INTERNATIONAL DESIGN CONFERENCE - DESIGN 2004
Dubrovnik, May 18 - 21, 2004.

DESIGN 2004

AUGMENTED REALITY AS A NAVIGATION AID FOR THE MANOEUVRING OF HIGH-SPEED CRAFTS

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Keywords: augmented reality, head-up displays, bridge design, user interface design, visual focus, high-speed crafts, navigation

1. Introduction

A natural goal for navigators of high-speed crafts (HSCs) is to visually observe the surroundings of their ship. After all, detection of any objects threatening the safety of the craft is a primary goal for the human operators onboard. During bad weather conditions, however, the amount of information received through direct visual supervision of the surroundings is reduced. During such circumstances the navigator receives almost all information from onboard instruments, such as radar, electronic charts, etc. Accurate awareness of the location and heading of the ship, as well as surrounding ships are essential. This is particularly relevant for the future since HSC-traffic is rapidly increasing. Furthermore, bad weather conditions also increase the amount of radar clutter, thereby potentially hiding relevant information, such as reefs and other ships. What makes the navigation task even more challenging is the fact that most HSC-navigators are stuck with traditional radar displays that are far too difficult to use and take up valuable time to adjust. Since HSCs are able to move long distances in short periods of time, it is vital to keep the radar image well calibrated at all times. Another important aspect that makes the manoeuvring of HSCs a complex task is the fact that the speed differences between HSCs and conventional ships introduce exceptions to the traditional rules for preventing collisions at sea. For example, navigators of HSCs sometimes use their higher speed to avoid and escape conflicting situations, instead of following the regulations.

Several accident reports involving HSCs indicate that navigators having trouble interpreting radar information has been the major cause of accidents. For example, the accident report from the grounding of the high-speed craft MS Sleipner in 1999 showed that, immediately prior to grounding, both navigators were busy adjusting their radar images [Statens forvaltningstjeneste, Informasjonsforvaltning 2000]. The collision in 1992, between the catamaran ferry Royal Vancouver and the Ro-Ro ferry Queen of Saanich serves as another example [Skjong, Adamcik, Eknes, Gran & Spouge 1997]. The nearly bow-on collision has been concluded to be due to disturbing VHF traffic and changes in the radar range, causing the navigators to misinterpret the radar echoes.

The general purpose of this paper is to investigate how the use of an augmented reality application (described in 0) affects the navigators' work procedures when manoeuvring HSCs. In accordance with the terminology used by Foyle, McCann and Shelden [1995] the information found by looking through the windshield with or without augmented reality will from now on be referred to as the "out-the-window scene". We expect the introduction of the augmented reality to cause the navigators to increase their focus on the out-the-window scene. Also the driving speed and the deviation from the ideal route are expected to change with the introduction of augmented reality.

1.1 Theory

Here a Cognitive Work Analysis (CWA) approach [Vicente 1999], [Rasmussen, Pejtersen & Goodstein 1994] is used in order to obtain the information necessary for the task of designing new information systems for high-speed crafts. Vicente argues that the CWA-framework is tailored to the unique demands of complex sociotechnical systems, and also that it is most useful when developing completely new systems. These qualities make the framework well suited for the problems at hand, and we anticipate that our work procedures will provide knowledge useful for the design of navigation tools that enable the navigators to adapt to unexpected events and changing demands. However, based on our longstanding tradition of working with skilled users in different disciplines [Gulliksen, Göransson, Boivie, Blomkvist, Persson & Cajander 2003], we know that it is necessary to involve users early in the development of a new decision support system.

1.2 Augmented reality

In this application, augmented reality is formed by presenting scene-linked information on a head-up display. A head-up display is a transparent screen, generally located above the instrument panel of a vehicle, on which graphical information can be presented. Scene-linked information is presented on a head-up display in such a way that it is perceived as being positioned in the real world [Foyle, McCann & Shelden 1995].

Our ambition with the use of augmented reality is to support the navigators' information retrieval task. This is done by letting them keep direct visual supervision of the out-the-window scene using augmented reality. The information traditionally presented using ordinary instrumentation, is thereby accessible without having to look down, e.g. to look at the radar screen. There are several positive aspects of this. For example, the navigators do not have to change visual focus to find relevant information, and they do not have to readjust their eyes to the changed light conditions. These two tasks normally take short but frequent time to perform.

By providing navigation related information directly in the field of vision, the navigators are able to direct their visual focus to the surroundings of the ship rather than the onboard instruments. During bad weather conditions less information is found by looking out of the window, and this causes the navigators of traditional HSCs to change their visual focus primarily to the onboard instruments. Even though most navigators have the ambition to keep watch by direct visual supervision, efforts are needed to actually do it.

Furthermore, by providing a 3D-representation of the augmented information, the navigator is relieved of the task of mentally transforming the 2D-data (radar and electronic charts) into three dimensions (i.e. the real world). This transformation can be considered as an easy task by a professional, but there is always a risk of misinterpretations. Earlier studies also show that the use of scene-linked symbology, using virtual augmented information matching the real world objects, may lead to efficient simultaneous visual/cognitive processing of both the head-up display symbology and the out-the-window scene [Foyle, McCann & Shelden 1995].

Although the advantages with the augmented reality technique are strong, there is also a potential risk in introducing more complex and advanced navigation tools, because this can make the navigator more dependent of the new technology. Since parts of the navigation task will change with the use of the suggested tool, it can be expected that the navigators adapt to these new conditions and develop new work procedures. Such changes can easily cause trouble when the automated tool fails and the navigator is forced to switch to manual control [Bainbridge 1987]. It is therefore important to find out early about any changes in terms of visual focus and attention. Such changes must be analysed further, in order to understand their consequences in terms of automation and manual control.

1.3 Previous work

Similar approaches to information presentation have previously been suggested in the field of aviation and that work has influenced other domains, such as the car industry as well as the high-speed craft application described here. For example, Möller and Sachs [1994] describe a "Synthetic Visual System" that share many aspects with our approach. Both approaches aim to use data from both sensors and terrain databases, to generate an augmented 3D-representation of the reality that can be used to manoeuvre the concerned vehicles during low-visibility conditions.

A very limited amount of research has previously been conducted using augmented reality onboard HSCs. One similar approach to ours has been suggested by Bjorneseth [2003]. His approach suggests that the predefined route of the ship is presented in a road like manner on a head-up display. The results of their experimental testing are not yet reported. Instead, our approach concerns the enhancement of real world objects such as buoys and shorelines. Perhaps a courteous combination of these two approaches might be the most appropriate, dependent on the situation. For example, a high-speed craft manoeuvring in foggy weather in a narrow fairway might need more guidance from physical properties of the surroundings, than when navigating on open water.

The experiment described here, has been preceded by an earlier study with three experienced navigators, using the simulator described later in this paper [Olsson, Jansson & Seipel 2002]. These mariners supplied us with feedback of what kinds of augmented information they considered relevant/irrelevant. E.g. shorelines were outlined using blue lines on the head-up display, and all mariners argued that this information stood out too much compared to its limited use, especially further ahead from the ship. Therefore efforts have been made to adjust the graphics of the simulator to comply with this feedback. In the initial setup, the shoreline data was copied, without modifications, directly from an electronic chart. But in order to better adopt the information to this new type of display, changes were made so that the brightness of the shorelines now is decreasing with the distance from the ship, and only shorelines on the front side of the islands are presented. After these two changes the information on the display was perceived as less disturbing, and it also gave the navigator a better understanding of the distances represented by the augmented shoreline information. Prior to the experiment described in this paper, an evaluation of both the experimental setup, and the measuring techniques was made. This work involved 20 students and resulted in some minor refinements to the procedures used during the experiment.

1.4 Hypotheses

Hypothesis 1: the introduction of augmented reality is expected to affect the efficiency, in terms of faster driving speed and lower deviation, compared to conditions without augmented reality!
Hypothesis 2: the visual focus is expected to change, from the radar screen towards the out-the-window scene as a consequence of the introduction of the augmented reality!

2. Method

2.1 Equipment

2.1.1 The simulator

A simple HSC-simulator that uses 3D-graphics visualisation was created (Figure), and a simulated 3D world was constructed from an electronic chart of the archipelago of Stockholm, Sweden (Chart 612: Furusund – Saxarfjärden).

This simulated world (Figure 2, left), corresponding to the real world as seen from the bridge, was projected onto a large front projection screen. Augmented information (Figure 2, centre) consisting of a 3D-representation of shorelines, buoys, "fairway lines" and ships were projected onto a separate transparent holographic Plexiglas screen, corresponding to the windscreen of the ship. The "fairway lines" were augmented using red and green lines connecting the red and the green buoys respectively.

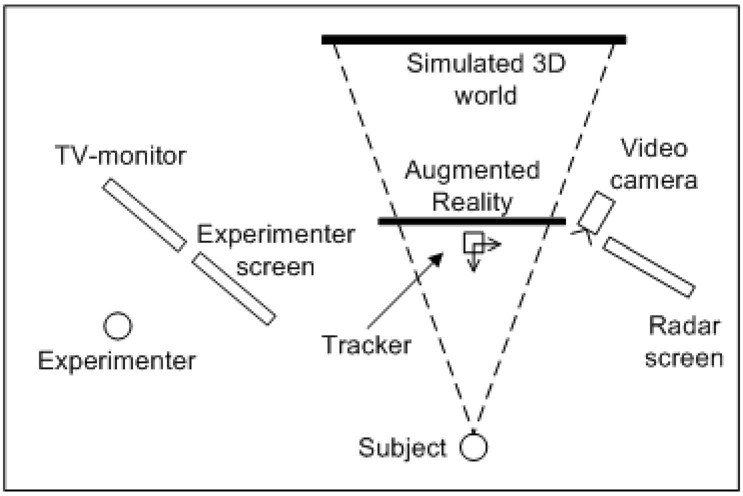

Figure 1. Schematic view of the experiment setup, as seen from above

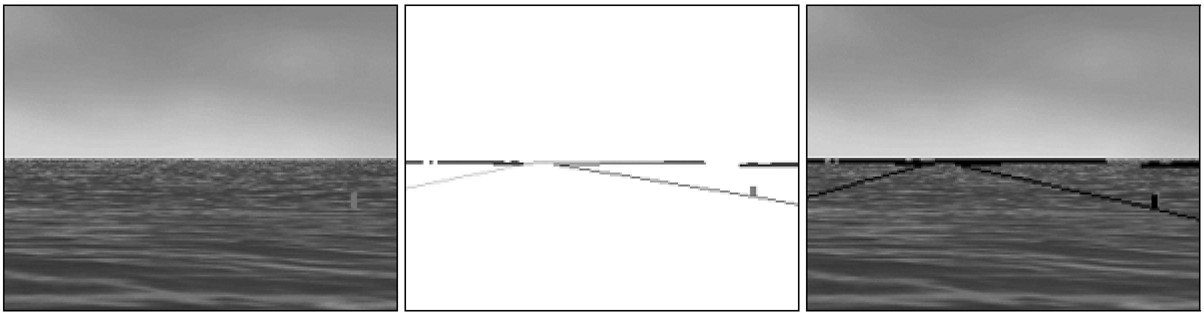

Figure 2. Screenshots of the graphics (modified to be shown in greyscale): Simulated 3D world (left), augmented world (centre), combined view (right)

The correct mapping between the simulated 3D world and the augmented world was maintained by the use of a head tracker, thereby achieving the view shown to the right in Figure 2. A radar screen was present to the right of the holographic screen. The room where the experiment was conducted was kept nearly dark during the experiments, in order to perceive the augmented information clearly. The subject's visual focus was captured using a transmitter of infrared light together with a video camera sensitive to light both from the visual spectrum as well as parts of the infrared spectrum. No complex physical properties of the ship were simulated, and the manoeuvring of the ship was performed simply by keyboard interaction. An experimenter screen was present showing a bird's eye view of the simulated world, together with a TV-monitor displaying the current view of the camera, in order for the experimenter to ensure that the subjects' eyes were in the camera's field of view. Four standard computers, sharing relevant simulation states via a LAN, were used to render all necessary data.

2.1.2 Data collection

The time usage and the position of the ship were logged by the simulation software. The subjects' eyes were recorded by the video camera.

2.1.3 Data analysing

The deviation of the ship was post calculated using both the ship position data and a predefined ideal route, described later. The video data was analysed to determine how the subjects distributed their visual focus throughout the experiment. A simple measuring tool was developed to make the registering of shifts in focus easier. Both the amount of time and the number of times that each information source got visual focus was measured. The task of discriminating between the different information sources was easy to perform, mainly because there were only two relevant sources available, but also because the video camera was positioned right between them.

2.2 Experimental design

2.2.1 Independent variable

The independent variable was made up by different modes of presentation of navigational information with altogether five conditions which are listed in Table 1.

Table 1. List of scenarios

a.	Control condition
b.	Darkness
c.	Darkness + Augmented reality
d.	Fog
e.	Fog + Augmented Reality

2.2.2 Dependent variables

Several dependent variables were measured during the experiment; the distribution of the subjects' visual focus over time, the number of times that the subjects switches visual focus, the ship's deviation sideways and the elapsed time during each scenario.

2.2.3 Subjects

Four male mariners with 20-30 years of maritime experience participated in the experiment. One subject at the time performed the steps described below and each subject participated for about one and a half hour.

2.2.4 Procedure

Initially each subject performed a learning phase, followed by a control condition where they manoeuvred a simulated HSC in a clear weather scenario, for a distance of roughly five nautical miles. This was then followed by four scenarios along the same route, but in fog or in darkness, with and without the use of augmented reality. The different scenarios are listed in Table 1. Two subjects performed the scenarios according to $S_1\{a,b,c,d,e\}$ and two according to $S_2\{a,d,e,b,c\}$.

3. Results

3.1 Time

The time spent manoeuvring the ship in scenarios with augmented reality was somewhat shorter than in the scenarios without (Figure 3).

3.2 Deviation

The ships deviation is measured relative to a predefined path which the subjects were instructed to follow. The deviation is lower in the scenarios with augmented reality, than in the scenarios without it (Figure 4).

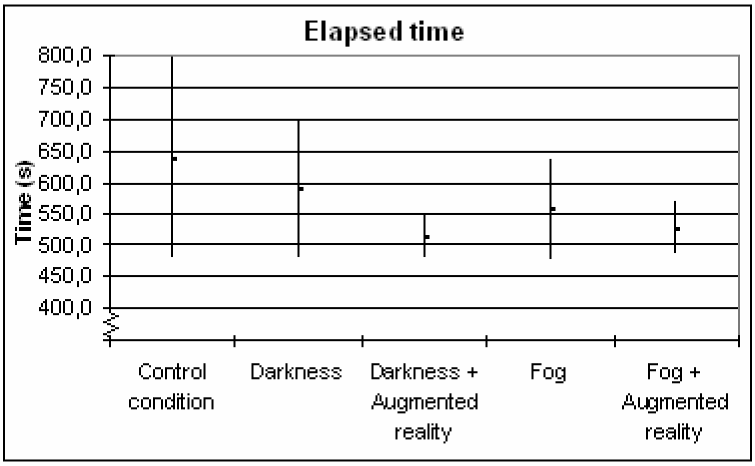

Figure 3. The manoeuvring time used per scenario

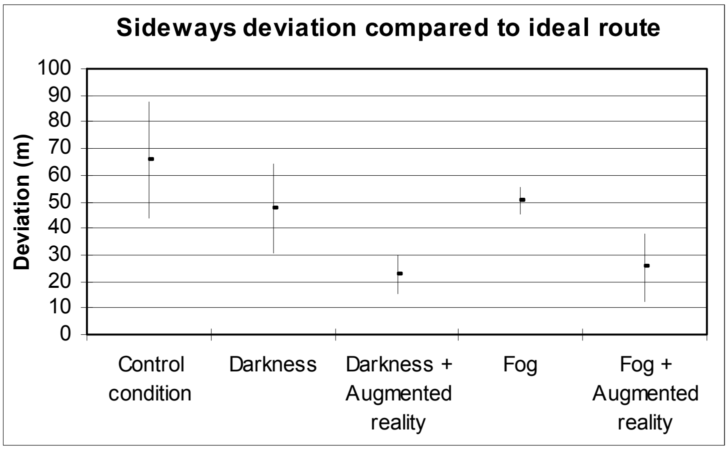

Figure 4. The deviation from the ideal route

3.3 Visual focus

Providing navigation related information in the field of vision changes the navigator's visual focus. During the scenarios without augmented reality, much of the subjects focus was directed towards the radar screen, but when augmented reality was introduced focus was changed towards the out-the-window scene (Figure 5).

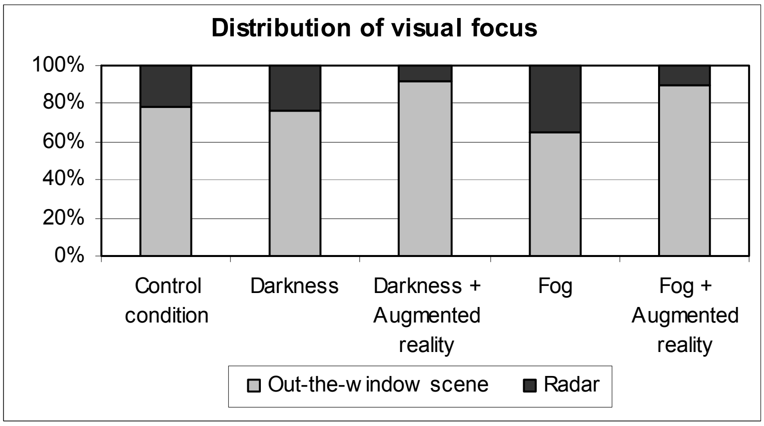

Figure 5. The distribution of subjects' visual focus

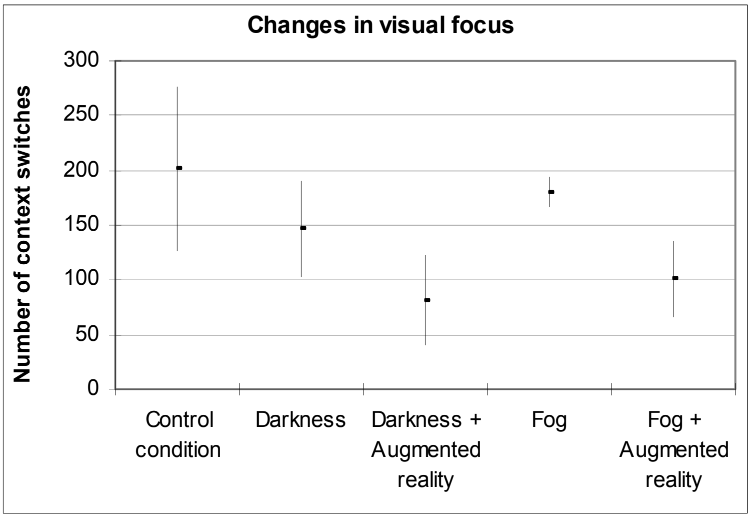

Figure 6. The number of switches in visual focus

The amount of times that the subject changed visual focus decreased when augmented reality was introduced (Figure 6).

4. Discussion

Most subjects considered the visual realism of the simulator to be sufficiently high, and they also commented on the future potential of the technique in situations with low visibility and high speed.

4.1 Time

It might be a change in driving style that causes the time differences seen in Figure 3. But another contributing factor might be that the augmented reality causes the navigator to feel safer in a low-visibility scenario, and thereby driving a bit faster. There is of course a risk in providing the navigators with augmented information, if this makes them feel too safe in a dangerous situation such as a low-visibility scenario.

4.2 Deviation

The fact that the control condition shows the highest deviation is mainly due to a too short learning phase. The lower deviation found in the scenarios with augmented reality indicates that augmented reality affects the navigator's choice of course. This change in behaviour hides a potential risk, if the navigator feels forced to keep the ship inside the augmented fairway markings, thereby perceiving the fairway as more narrow than it actually is. Although this problem might be avoided by providing the navigator with different kinds of augmented information. For instance, subjects have proposed the presentation of predefined routes, safe water, rings indicating the approximate position of buoys, etc.

4.3 Visual focus

When introducing augmented reality, the amount of time spent looking towards the out-the-window scene increased, indicating that augmented reality allow the navigator to focus more on the out-the-window scene. The number of times that the navigator switches visual focus decreased, when augmented reality was introduced. This decrease relieves the navigator from some visual scanning as well as light adjustments of the eyes, which occur every time focus is changed.

At present, the simulator does not provide any realistic way of measuring at which distance the subject fixates, and therefore no distinction can be made between the augmented reality and the simulated 3D world. This aspect will be relevant to consider at a later stage of research.

5. Conclusions

This paper has shown that the use of augmented reality for the task of manoeuvring HSCs clearly has some interesting advantages, especially how it affects the navigator's visual focus and choice of course. But it also emphasises the difficulties that have to be faced before introducing such techniques into the HSC bridge environment. It is concluded that the changes in behaviour must be analysed more thoroughly, and that this new technique must be developed further in cooperation with the real experts, the skilled navigators.

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