Evaluating Realistic Visualizations for Safety-related In-car Information Systems

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CHI 2010, April 10–15, 2010, Atlanta, Georgia, USA.
ACM 978-1-60558-930-5/10/04..

Abstract
This paper reflects on the currently observable evolution of in-vehicle information systems towards realistic visualization. As compared to common schematic maps, hi-fidelity visualizations might support an easier recognition of the outside world and therefore better contribute to driving safety. On the other hand, too much visual detail might distract from the primary driving task. We present an experimental car-simulator study with 28 users, in which the in-car HMI was systematically manipulated with regard to representation of the outside world. The results show that perceived safety is significantly higher with 1:1 realistic views than with conventional schematic styles, despite higher visual complexity. Furthermore, we found that the more demanding the safety recommendation on the HMI, the more realistic visualization are perceived as a valuable support.

Keywords
Visualization, Handheld Devices and Mobile Computing

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation: User Interfaces—GUI

General Terms
Human Factors, Verification

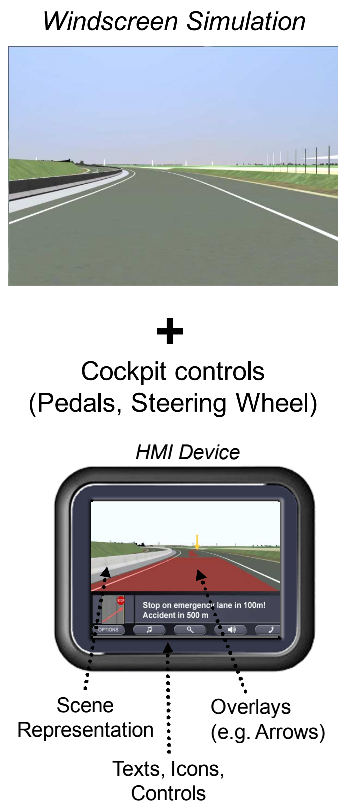

Figure 1: PC-based realtime simulation engine, rendering both the outside (windscreen) view and the HMI view, based on a detailed geospatial model of existing and planned Austrian highways.

Introduction

In-vehicle information systems, such as built-in driver assistance units, personal navigation devices, and mobile phones, have become standard equipment in cars - and their capabilities are quickly evolving. The most obvious advances are related to the visual presentation at the in-vehicle human-machine interface (HMI). On the consumer mass market, we witness an increasingly realistic representation of the driver's outside world, including textured 3D representations of highway junctions, road details, mountains, and buildings. This trend towards realistic visualization is even strengthened by the advent of augmented reality navigation systems on market-available handheld devices (e.g. [6]).

Currently, such realistic visualizations are mostly applied to navigation, but with emerging co-operative vehicle-to-infrastructure or vehicle-to-vehicle communications technology (e.g., [1]), they will also become relevant for delivering more advanced safety-related services. For example, drivers could be notified about urgent incidents and provided with recommendations on what to do next.

The key purpose of realistic visualizations is to reduce the amount of abstract symbolization. This way, map use is characterized by "looking rather than reading" [8]. In the car, realistic views could potentially make visual processing easier and enable better concentration on the driving task. Inferring from earlier results in cognitive psychology [2], one might argue that the more realistic a virtual representation (of the road situation) is presented, the easier a mapping to the real situation based on perceptual features is possible. Especially in complex driving situations, this could result in increased driving safety. Furthermore, a higher realism of visualizations may promise higher usage satisfaction and appeal to customers than standard visualizations. On the other hand, also problematic aspects of realistic visualizations in cars need to be taken into account. As compared to conventional schematic maps, it may take more time to identify task-relevant information in realistic displays, which would limit a faster mapping between virtual and real environment. This may lead to serious restrictions and poor compliance with international car safety standards, such as the 'European Statement of Principles' [3].

While there is some research on augmented head-up displays, especially the use of reality views on head-down displays are only beginning to be explored (compare [5]). This paper presents first results from ongoing empirical research to overcome the scarcity of knowledge regarding this topic. As a starting point, we wanted to know whether or not a full 1:1 mapping (3D, egocentric) of the outside reality supports the driver in following HMI recommendations, as compared to a conventional view found in the majority of today's navigation systems (2D, bird's eye).

Second, we wanted to understand *when* such a 1:1 realistic view should be presented. Current state-of-the-art navigation systems (e.g., [7]) 'interleave' quasi-realistic with schematic representations: they show realistic representations only in critical moments, mostly when a driver approaches a complex junction, and show schematic route overviews in 'normal' situations. The general question is whether such an interleaved or rather a continuous presentation strategy is preferable.

Our third research issue was the *urgency level* on the preference of realistic visualizations. When driving

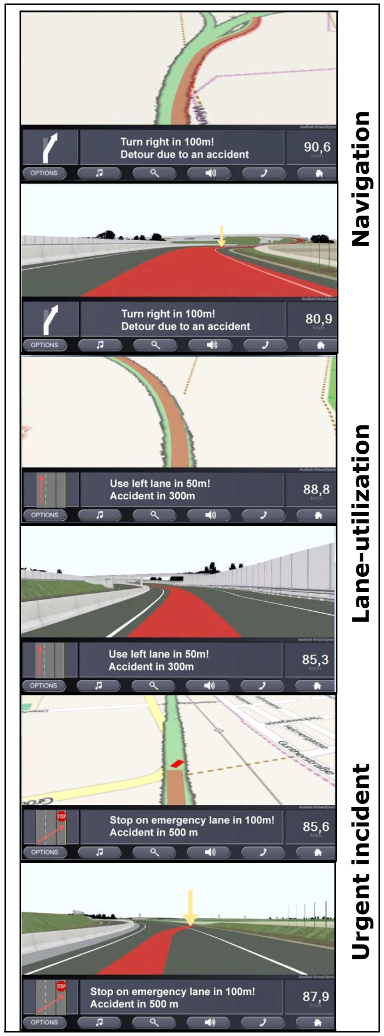

Figure 2. Realistic and conventional visualization for navigation, lane utilization, and urgent incident

along a prescribed route without any incidences, the information by the HMI must be monitored from time to time, but instantaneous reactions are not necessary. However, when the system calculates a detour (e.g., due to a congestion), the driver needs to be given instructions on how to change the route. Recommendations get more urgent when a user is asked to use a certain lane on the road, due to temporary roadwork. The highest level of urgency is given in case of an emergency warning, for example of an accident behind the next curve. A special challenge here is that the required actions can be quite unusual and therefore not as thoroughly learned. For example, drivers may be asked to stop before the tunnel on the emergency lane.

Method

To address these research issues, we conducted a driving simulator study with potential future users of advanced traffic telematics systems. 28 participants, 16 male and 12 female, took part in the study. Their mean age was 32.7, ranging from 18 to 59 years. 70% were frequent drivers. 60 % of the users owned a navigation device. As remuneration, each subject received a voucher for a consumer electronics store.

A simulation instead of a field environment has been chosen, because the investigated scenarios would be harmful for the involved drivers and impracticable with the currently installed telematics infrastructure. We have developed a versatile simulation environment that renders the "outside reality" (windscreen simulation) and the HMI display with the same engine and the same spatial model. This architecture enables systematic and fine-grained variations of scene representations on the HMI display. Users were sitting on a driving seat and in front of a dashboard, both taken from a real car. They were operating a steering wheel, gas and break pedals. The windshield view was displayed by a large 42" TFT screen, covering about 75 degrees of participants' field of view. The HMI was modeled by a second 8" TFT screen (landscape format) mounted to the lower left side of the windscreen, according to guidelines provided in [4].

The test users were exposed to *three safety-related application scenarios*: navigation with unexpected route change, lane utilization, and urgent incident warning. *Four visualization variants* were specified: 'none' (as a control condition), 'conventional', 'realistic' (a 1:1 representation of the windscreen simulation, and 'interleaved' (combination of conventional and realistic). Each visualization style was then realized for the three application scenarios, resulting in 12 different combinations. Fig. 2 illustrates the realization of the conventional and the realistic view for navigation, lane change, and urgent incident. In the 'none' variant, the map area was filled with grey color. In the interleaved variant, the conventional view was in the initial and the final phase, and the realistic view in the critical phase.

Procedure and measures

The overall duration of test was approximately two hours. A test assistant was present to conduct the interview, to provide task instructions, and to note specific observations made during the experiment. Each individual test consisted of an introduction phase, in which the test persons were briefed about the goals and procedure of the test, and data on demographics and previous experiences was gathered. Then, participants were enabled to familiarize themselves with the driving simulator and with the HMI. To minimize a potential habituation effect, it was assured that the users

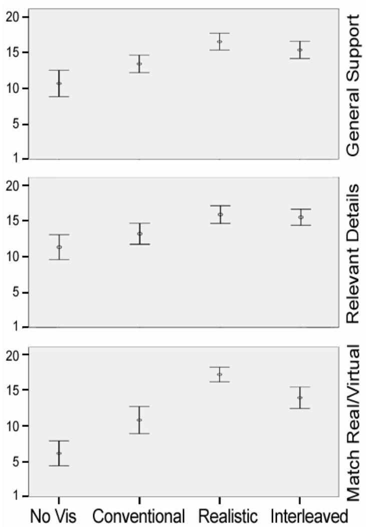

Figure 3: Mean post-condition ratings on the visualization styles, with regard to perceived general support in the driving situation, the support for identifying relevant details and for matching the virtual representation with the real-world. Error bars indicate 95% confidence intervals.

were informed about and had actively used each visualization and each application scenario. The subsequent phases of the study will now be described in detail.

The two independent factors of the experimental part were visualization and safety scenario. Each participant was driving 12 conditions, 4 of each scenario type, and 3 of each visualization variant (thereby encountering every possible combination between the 4 visualization and 3 scenario types). Order of scenario types and visualization styles, as well as their combinations, was counterbalanced systematically between test participants. In the critical phase of each driving condition, the experimenter assessed *task completion*. Task completion was given if the subjects generally followed the system instructions (taking the correct exit, selecting the right lane, and emerging stop on the right lane). Furthermore, the test facilitator noted incidents that occurred during the driving situation.

To capture the immediate driving- and HMI-related impressions, the participants filled out a questionnaire after each of the 12 conditions. The first question aimed at understanding the *general support* perceived in the driving situation. The two subsequent questions were designed to understand the visualization's support for *identifying relevant information* and its support for *finding matches between the road situation and the HMI display*. After having completed all driving scenarios, the subjects were asked to rank the four alternatives with regard to their support in *matching the road situation with the HMI display*, and to their ability in *identifying the task-relevant details*.

Results

The analysis was based on the data from 28 participants. For better readability, statistical details are not individually included in the text. Mean differences were calculated with non-parametrical techniques for dependent samples (Friedman and Wilcoxon tests). All mean score differences reported to be statistically significant have a probability of $p < .05$. Throughout the measures used in the study we did not find difference with regard to age, gender, or experience with navigation systems. We derived a very high task completion ratio across all test conditions: 99.4% of the navigation, lane utilization and urgent stop recommendations were generally followed. No significant differences between the different visualization styles were found.

Fig. 3 provides an overview of the visualizations' perceived *general support* in the respective driving situation, as well as their support for *identifying the relevant details* and for *matching with the outside real world*. On all three scales, participants rated those visualizations without a real-world representation worse than all others. Participants consistently judged the realistic view as more supportive than the conventional view (all differences significant). On none of the three scales, any difference could be found between the realistic and the interleaved visualizations.

Fig. 4 again shows the perceived overview support in the driving situation, but here separated by the *three safety scenarios*. The ratings are mostly consistent throughout all safety scenarios. A notable exception was observed when looking at the difference between the conventional and the realistic view: this was perceived as significantly lower rated in the urgent incident and lane utilization scenarios, but not in the navigation

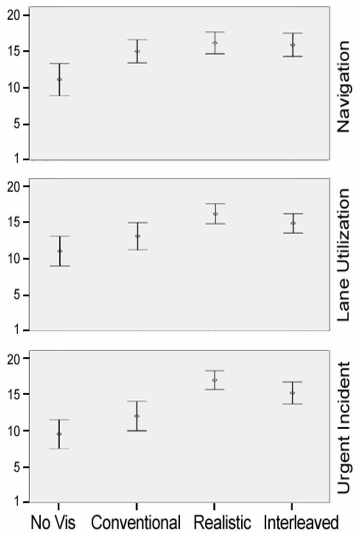

Figure 4: Mean post-condition ratings on the visualization styles, with regard to perceived general support in the driving situation, separated by the three scenarios. Error bars indicate 95% confidence intervals.

scenario. When directly comparing the rating values for the conventional visualizations between the different scenarios, the conventional visualization was rated better in the navigation than in the urgent incident scenario. The mean ratings in the lane utilization scenario also tended to be lower, but the difference did not reach significance. The main observations of incidents noted during the test conditions were as follows:

No visualization: When being confronted with on-screen navigation instructions, drivers did not encounter notable problems. In the two other scenarios, subjects often appeared to be confused about how they should behave correctly. They were unsure about where exactly to change lanes or where to stop (but as indicated above, the vast majority stopped correctly). Several users also got noticeably excited after receiving a warning and very attentively looked onto the road situation, to look for the announced incident.

Conventional: During navigation, no notable problems were observed. However, in the other two scenarios many users were unsure about where to stop or which lane to take. This was obviously due to the rather schematic visualization on the 2D map.

Realistic: In the realistic view conditions, users tried to follow the indicated arrow as closely as possible. In the urgent incident scenario, this attitude sometimes resulted in driving significantly slower to exactly stop at the indicated location. However, this behavior was mostly observed the first and second time a realistic view was used.

Interleaved: The switch from conventional view to the realistic view was noticed well by the drivers. In general, the observations made in the critical moment were similar to the ones made for the realistic visualization.

The participants widely stated that realistic visualizations had enabled them to find a match between the HMI and the real road situation (mean rating of 16.11 on a 20 point scale, SD = 3.8). Similarly, many participants stated that realistic visualizations had *not* hindered them in finding the relevant details on the screen (mean of 5.5 on a 20 point rating scale, SD = 4.4).

Conclusions

The experiment presented in this paper is the first systematic evaluation of realistic visualization for in-car safety information systems. Our results show that realistic HMI visualization styles have a significant positive impact on the user experience. In comparison to other visualization styles, realistic views provided added value in terms of driver support and perceived safety, beyond a purely aesthetic function as visual enhancement or "eye candy". We did not find any evidence for negative impact of realistic views on participants, e.g. in terms of diminished task-performance, distractions by visual clutter or reduced safety.

Our findings may thus challenge conventional recommendations which postulate the simplification and reduction of visual HMIs designs (such as [3]). In the light of our results, the application of realistic views in safety contexts should be considered again on a broader level. We therefore suggest further systematic research on the merits and demerits of realistic visualizations for in-vehicle navigation and safety applications.

We furthermore found that switching between a conventional visualization (shown in non-critical situations) and a realistic visualization (shown in critical situations) does not provide an added benefit, as compared to the continuous display of a realistic visualization.

Compared to traditional navigation, urgent safety scenarios have different properties than traditional navigation, and our study shows that this implies different visualization requirements: in the navigation scenario, users saw no additional benefit of realistic views over conventional, schematic ones. However, with rising urgency of the scenarios, participants found realistic views to be significantly more useful. This shows not only that reality views provide tangible benefits for the driver, but also that safety-related HMI represent an application class distinct from pure navigation, requiring dedicated user experience research.

Our study participants were only exposed to relatively simple environments (highway) and tasks (such as stopping at the emergency lane). This may explain the observed insensitivity of users' (near to perfect) task completion rate to visualization style. Thus, our results should not be generalized towards more challenging high complexity scenarios. Under high strain and cognitive load, users might change preferences and perform better with other or even without HMI visualizations. As this study strongly focused on the user experience, we are currently running a replication study with further objective measures, most importantly eye movements.

In this study, we were deliberately interested in understanding the effects of certain prototypical extreme variants (no visualization, conventional, realistic and interleaved views). Obviously, further visualization variants are possible in this context. Most importantly, we want to stress the fact that these three styles represent idealized variants highly suitable for experimental testing, but which in practice are rather encountered as downgraded or simplified implementations. For example, visualizations currently marketed as "reality views" actually still have many aspects of schematic representations: often they do not display the current situation, but only display 3D templates or 2D images of prototypical junctions. To advance towards safe and satisfactory realistic visualizations in the car, the results clearly encourage the scientific advancement and understanding of the design space for realistic visualizations.

Acknowledgements

This work has been carried out within the projects REALSAFE and U0, which are financed in parts by ASFiNAG AG, Kapsch TrafficCom AG, nast consulting, the Austrian Government and by the City of Vienna within the competence center program COMET.

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