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A New User Centered Approach to the Design of Driver Support Systems

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Abstract—**This paper presents a new product design method that gives users a proactive role in the design process. Within a dedicated design environment, users are allowed to create their own designs and immediately test these in a wide variety of scenarios. By letting users realistically interact with their personal creations, designers can quickly and reliably pinpoint their needs and preferences. At the same time, good designs are generated. To evaluate the new method, it was applied to a design case: the design of a lane change support system. It was found that the new method offers added value for the design of driver support systems.**

I. Introduction

DRIVER support systems form the "link" between contemporary human controlled car driving and future computer controlled car driving. The technology needed to successfully create driver support systems is maturing, and there are many different possibilities to implement this technology. The question that manufacturers and governments are now struggling with is: what is the "best" implementation? Answering this question is particularly difficult. There are a couple of reasons for this.

First of all, many different people have an interest in driver support systems. Not only manufacturers and governments, but also mainly just car drivers. Each driver has his own needs and preferences, which may conflict with the needs and preferences of others. Designers have an extremely tough job trying to satisfy all these differing needs and preferences.

Secondly, it is difficult for designers to determine what those needs and preferences are in the first place. Using natural language as the only communication medium can easily lead to misunderstandings – and, therefore, to unreliable conclusions. A more reliable approach for determining other people's preferences is to supplement the use of natural language with other communication media such as images, movies, simulations or real-world artifacts. This offers designers the opportunity to conduct experiments in which the values of a support system's parameters are varied and in which drivers are asked for an opinion about the changes. However, this approach only works for systems of which the relevant parameters are already known. This is, for example, the case when redesigning a driver support system that already exists for quite some time. When designing a system of which the parameters are unknown (i.e. a brand new driver support system), it is much more difficult to perform such experiments.

Finally, a driver support system has so many design parameters that the number of possible implementations is virtually endless. Moreover, many of those parameters are interrelated. This means that changing the value of one parameter has an effect on the possible values of other parameters. For example, the amount of parameters needed to describe a modern car ranges from 10^5 to 10^6 [1]. Because driver support systems are subsystems of a car, the amount of parameters needed to describe them is many times less. But still, deducing drivers' preferences in relation to all those parameters would require an enormous and unwieldy amount of experiments. And even if a designer would be prepared to undertake such a series of experiments, how would it be realistically possible to vary all those parameters and let drivers experience the consequences of those changes?

The above illustrated difficulties do not only play a role during the design process of driver support systems. They are a general factor in the design of products that are new, that are complex, and that involve many different users. That is why, through the years, methods and tools have been developed that support designers in dealing with those difficulties. Among these are methods that give users an active role in the design process so that they can defend their own interests (e.g. [2]). There are also design methods that utilize scenarios in order to explicitly address problems, needs, constraints, and possibilities (e.g. [3]). An example of a tool that supports in getting insight into the consequences of decisions is virtual reality (VR) simulation. It can help to avoid misunderstandings, save money and time, and evaluate candidate designs early in the design process [4].

But, so far, these methods and tools have only been a band-aid on a wound. Designing products that are new, that are complex, and that involve many different users has essentially remained a process in which designers are forced to make assumptions about what users want. There is no method that adequately supports designers in determining users' preferences and finding the best compromise between those preferences.

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This paper presents a new product design method that was developed to fill this "gap in the market". A method that supports designers in determining users' preferences and finding the best compromise between those preferences. A method that allows all users to obtain insight into the consequences of decisions and that enables them to express their preferences. A method that provides designers with the information necessary to draw a reliable conclusion about what would be a good design. A method that specifically supports the design of products that are new, that are complex, and that involve many different users – products such as driver support systems.

Section II presents the new product design method. To test whether it offers added value for the design of driver support systems, the new method was applied to a design case: the design of a lane change support system. Section III gives a description of the design process that emerged and section IV presents some findings. Section V contains concluding remarks.

II. THE NEW PRODUCT DESIGN METHOD

A. Introduction

This section presents the new product design method that supports designers in determining users' preferences when designing products that are new, that are complex, and that involve many different users. Using scenarios, virtual reality simulation, and gaming principles, the new product design method gives users a proactive role in the design process.

A product design method specifies activities and provides guidelines for how to perform those activities. However, it would go beyond the scope of this paper to describe those activities and guidelines in great detail. Instead, a description is given of the *design process* that should emerge as a result of using the new product design method.

B. The design environment

The backbone of the design process is a simulation model. This simulation model consists of two elements - an environment database and a technology database. The environment database contains the set of elements that represent the world relevant to the product. The technology database contains the set of technology that might be relevant to the product (i.e. the technological potential that could be exploited by the product). Both databases are created and maintained by the designer[1]. By means of a VR simulation system, users can have lifelike interaction with the contents of both databases. By means of configuration panels, users can adapt parameters of both databases, thus generating candidate designs and test environments for the candidate designs. The simulation model, the VR simulation system, and the configuration panels together form the design environment.

[1] Unless explicitly indicated, the word "designer" may also be read as "design team".

C. The basic cycle

A scenario is formed by a combination of elements from the environment database together with a task description. A user experiences a scenario by trying to perform the task in the simulated environment. From these experiences, the user identifies what he needs and/or wants. By combining elements from the technology database, the user can configure a candidate design with which he expects to fulfill his needs and desires.

By applying a self-configured design to a self-configured scenario, the user can assess whether his expectations about the functionality, behavior and performance of the design were correct. By applying the design to a different scenario (i.e. a different combination of elements from the environment database together with a different task description), the user can test whether it also functions satisfactorily under different circumstances or whether new needs emerge. At any point during the session, the user is allowed to alter the configuration of the design or even to start all over again with a completely different design. Similarly, at any point during the session, the user is allowed to alter the configuration of the scenario or even to start all over again with a completely different scenario.

D. Two phases

The design process is split into two separate phases. The first phase is aimed at developing the design environment into a valid representation of the world relevant to the product and the technology that may be usefully applied to the product. During the second phase, the design environment - as it was created during the first phase - is used to specify a good design.

E. Procedure during the first phase

The first phase starts with activities such as observing the real-world, reading literature and talking with stakeholders. Based on results from such activities, the designer makes initial assumptions about the necessary contents of both the environment database and the technology database. In other words, the designer attempts to identify all aspects of the world relevant to the product as well as all technology that may be usefully applied to the product. Based on the results from this identification process, the designer creates an initial simulation model. Simultaneously, the designer creates a VR simulation system that enables users to have lifelike interaction with the simulation model, as well as configuration panels that give users the possibility to generate candidate designs and test environments.

After the initial design environment has been created, its validity is tested. More specifically, the designer tests whether all relevant aspects of the design case are present and whether they are correctly modeled. This is done by inviting users for reflection sessions. During a reflection session, a user is told that the goal is to create the most satisfying "personal design" of the proposed product. By generating designs and scenarios, and evaluating those designs in the scenarios, the user is able to iteratively work towards this goal. In the meantime, the designer observes the user's behavior and asks the user for opinions about the generated designs. However, the designer only performs these activities in order not to reveal the true purpose of the session. This true purpose (i.e. collecting feedback on the quality of the design environment) is only accomplished at the end of the reflection session when the user is interviewed. The feedback from all users is used to create a list of required adaptations to the design environment.

The designer implements the required adaptations into the design environment. Subsequently, the same people that participated in the reflection sessions are invited again, but now for verification sessions. During a verification session, a user is confronted with the adaptations to the design environment that he explicitly or implicitly proposed. The user is asked whether he agrees to the adaptation or whether something else was intended. Additionally, the user is confronted with adaptations that were proposed by others. This time, the user is not asked whether he agrees to this adaptation. Instead, the user is asked whether he rejects the adaptation; not rejecting an adaptation is considered sufficient for acceptance of the specific adaptation.

By performing this cycle of reflection sessions, implementation of the required adaptations and verification sessions, the design environment evolves. Initially, the design environment will evolve rapidly. After a certain number of cycles, the speed of evolution will decrease. Ultimately, the evolution of the design environment will practically stop – users will only be able to confirm the completeness and correctness of the design environment. The design environment has become "saturated". It will contain the "problem-solution space" of the design case in a form that is both verifiable and controllable. When this state of saturation is achieved, the first phase of the new product design method has come to an end.

F. *Procedure during the second phase*

During the second phase of the design process, the design environment - as established during the first phase - does no longer change. There is now an emphasis on the quality of the proposed product, instead of on the quality of the design environment. Users are invited for design sessions. The activities of the users during these design sessions are quite similar to the activities during the reflection sessions of the first phase of the design process. A user is given the assignment to iteratively work towards the "most attractive design" by generating designs and scenarios, and evaluating those designs in the scenarios. In the meantime, the designer observes the user's behavior and asks the user for opinions about the generated designs. In contrast to during the first phase of the design process, the designer now actually uses the collected information. For every user, the designer creates a "personal report". This personal report contains both objective information (i.e. personal information and a specification of the "most attractive design") and subjective information (i.e. reasons for why the specified design is so attractive and why other product features are less desirable).

All information from the personal reports (both the objective and the subjective information) is organized into a hierarchy of which the structure is meaningful from a user's perspective. Such a hierarchy enables the designer to specify the "best" design within any set of constraints - for example, constraints set by stakeholders such as manufacturers and governments.

III. Applying the New Product Design Method to the Design of a Lane Change Support System

A. *Introduction*

To test whether the new product design method offers added value for the design of driver support systems, it was applied to a design case: the design of a lane change support system. Section B gives a description of the first phase of the design process; section C describes the second phase.

B. *The first phase of the design process*

Results from observing the real-world, talking to stakeholders, and performing a literature study (see, for example, [5]) were converted into an initial design environment. It consisted of the following main elements:

1) An environment database filled with traffic scenarios;
2) A technology database filled with lane change support system technology;
3) A lane change support system configurator that enabled a user to generate lane change support system designs;
4) A driving simulator that enabled a user to control a vehicle within the traffic scenarios, thereby realistically experiencing them. The driving simulator also allowed the user to realistically experience the behavior of the lane change support system designs within the traffic scenarios.

Fig. 1. The initial design environment.

Fig. 1 shows the initial design environment. It consisted of a mock-up of a vehicle, a large curved screen that displays the traffic environment, and a sound-system that displays sounds from the traffic environment. The mock-up itself consisted of a force feedback steering wheel and a pedal set, a driver's seat equipped with vibrating elements, four flat screens that together form a dashboard, three flat screens that offer rear view mirror functionality, and an in-car sound system. In the middle console, a touch screen was integrated as an interface for the lane change support system configurator.

Twelve users were invited for reflection sessions. A reflection session involved one user at a time. The real purpose of the reflection session (i.e. checking the design environment for completeness and correctness) was not revealed. Rather, users were told that the session was aimed at finding out which lane change support system design is most desirable. After having become familiar with the design environment, users were offered the opportunity to iteratively work towards their personal "most attractive design". They did this by generating lane change support system designs and by evaluating them in the scenarios that were offered by the designer. Fig. 2 shows a user generating a candidate design. Fig. 3 shows a user evaluating a candidate design.

Fig. 2. Generating a candidate design.

Fig. 3. Evaluating a candidate design.

At the end of a reflection session, the user was asked for feedback about the quality of the design environment. More specifically, the user was asked whether all elements relevant to a lane change support system were present in the design environment, and whether all present elements were correctly modeled. From the feedback that was collected from all users followed that a total of 30 adaptations needed to be implemented: 17 to the environment database, 8 to the technology database and 5 to the lane change support system configurator. An important finding was that a lane change support system should not be considered as one integrated system, but rather as an assembly of independently functioning - and independently configurable – assistants (i.e. modules). The working principle of the support system as a whole is simply the sum of the working principles of the assistants.

After having implemented the adaptations, the same group of users was invited again, but now for verification sessions. The objective of the verification sessions was to test whether the quality of the design environment had improved. It appeared that all users confirmed that the personally proposed adaptations had been implemented correctly (i.e. implemented as they had intended them). Generally, users also agreed that the adaptations proposed by others improved the quality of the design environment. Incidentally, users proposed new adaptations during the verification sessions.

By performing one iteration of the first phase of the design process (i.e. one cycle of reflection and verification sessions), the design environment had become a better representation of the problem-solution space of a lane change support system. Performing another iteration (i.e. a new cycle of reflection and verification sessions with a new group of users) would have undoubtedly resulted in an even better representation. However, because the design process was not performed to develop the most promising lane change support system, but to test whether the new product design method offers added value for the design of driver support systems, the first phase of the design process was concluded and the second phase was started.

C. The second phase of the design process

Forty-eight users were invited for design sessions in which they iteratively had to work towards their personal "most attractive design". Literature findings suggested that a user's preferences with regard to a driver support system may be correlated with age and driving style [6]-[9]. Therefore, the total group of users was divided according to these two scales. This resulted in a group of 24 "young users" versus a group of 24 "old users", and a group of 24 "aggressive users" versus a group of 24 "non-aggressive users".

A design session involved one user at a time. The behaviors of users while generating and testing candidate designs, and the opinions of users while reflecting on them, were registered by audio/video recordings and by notes. In addition, the design choices of users were also automatically stored in data files. For every user, the raw data collected during the design sessions were converted into a "personal report". Each personal report contained four sections:

1) Personal information of the user (age, driving style);
2) A complete specification of the design that was marked "most attractive" by the user;
3) An explanation for why the specified system was so attractive for the user;
4) A brief description of the user's behavior during the design sessions.

Organizing the information into a hierarchy was done by following an approach similar to "grounded theory" [10]. Originally, the aim of grounded theory is to develop a theory that fits a set of collected data. However, it has also become increasingly popular in product design processes to answer specific questions and address design concerns [11]. Within grounded theory, identification of themes, and organizing these into a hierarchy, is achieved by "coding" the data.

A random sample of personal reports was used to make an assumption about the set of codes from which the coding system should be made up. For every statement in these personal reports, one or more codes were defined. The defined codes were combined into a list. A trained second rater was asked to assign one or more codes from the list to every statement in the sample of personal reports. Next, the average inter-rater reliability per statement (the percentage of the assigned keywords per statement that matches between the two raters) was calculated. The reliability was 75%, which was considered sufficient to accept the coding system as a definition of relevant themes. The three main categories of this coding system were:

1) Desirable/undesirable system features;
2) Reasons for considering a system feature to be desirable/undesirable;
3) Circumstances under which a system feature is considered desirable/undesirable.

The coding system was used to code the subjective information in all personal reports and re-organize the objective information into categories that are meaningful from a user's perspective. Because the coding system has a hierarchical structure, this resulted in a hierarchy of information that represents the preferences of all users. A hierarchy of which the structure is meaningful from a user's perspective and that enables the designer to specify the "best" design within any set of constraints. To illustrate what the hierarchy of information can be used for, the next section presents some findings from analyses that were performed.

IV. Some Findings

It was found that a lane change support system should be asymmetric. Many users indicated that their needs for lane change support on the left side of the vehicle were different from their needs for on the right side of the vehicle. Vehicles on the left are generally moving faster than the subject vehicle, and vehicles on the right are not. Lane changes to the left are generally meant to enter traffic or to start a passing maneuver, whereas lane changes to the right are generally meant to exit traffic or to go back to the right lane after a passing maneuver. The few users who preferred a symmetric system argued that asymmetry increases the perceived complexity and perceived inconsistency of the system. This makes the meaning of a signal less intuitive and, therefore, the system may even cause confusion.

As explained in section III.B, a lane change support system was considered as a modular assembly of independently functioning assistants (i.e. modules). It was found that users distinguish two main types of assistants: "comfort assistants" and "safety assistants". Comfort assistants give feedback about the traffic environment, independent of the intention to change lanes. Safety assistants issue a signal (or an intervention) when making a mistake (i.e. when intending to change lanes whereas another vehicle is present in an adjacent zone).

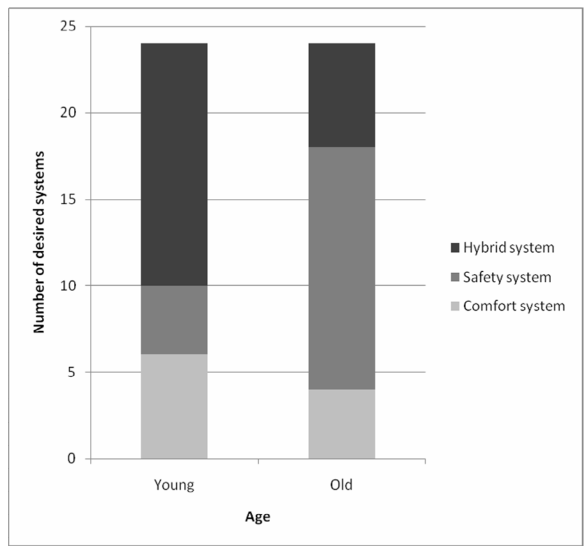

Fig. 4. Relationship between the user's age and the desired system type

Per age group, Fig. 4 shows the number of users that want a "comfort system" (i.e. a system only consisting of comfort assistants), the number of users that want a "safety system" (i.e. a system only consisting of safety assistants", and the number of users that want a "hybrid system" (i.e. a system consisting of both comfort and safety assistants). Only 4 of the 24 (=17%) young users desire a "safety system", whereas 14 of the 24 (=58%) old users desire such a system. Similarly, it can be seen that 14 of the 24 (=58%) young users desire a "hybrid system", whereas only 6 of the 24 (25%) old users desire such a system. This indicates that young users are particularly fond of hybrid systems, and that old users are particularly fond of safety systems. A similar relationship was found between the user's driving style and the desired system type: hybrid systems are better appreciated by aggressive users, whereas safety systems are better appreciated by non-aggressive users.

However, despite these relationships, it appeared that there are generally large individual differences between users' preferences for a lane change support system. These differences were not only about design parameters that users generally considered as "details" (such as the "color of a visual signal"), but they were often about design parameters that were generally considered to have an "essential influence" on the overall behavior of the system (such as the "criteria under which support is issued", or the "modality of the issued support"). Quite often, these differences were insurmountable in the sense that what one user finds "fantastic" another user finds "horrible" (and vice versa). For example, there were users who said: *"The interventions on the steering wheel are fantastic: they feel very intuitive."* But there were also quite a few users who said: *"The interventions on the steering wheel are horrible: they scare me and they make me want to counter-steer."*

It also appeared that users have very different reasons for considering certain system features desirable or undesirable. This makes it so that they solve the trade-offs between arguments *for* and arguments *against* certain system features in very different, and individual, ways. For example, there were users who said: *"A warning sound is very conspicuous: I always hear it. A warning light on the dashboard would be useless, because I'm already busy with looking at the traffic around me."* But there were also users who said: *"A warning light on the dashboard is very conspicuous: I see it clearly in my peripheral field of vision. A warning sound would be useless, because it would drown in the background of driving sounds, music, and conversations."*

V. Putting the Information into Other Perspectives

The results of the design case imply that, from a user's perspective, a lane change support system should be *fully adjustable*. However, in order to successfully bring a driver support system (or any other product) to the market, not only the needs and desires of users should be considered, but also those of stakeholders such as manufacturers and governments. And this is exactly where the new product design method distinguishes itself from other design methods. Applying the new method produces a detailed, consistent and reliable image of users' preferences. The hierarchy of information represents those preferences such that they can be easily put into the perspectives of other stakeholders.

To illustrate this, a constraint from a lane change support system manufacturer was imposed: "*A lane change support system should be modular. Every assistant (i.e. every module) should function independently of the other assistants (i.e. the other modules) in the system. Users may or may not order specific assistants to be installed in their vehicle. A total of six assistants should be offered: two "comfort assistants" (one for every side of the vehicle) that give feedback about the traffic environment, independent of the intention to change lanes, two "safety assistants" (one for every side of the vehicle) that issue a warning when the user makes a mistake (i.e. when the user has the intention to change lanes whereas another vehicle is present in an adjacent zone), and two "safety assistants" (one for every side of the vehicle) that impose an intervention when the user makes a mistake."*

It appeared that by combining this constraint with the preferences of users as reflected by the hierarchy of information, the specifications of the six assistants could be easily deduced. Moreover, it appeared that the hierarchy of information could be used to specify why users would be attracted to every assistant, what they might not like about them, and how this is related to the circumstances under which they use them.

VI. Conclusion

From the evaluation process appeared that the new product design method gives designers all the information they need to draw a conclusion about what would be the best design. Moreover, because users are enabled to directly express their preferences and realistically experience the consequences of their decisions, this conclusion has a solid foundation. Finally, determining users' preferences has happened without putting them in dangerous situations. In short, the new product design method offers added value for the design of driver support systems.

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