Glass Cockpit Simulators
Tools for IT-based Car Systems Design and Evaluation

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Abstract
At Linköping University/Institute of Technology we use a simulator platform (A-Sim) for human-in-the-loop simulations based on our experiences from the aviation area and its glass cockpit concept. Every new commercial and military aircraft have this concept implemented and it refers not only to electronic displays instead of “iron instruments”, but also to the underlying technology, which makes flexible functionality and interface solutions possible. This concept also opens for new solutions during the aircraft life cycle since the main part of the complete system is computer-based. In this the aircraft manufacturer delivers new software editions in a similar way that we can experience in the personal computer area. The same glass cockpit philosophy could be used in the driving simulator area as it has been used in flight simulators in the aerospace industry in order to support simulator-based design processes. We have implemented this concept at Linköping University by the A-Sim software and supporting hardware solutions in our simulator site. A corresponding evolution in the ground vehicle area is prevalent today. We have not seen that much yet for the cockpit part but the underlying functionality is more and more software-based. Examples of evolving car systems, which we refer to, are all kinds of X-by-wire systems, Advanced Driver Assistance Systems (ADAS), and In-Vehicle Information Systems (IVIS). In this paper we present two empirical studies from the ADAS class carried out in our simulator, Adaptive Cruise Control and Night Vision. Moreover, we present an architectural framework for such systems, which could be realized in real vehicles or in simulator environments, and we also briefly present the A-Sim system.

Keywords: Glass Cockpit Simulator, Virtual Prototyping, In-Vehicle Systems, Simulator-based Design
Introduction

The ongoing evolution of in-car technologies is based on a rapid change from mechanical functions and displays to computer-based solutions and electronic devices with new possibilities for flexible configuration and control. Also automated functions are emerging. We have experienced a corresponding development in the aviation area that started more than thirty years ago and a synthesis of this change is the background to the glass cockpit notion. Another result of this technology shift in aviation was that new demands for the design process were recognized. Simulator-based design was introduced for most in-vehicle systems close to the pilot and virtual prototyping was invented. This change of the design process was needed because of the huge increase in system complexity that made the old principles of good mechanical engineering outdated and no longer considered as the best way to approach system design.

Our background from aviation R&D at the Linköping University (LiU) and the aerospace industry has influenced our research in the ground vehicle area. Our interest is in the new car technology and its possibilities to meet safety related challenges and give the drivers an improved interface to manage the arising complexity of the vehicles. We considered simulator-based research with “unlimited” possibilities for implementing virtual prototypes of any in-vehicle system crucial in our research ambition. At that time there were no such simulators available on the market. However, we run a VR and simulation lab at LiU since the middle of the nineties and in 1999 we launched a spin-off company, which sponsored by two automotive companies and in close cooperation with LiU started to develop simulator software based on the glass cockpit vision.

The use of human-in-the-loop simulators

The use of human-in-the-loop simulators in the automotive industry has not a very long tradition compared to the decades of use in the aerospace area. Edward Link introduced his flight simulator as early as in 1927. In those days an aircraft was completely mechanical, which naturally also was the case with the Linktrainer. Today, most functions in the aircraft are computer-based and the simulators have had a corresponding development. There are probably many reasons for the late introduction of simulators in the vehicular area, but one interesting background could be found in the vehicle technology itself, the late transfer from mechanical solutions to computerized functions and display technology. This transfer started in the sixties for aviation, supported by simulator-based design activities. Since some years a corresponding transfer is ongoing for cars and trucks, but so far with limited support from simulation.

Another observation from the use of car simulators is that Human-Machine Interaction (HMI) studies mostly are focused on behavioral aspects, for example, distraction and drowsiness studies in various traffic scenarios, or driver intersection behavior. These studies give valuable information on the limitations of human drivers and a profound understanding of the H in HMI. In our research, however, we prioritize design issues and therefore we focus more on the MI part of the HMI notion. Further, the interaction design is more comprehensive than what normally constitutes the interface. In our research
agenda the interaction includes not only the visible interface between the driver and his/her car but also the basic functionality involved in this process as well as architectural issues.

Another issue of great importance about human-in-the-loop simulators is validity. Many studies demonstrate that the human behavior change between real car and simulated car driving. In this discussion also the simulator class is important. High fidelity simulators with expensive movement platforms are considered as less suffering from the validity problem than fixed-base simulators. We accept this view on the validity problem, but have a strategy for handling these problems in order to deliver reliable results from simulator-based research. The solution is comparative studies. Central to this concept is that different system designs are evaluated under exactly the same conditions and the simulator validity is the same for all design alternatives and thereby become counter-balanced. Another part in our validity strategy is to construct ecologically valid scenarios and secondary tasks. We believe that irrespective of the degree of fidelity of the simulator, testing of single non-integrated systems can compromise the validity. Thus, we have the ambition to test HMI issues in integrated systems environments in order to further strengthen the validity in our research.

In-vehicle systems

The increased number of new Advanced Driver Assistance Systems (ADAS), In-Vehicle Information Systems (IVIS), more intelligent Primary Control Systems (PCS), and Ubiquitous Safety and Comfort Systems (USCS) in modern cars calls for holistic approaches from many perspectives. One aspect is about system architecture and another is about HMI design. We have suggested a concept, which covers both aspects on a relative high conceptual level. The concept, which is called AMMI (Adaptive Multi-Modal Interfaces), will be very briefly described in the following but first a few more comments on in-vehicle systems (IVS).

Most ADAS and IVIS are implemented in the vehicles as “isolated” systems. This means that they have their own sensors, separate software-based functionality, and separate devices for driver interaction. In the holistic approach we suggest, the strategy will be to share resources (e.g., sensors and displays) as much as possible and to coordinate the driver interface over all systems. About PCS the development might partly follow other paths and we will discuss one aspect here.

The expression X-by-wire system refers to PCS, which are converted from mechanical solutions to computer-based functions. The most central of these control systems is steering. Fly-by-wire was introduced in aircraft more than ten years ago. The reason behind this shift was to reduce weight and open for more sophisticated principles for flight control. Similar demands will also be the driving force in the vehicular area. We know from aviation that this paradigm shift will put a strong pressure on the HMI aspects. Since there are no natural (physical) feedback in such a system this has to be simulated in order to give the pilot information on how the system understands the pilot input and operates. Moreover, this feedback has to be designed so that the tactile signals correspond with the pilot’s mental model of the ongoing activity and its goals instead of the actual positions or movements of the rudder planes (as in the mechanical systems).
The parallel for cars is the combination of steer-by-wire and four-wheel operation. This indicates that there is a strong need for more research in this area.

Our view on IVS design is based on the AMMI concept mentioned above, where we have defined three principal levels. The first is the measurement level where data from various sources is collected, e.g., driver data, vehicle systems data, and environmental data. The second level includes the intelligent part for data analysis and automated “decision making”. On the third level we have the presentation and control resources. In Figure 1, we present an IVS sketch, based on the AMMI concept and complemented with a “box” for actuators, which are mandatory in all X-by-wire and automated systems. In a holistic design approach, sharing principles should minimize the number of technical resources.

![Figure 1. A principle IVS design approach based on the AMMI concept. The arrows represent in-vehicle systems and their basic data-flow. Systems symbolized by blue arrows (continuous lines) do not use any 2:nd level resources, while the other systems depend deeply on these functions.]

Simulator description

In the following we give a short presentation of the PC-cluster based driving simulator at Linköping University/Institute of Technology. The first section is a description of the software system, A-Sim, and the second part will give an overview of our simulator site.

The A-Sim platform

For a simulator to fully support the simulator-based design concept outlined above a set of requirements must be fulfilled:

- Open and dynamic architecture
- Integrated and synchronized data logging
- Software based modular functionality
- Easy access to scenario production (environment, objects and events)

These requirements must be fulfilled so that new or adapted simulator functions can be inserted as modules that work synchronized and seamless with the other simulator functions. This is vital for fast and efficient simulator-based design of in-vehicle systems.
This allows high flexibility in scenario and interface production which is paramount both for user studies and design of ADAS/IVIS (see e.g. Strobl & Huesmann, 2004). A-sim fulfils the gap (or remedying lacking integration) between driving simulators and corresponding prototyping tools, which is described elsewhere (e.g. Bullinger & Dangelmaier, 2003).

**Figure 2.** Schematic view of A-Sim. Presented with permission from ACE Simulation AB, 2005.

The driver environment consists mainly of physical hardware, video projectors, data screens, loudspeakers, physical cockpit with steering wheel and pedals etc. The prototyping facility is a dynamic set of software-based modules that handles specific tasks in the simulation. Most of the devices in the driver environment have a direct mapping to one of these modules in the prototyping environment. This means that the entire driver environment is fully accessible for software-based prototyping and thereby for simulator-based design and interaction activities.

**Figure 3.** A-Sim communications architecture
All modules in the prototyping facility communicate with each other through the communication functions provided by the A-Sim simulator kernel. Two critical issues are solved by this approach. First, every module has access to all information in the simulation. Second, every module is synchronized and can be logged with the rest of the simulation data. With this approach a user can add its own IVS logic for future in-vehicle system designs. Since all simulation information is accessible through the RT communications layer this module can listen to the data provided by the standard driving control module (steering, gas, brake). This data can then be manipulated together with other simulation data to implement an adaptive cruise control for example. The new data is then provided to the standard dynamics module. The performance of this new IVS-function then can be logged and evaluated.

**Hardware solution at Linköping University**

We have two different cockpits, one sedan model (Saab) and one truck cockpit (Scania), which are used alternately depending on the character of the research project. Both are rebuilt in order to meet the glass cockpit demands, which mean that for example the main instrument hardware is replaced with configurable screens (LCD’s) and the central consoles are replaced with touch screens. Further information is available at [www.iav.ikp.liu.se](http://www.iav.ikp.liu.se), laboratory resources.

**Two project examples**

The following research projects have recently been conducted in the simulator at LiU. The purpose of this presentation is to mirror the way of working in the simulator more than to go deeply into specific results, which are presented in other papers.

**Adaptive cruise control**

Cruise controls are standard equipment in many production cars. Cruise controls are designed to help the driver keep a constant speed during highway driving and make it easier to follow speed regulations. A more advanced version of the basic cruise control is the *adaptive* cruise control (ACC), which can adjust the host vehicle’s speed when a slower driving car ahead is detected.

However, research results also indicate potential safety problems with ACC. While no automation can be perfect, drivers seem to trust automation without fully realizing the system’s limitations (Nilsson, 1995; however, see Weinberger, Winner & Bubb, 2001). Empirical investigations show that drivers are often too slow to resume manual control (i.e., apply manual braking) when the system’s actions are insufficient or inadequate (OECD, 1990; Rudin-Brown & Parker, 2004; Stanton, Young, & McCaulder, 1997).

We recently conducted a driving simulator experiment where we evaluated an alternative design for ACC and measured how drivers performed with this system (cf. Kovordányi, Ohlsson, & Alm, 2005). Using the glass-cockpit approach, ACC-functions could be recreated in purely software. Time headway could thus be based on knowledge of object positions in the simulated world, excluding the need for tedious sensor implementation. Also, central features of the simulated ACC could easily be changed and alternative
designs tested before running the actual experiment, without the overhead cost that would be involved if the ACC had been implemented in physical hardware.

Our objective with the experiment was to evaluate the traffic safety of the redesigned system by comparing driver performance with traditional ACC, as well as with driver performance during unassisted driving. The test took approximately 45 min (excluding the time need for filling out questionnaires). In addition to overall driving performance, drivers’ reactions were recorded in two types of critical scenarios (one instance of each of these scenario types occurred in each of the three test conditions):

1. A slower going car that is caught up by the host (ACC equipped) vehicle is suddenly hard braking.
2. An overtaking car reenters in front of the host vehicle and brakes hard.

Between and after the three test conditions, participants were asked to fill out a questionnaire containing questions about acceptance, trust, and usefulness of the ACC they just used, a standard NASA-TLX (Hart & Staveland, 1988), and after the three sessions, questions about sensation seeking and locus of control (Montag & Comrey, 1987; Zuckerman, 1994). The data from this experiment are under analysis and will be made available in detail in Kovordányi, Olofsson, & Toor (2005).

Night vision systems

Night vision systems are already introduced on the market. Most products could be considered as vision enhancement systems, which mean that all sensor information will be passed to the driver and presented continuously. There has been some criticism on night vision systems and other ADAS systems as well based on the risk for negative behavioral adaptation (e.g., Smiley, 2000). Night vision systems were introduced in order to increase the sight distance and visibility in dark conditions and thereby give a contribution to safety. The effect of negative behavioral adaptation in this context is that the driver would increase speed.

The purpose was to study this problem using two different concepts. One was the approach with continuous presentation on the windshield and the other was a warning system based on the same kind of sensor presentation. This was activated only if an upcoming object was measured and evaluated as a dangerous object. This system would be designed as the warning system example shown in Figure 1. In the simulator, however, the two alternative systems were realized in quite a different way. The display presentation was simply a black and white copy of a central view of the environmental presentation, over-laid this presentation through a separate projector. The evaluation procedure (level 2 in Figure 1) was replaced by predetermined triggers in the scenario setting at realistic distances (= real sensor range) from dangerous objects.

This way to take shortcuts in order two get answers to research/design questions is normal procedure in our approach to simulator-based research/design. In this case we wanted to know if negative behavioral adaptation could be avoided or at least minimized by using a warning system concept for night vision instead of the traditional continuous IR-display implemented, for instance, in Cadillac and BMW.
The project was carried out by a group of second year master students at Linköping University. They found more consistent object detection with the warning system, while some drivers in the continuous system did not recognize dangerous objects (people on the road) until very late or too late. There was also a tendency that higher speed was prevalent in the continuous night vision presentation compared with the warning alternative.

All subjects were interviewed as a complement to the simulator measurements (speed, detection distances, etc.). One interesting answer was that all 23 subjects preferred the warning alternative. The most prevalent motive for this opinion was that the visual search while looking for dangerous objects in the continuous display was demanding and not comfortable. (Alin Nilsson et.al., 2005).

Conclusions

The main purpose of this paper was to present the advantages of using a glass cockpit simulator in a simulator-based design approach as an alternative to traditional development and evaluation processes of systems and functions close to the driver. The main benefit is timesaving. The virtual prototyping with adhered testing takes a fraction of the time needed in a more traditional iterative design process. Another important advantage is the cost beneficial development process, with exclusion of bad design solutions at an early stage. A third advantage with our approach is the possibility to test systems in potentially dangerous situations and simultaneously impose difficult and even impossible workload on the driver (cf. Ivancic & Hesketh, 2000). The systems could accordingly be tested to the edge. One of our automotive industry partners used our approach and simulator facility in the development of a driver assistance system. The project manager reported a two by three cost reduction compared with his original budget idea based on traditional procedures. In the two studies reported here, about 90% of the modeling and prototyping work was carried out by undergraduate students with no or limited experience of programming. This indicates that the use of commercial tools like ours is easy as is the virtual prototype implementation in the glass cockpit simulator. In fact, the most challenging work is the data analysis, mainly caused by the huge amount of available data. This is something we have addressed for some time in order to find ways to rationalize also this part of the work. Statistical analyses are necessary for academics, since we always need valid and significant research results. In the industry, however, the benefits is equally important to have a tool for full-scale demonstrations at early project stages in order to chose the most promising system alternative for further development.
References


