynamic state, failures, detected objects, …) is communicated to the driver and how? What elements could an integrated display design have?

Communication Channel: Which communication channel (e.g. visual, auditory and haptic) is used how by the system to communicate with the driver?

Sequence of Interaction: How does the assistance evolve (in certain situations)?
Arbitration: Which strategies are there concerning the arbitration between driver and automation, when conflicts occur that need to be negotiated and decided?

Adaptivity & Adaptability: When and how does the system adapt itself? When and how can the system be adapted by the driver?

Harmonisation & Prioritisation (Machine-Machine): What strategies are there to harmonise information, warnings, and interventions of several concurrently or subsequently active systems? What strategies are there to prioritise or integrate signals from different systems?

Situation Awareness: How can the situation awareness of the driver be improved?

Driver's mental model of technical subsystem: What strategies are there to help the driver to build a good mental model of the assistance system to foster his system understanding?

Trust: What strategies are there to create the right level of trust and prevent over-, mis-, or undertrust?

Mental workload: How can the mental workload of the driver be optimized?
The following subsections exemplify a few important strategy aspects and detail some of the major issues and open questions that arise there.

4.1 Strategy Aspect Modes and Mode Transitions

This aspect covers the individual *modes* which exist for the different assistance and automation systems, the *transitions* between these modes and the *grouping* of the individual modes of multiple assistance and automation systems into overall system modes. Important discussion points refer to the driver's mode awareness, e.g. [8], which is very important because if he is not aware of the current system mode a mode error [9] or mode confusion can occur, e.g. [10]. Mode awareness is determined by the driver's knowledge and understanding of the system's actual and future status based on the current mode [11]. The understanding of the system is thereby influenced by the driver's mental model of the technical system which develops and is modified through the interaction with the system [12].

In order to ease system interaction and enhance system understanding and mode awareness, a grouping or integration of single subfunctions, subsystems or modes could be beneficial. Furthermore, a transparent, intuitively understandable feedback and communication of the current mode and relevant transitions is crucial – which is a tight link to the strategy aspect Communicate System Status.

One example strategy belonging to this aspect could be: "Functions can be temporarily disabled or muted via a button or other action." An advantage of this strategy is the minimization of annoyance in certain situations. This strategy could still allow a default-activation of the functions. Additionally, with this strategy no alteration of the settings for warnings is absolutely necessary, since they can be temporarily disabled. For emergency intervention functions, such as collision mitigation systems, legal aspects require the possibility to override and/or turn off the function at any time.

4.2 Strategy Aspect Communicate System Status

Not all system states need to be communicated to the driver. For this job an intelligent interaction & information architecture needs to determine which state should be communicated when and in which way.

Typical states of high relevance are system status *on, off, active, warning, intervening, standby, available, unavailable,* and *failure*. It has to be considered in detail, in which way, when and how long these states need to be indicated visually, haptically or acoustically.

Most ADAS systems have a limited operation range, the system function is only *available* e.g. inside a certain speed range. Above or below a specific speed threshold the system function is *unavailable*. One general example strategy could be "Communicate the system status to the driver." Further analysis shows that some states for certain systems are more important for the driver to know than others. Lane Keeping Support systems for example rely on detecting the lane markings and will therefore more often switch between availability and unavailability status depending on the accessibility of lane markings. For these systems it is crucial to indicate the availability status permanently in order to inform the driver when he can expect system support and when not. Therefore, the necessary affordance of the status indication might depend on the probability and consequence of status changes, e.g. "The communication of the system status depends on the status confusion risk."

4.3 Strategy Aspect Communication Channel

The strategy aspect Communication Channel covers what modalities the system should make use of during interaction with the driver (i.e. visual, auditory, haptics) as well as what combinations (e.g. vibrations and visual) that should be used. Additionally, its important to define more exact details in how the specific information/warning and/or intervention is designed with respect to e.g. location of visual output, level of steering wheel torque, tonal or verbal auditory information etc. Well chosen IWI strategies here could mean enhanced perception and interpretation of e.g. a warning and assistance for action selection and implementation as a consequence. Proper information indicating e.g. the location of the dangerous situation could enhance the information process by directing a driver's attention, e.g. [13, 14]. Overall research questions with regards to communication channels would be (i) what specific modality channel to choose for specific use cases, (ii) what characteristics to use for the specific modality channels (e.g. strength of steering wheel torque, type of sound), (iii) what combination of modality channels be present or whether to use a single modality.

4.4 Strategy Aspect Sequence of Interaction

The strategy aspect Sequence of Interaction looks at how the assistance evolves, and when (i.e., depending on changes in the environment, the system capabilities, and the driver behaviour) certain information, warning, or intervention elements are presented. A special focus lies on escalation (and de-escalation) sequences in critical situations as the lateral or longitudinal approach of an obstacle.

ISO 15624 indicates the following types of information as relevant for the driver [15]: a) instruction for action, b) attention, c) explanation of present situation, d) forecast of situation. These types of information support the driver in his different stages of information processing and decision making, see e.g. [16].

Considering the wide variety of addressed assistance and automation functions it could be possible to identify 4 general levels or stages that, as a strategy, can be selected or combined for the implementation of a certain system:

1. Pre-warning stage: prepare the driver to react (himself)
2. Imminent warning stage: urge the driver to act immediately
3. Intervention stage: technical system intervenes to assist driver or take over control of the vehicle in critical situation
4. Explanation stage: present information to explain interventions to driver

5 IWI Requirements

The functional aspects of interaction as described by the IWI strategies must be completed and complemented by non-functional requirements, in order to guarantee that the interaction serves effectively and efficiently the driver-vehicle system in order to accomplish the IWI strategies. A series of actions has been identified in order to come to a relevant and feasible set of requirements.

First of all, each demonstrator identifies the preferential interaction channels and modalities (in interplay with the definition of the IWI strategies), and in quite a few cases devices and components are already identified, typically based on previous experiences in similar applications. For this, the set of candidate solutions has been defined, in particular related to hardware features. This set has been used to define the initial set of requirements, which are guiding an extensive phase of literature analysis, based on existing standards and best practices, state-of-the art of the market, and available results from recent and running collaborative initiatives. Relevant examples include EU Projects such as Prevent and Aide, to quote only a few.

This analysis has produced a first version of the HW requirements, which has been anticipated to the demonstrator teams, to be crossed with the candidate solutions, in order to (i) support the definition of the component characteristics and (ii) pinpoint the areas where further investigation is needed. Existing accessible requirements are available related to several interaction channels (visual, haptic, sound and vocal, manual and vocal input) and corresponding modalities (e.g. text vs. graphics or tonal sounds vs. vocal messages). The requirements will be updated according to the sketched iterative process upon results from simulator studies addressing specific strategy aspects and further information e.g. from the evaluation of certain demonstrators in other subprojects.

Eventually, a final version of the IWI requirements is planned to be valuable also beyond the duration of the project. It is expected that here requirements related to hardware will be complemented by more systemic and configuration related requirements such as e.g. response times, guidelines and criteria related to modality and coding choice, as well as related to the interaction design as a whole, to support general design goals such as to promote adequate situation awareness and the avoidance of errors.

6 Conclusion and Outlook

It was shown how the goal of a user-centred development can be addressed in a large and diverse project such as interactIVe by means of an iterative design-prototyping-testing cycle and the definition of IWI strategies in as structured strategy space around the human-machine interaction.

At the current stage of the project, the elaborated methodology for the definition of appropriate use cases based on target scenarios has been applied. Initial user needs have been described as well as initial requirements. The strategy space has been spanned and successfully structured using the flexible concept of strategy aspects.

Future stages in the project include the described iterations of IWI requirements and strategies by means of extensive testing and continued close collaboration with the function-developing subprojects. Available testing facilities are two static vehicle simulators and 1 truck simulator (all with dynamical traffic and environment simulation), one real cab moving based simulator, and one test vehicle with full drive by wire capability. Overall it is planned to execute 12 experimental studies with more than 200 test persons.

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