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Remote Operation of Unmanned Surface Vessel through Virtual Reality - a low cognitive load approach

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ABSTRACT

An unmanned ship can be designed without considering human comfort, and can thus be constructed lighter, smaller and less expensive. It can carry out missions in rough terrain or be in areas where it would be dangerous for a human to operate. By not having to support a crew, lengthy missions can be accepted, enabling, e.g. reconnaissance missions, or reducing emissions by lowering the speed.

Breakthroughs with autonomous systems enable more advanced unmanned surface vessels (USVs), but to be able to handle complex missions in a dynamic environment, a human operator is still assumed an effective decision maker. Thus, we propose a method for remote operation of a USV, where the operator uses Virtual Reality (VR) to comprehend the surrounding environment. Great importance has been given to the ability to perform safe navigation, by designing a Graphical User Interface (GUI) that guides the operator through the navigation process, by presenting the important information at the right place in the right orientation.

KEYWORDS

Remote Operation, Virtual Reality, Unmanned Surface Vessel, Autonomous Surface Vessel, Navigation, Cognitive Load

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1 INTRODUCTION

Autonomous Surface Vessels (ASV) have evolved during the last decades [19], and have now reached a maturity level where they are starting to be used commercially. We believe there are many potential benefits, including:

- Cost-effectiveness, where the expensive human operator can be removed. By removing the operator, the ship will no longer be constructed for human comfort, and the cost can thereby be reduced even further.
- Human work environment. By reducing the crew size, the risk of a shortage of seafarers is reduced.
- Safety. By developing algorithms for safe navigation, the ship can operate continuously without making human errors.
- Persistence. An unmanned vehicle can be used during long periods of time when there is no humans on-board who have a limited amount of working hours.
- Ability to operate in hazardous conditions, e.g., rough weather or during anti-piracy operations.

Even bigger oceangoing commercial container and bulk ships are being developed for unmanned usage [4], and are anticipated to be in commercial service in 10-15 years [12]. The foreseen benefits are increased safety, but also reduced workload for humans. As a consequence of a significantly reduced crew-size, it will also be possible to reduce the speed of the ships, lowering the fuel consumption, and thereby the environmental impact [6, 12].

Compared to car traffic situations, traffic at sea is often characterized with more available time for decision making. Many ships also travel most of their route at open sea, where there is hardly any traffic at all. On the other hand, when entering a highly trafficked harbor during bad weather, many complex situations arise, which gives a need for either human decision making or intelligent autonomous algorithms.

Also in other situations, it might still be beneficial or even crucial to allow for human decision making. Hence, we assume that allowing a human operator to have both an insight into the situation an unmanned, maybe to a certain degree autonomously navigating vessel is, and the opportunity to take at will control over the vessel, can be very beneficial to overcome the gap between manned and fully autonomous vessels.

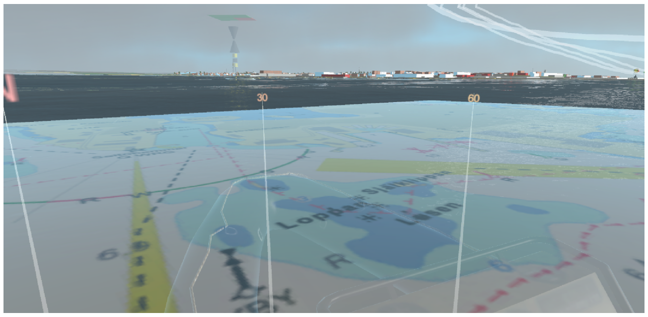

Figure 1: The GUI from the project, presented in the Virtual Environment. The sea chart is rotated to fit the surrounding world, and the sea marks are increased in size to be simpler to detect.

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However, during complex situations at sea, it can be hard for even a human to interpret and match the surrounding environment with the information from the navigation equipment. There are several situations where the navigation operators, due to the high cognitive load, have mixed up sea marks, directions or landmarks, which in many cases have led to fatal accidents [16].

We propose thus a Graphical User Interface (GUI) developed for remote operation of an Unmanned Surface Vessel (USV). The GUI is created for VR utilization so that the operator can experience being situated on board the ship. The real world environment is re-created from sea charts into the Virtual Environment (VE). The GUI is then placed in another layer in the VE, where, e.g., seamarks augment directly the operators' view of the environment, making it easy for the operators to interpret them, see figure 1.

To evaluate the GUI, sea trials have been conducted in an archipelago by a USV called *the Piraya*, developed by *Saab Kockums AB* [1].

Naval officers have been involved in the implementation and have given a brief initial evaluation of the GUI.

This paper is organized as follows: In Section 3, an overview is given of how other research has investigated how the cognitive load can be reduced during navigation. These learnings have been used in our GUI created in our project, presented in section 4. Section 4.6 presents a brief operator evaluation, concluded by a discussion in section 5.

2 SCOPE

There are many scenarios where VR and Augmented Reality (AR) can be used in order to enhance Situational Awareness (SA) at sea. On a bridge, AR can be used for augmenting the surrounding environment with information from the ship's sensors. In a control room on board a ship where there are no windows, VR can be used in the same way, but in this case, the surrounding environment also needs to be created virtually, or by streaming video from all available directions. In this scenario on board the ship, sensor information such as video can be added directly to the Virtual Environment (VE).

In order to bound the scope of our study, we have chosen to focus our work on a GUI with the task to control a USV, where the USV has a limited bandwidth connection to the GUI which inhibits video or high-resolution images to be sent. The implementation can easily be extended to also fit the other scenarios. For these, however, features in the GUI need to be added or changed, and an AR HMD (Head Mounted Display) needs to be used for the bridge scenario.

3 RELATED WORK

Much research has investigated how the operators can interact with the navigation systems, in order to increase safety. There has also been done a lot of research regarding USVs, where remote control often is an essential part. However, we have not found any research done in the combination of these two areas.

3.1 Safe navigation with low cognitive load

The traditional way to navigate at sea is to use a paper sea chart, showing an abstracted map of, e.g., islands, groundings, depths measurements and sea marks. The paper sea chart is constructed with north facing up. During the last two decades, there has been a transition on bigger ships to use electronic chart systems, where the sea chart is instead visualized digitally on a computer screen. The main benefit is that the own ship's position, normally received from the GPS, is visualized at the correct location on the sea chart. The sea chart can be presented with north-up or head-up reading rotation.

The human ability to mentally rotate a map or sea chart, so that the symbols in the map can be matched with surrounding real-world objects, is rather limited. Shepard et al. [21] showed that the time to recognize that two perspective drawings are showing the same three-dimensional shape is linearly increasing to the angular difference of the perspectives. This means that a human can match the ship's surrounding quite well when steering in north direction when reading a north-up oriented sea chart, but will need more time reading the same north-up oriented sea chart when steering in the opposite direction. Operators often choose to present the sea chart with north-up and radar with head-up [16] rotation, thus mental rotations are needed both between those two systems, and between the systems and the surrounding real world.

Another way of presenting a map is to view it from the driver's perspective. This is normally done in a GPS navigator for car drivers. The benefit is that the driver can quickly understand which roads and buildings on the map match the roads and buildings in the real world surrounding. By letting the machine do the mental rotations instead of the human operator, valuable time is saved, and many accidents are thereby likely to be avoided.

Porathe [17] compares these four map views in a simplified indoor environment where persons navigate on a floor trying to navigate fast but striving to avoid groundings. The compared views are the already mentioned:

(1) Traditional paper sea chart (north-up)
(2) Electronic chart system (north-up)
(3) Electronic chart system (head-up)
(4) 3-D map with Ego-centric View

The results of this test show that (4) gives the fastest decision makings, least groundings, and is perceived as the most user-friendly. The results also clearly show that using an electronic chart system gives better results than using paper charts.

Some persons are more skilled than others when it comes to interpretation and mental rotations of maps. Porathe [18] has divided the persons into sub-groups depending on previous map experience, gender, and age. Persons with map experience, males, and younger persons generally perform better, but disregarding which group that compares the four different map views, the results remain the same; (4) gives the best results, followed by (3), (2) and (1). An interesting finding is that although persons have a great experience from using an electronic chart system, they still perform better when switching to 3-D maps, despite that they are not used to it.

With the results in mind, Porathe [16] suggests using a 3-D map with the ego-centric view as a navigation aid, viewed on a computer screen or tablet. Witt [22] has also proposed a similar solution with a tablet where the ego-centric view helps the operator reducing the cognitive load. Our GUI is influenced by these results, as we place the operator directly into the 3D world where the surrounding world easily can be matched with the sea chart.

Much research has also been done investigating how AR can reduce cognitive load when navigating. In these applications Head Mounted Displays (HMDs), normally with see-through technology, augment important information, such as sea lanes, conning information or AIS information. [5, 10, 11, 13, 14]. We use the same technique to augment important information in the VE instead of overlaying it on top of the real world.

3.2 Remote control of USV

Since there is no fully autonomous USV developed yet, USVs in general still need some remote operation. Respective GUIs often contain a map where the USV is positioned, along with functions for describing the status of the USV [7, 15]. We have not been able to find any research describing remote operation in VR though.

4 NAVIGATION AND CONTROL IN VIRTUAL REALITY

4.1 Platform Description

The Piraya boats used in the project have a length of 4 m and a maximum speed of approximately 20 knots [3]. They are equipped with GPS for position measurement and a PTZ-camera (Axis Q6155-E) for video streaming. During operation, the position and attitude data are sent to the GUI, so that the GUI is positioned in the correct location in the VE. Sea-trials have been carried out to log entire trips, which have been used during the development of the GUI, along with simulations of comparable scenarios.

4.2 Architectural Description

There are two main parts in the architecture; the *Shore System* and the *USV (Piraya)*, see figure 2. The main contribution of this paper is the *VR GUI* in the*Shore System*. It is integrated with the *Unity world* that provides the VE, including the simulated ships. The VE is updated according to the *Simulation kernel*.

In the *USV*, already present functionality was used for steering the USV as well as the camera. These functions are planned to be integrated with the *VR GUI* in the future. A function that has been developed for detecting persons in the water (simulated by orange buoys) was also used. When this function detects a buoy, it sends a small cropped image to the *VR GUI*, where the real world image can be visualized in the VE. In the future, functionality for controlling the camera directly from the GUI is foreseen to be added. Another valuable function is to be able to detect other objects than buoys. Cropped images from other detected objects, e.g., boats could then be sent to the *VR GUI*.

4.3 Goals with the GUI implementation

The intention is to create an easy-to-use GUI for remote operation of a USV. It is important to uphold a safe navigation, and the goal is to create a system which is at least as safe as a comparable ship of its size. Thereby, the USV and the GUI must have functionality for creating a good understanding of the vessel's environment and the USV needs to have functionality for making some decisions about what information that should be sent to the GUI. The GUI also needs to give the operator better navigation tools than normal ships, to compensate for the operator not being on-board.

In this paper, the first baseline of the GUI is presented, which will be evaluated so that it can be evolved to finally meet the goals.

4.4 Main Operational Views

Two different main views have been created; *Egocentric view* and *Tethered View*. These will in the future be complemented with the *Exocentric View*, which will show the USV in the middle of a north-up sea chart. Each of the views has their own benefits and shall be seen as a complement to each other.

4.4.1 *Egocentric View.*

The *Egocentric View* in figure 3 visualizes the world from the USV's (ego) perspective, hence it simulates what the surrounding environment looks like. The camera has good bearing accuracy but poor range accuracy. From the egocentric view, the range is of lower importance, hence information from passive sensors such as cameras are well visualized in this view. By capturing real-world images of landmarks and comparing the bearings to the sea chart, it will be obvious if the current GPS position diverges from the correct position, as the landmark bearings will not match the chart.

4.4.2 *Tethered View.*

The *Tethered View* is created by a camera hanging after the USV up in the air, viewing the USV from above, see figure 4. The operator has a good overview of the USV and what is around it, and can at the same time see where the USV is situated on the sea chart. In figure 5 the USV is going to the right in the sea lane in the direction towards a lighthouse where yellow light is emitted.

4.5 Features to reduce the cognitive load

Several features have been implemented to support navigation and situational awareness, while still limiting the cognitive load.

4.5.1 *Sea chart.*

A sea chart is visualized both in *Egocentric View* (see figure 7 and 1 and in *Tethered Veiw* (see figure 4 and 5). In the *Tethered View*, the sea chart is shown instead of the water. The operator can see where groundings or sea marks are located and adjust the steering to adjust to the map.

In the *Egocentric View* the viewing camera is located at the center of the sea chart, showing the surrounding area of the USV. The sea chart is always arranged in the correct orientation so that the operator easily can match surrounding objects and islands to the symbols in the sea chart.

4.5.2 *Orientation and Compass Rose.*

It is important to be able to uphold an orientation at all time. To help the operator, the following clues are given:

- The sea chart is quadratic and is always heading north, together with all text and numbers on the chart.
- The sun is visible at all time in a direction that matches the time and day of the year.
- The *Compass Rose* is visible at all time

The *Compass Rose* is visible both during *Egocentric View* (see figure 3) and *Tethered View* (see figure 4 and 5). Other research has shown that the usage of different colors can increase the orientation capability, and by overlaying colors, the time to translate to a

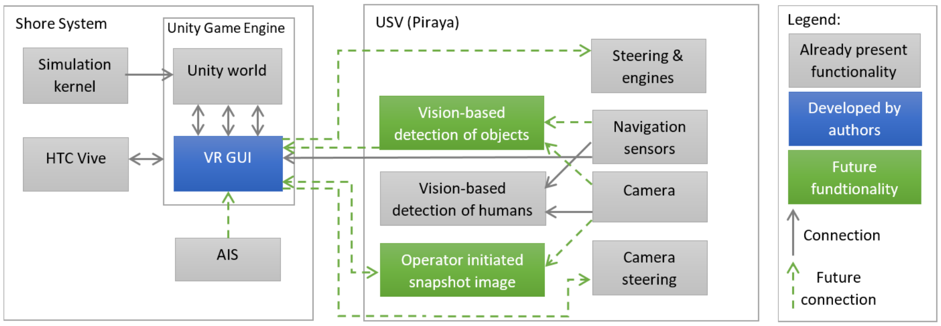

Figure 2: Architecture Overview. The VE with the GUI is created ashore (left part of the image). The USV (right part of the image) has functionality for steering the ship and camera, and sends cropped camera images, USV position and USV orientation to the GUI.

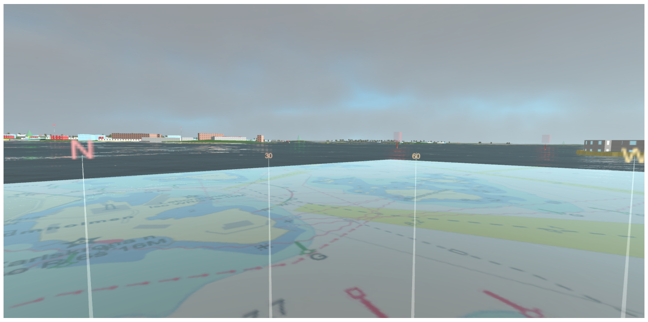

Figure 3: In the Ego-Centric View the camera is placed onboard the USV so that the operator experience being onboard. The center of the sea chart is placed in the operator's location and rotated so that it is consistent with the orientation of the world.

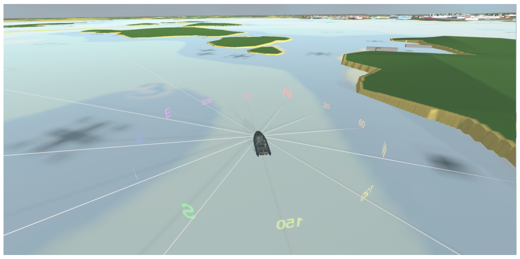

Figure 4: The USV is visualized from above in the *Tethered View.*

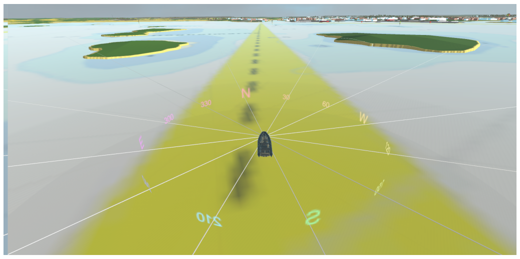

Figure 5: *Tethered View.* The USV is going in the yellow light segment from a lighthouse.

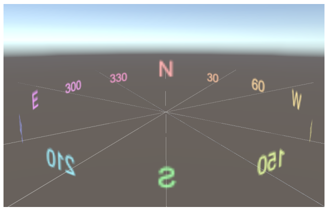

Figure 6: The angle indicator on the compass rose shown above the sea chart, have been color coded according to a rainbow. By doing so, the intention is that a human operator will eventually learn which color corresponds to which orientation.

rotation can be shortened [8, 9]. Thus, the *Compass Rose* has been colored according to a circular rainbow pattern, with the potential benefit that the operators in time will learn to associate the different colors with the related orientations. The *Compass Rose* can be seen in figure 6.

4.5.3 NoGo-areas. There are many parameters which influence under-keel clearance. First, the accuracy of the current position needs to be estimated, resulting in an area in where the USV is located. Then this area is compared with the bottom topography of the same area. The last step is to compensate for current draught and for the current water level. All these steps are time-consuming and hard to do for a human. A computer can instead perform the calculations. Porathe [16] suggests coloring the water in his proposed 3D-images so that the operator knows where not to go. We have proposed a comparable way, by showing icebergs where it is too shallow. In the images, the operator is warned when shallower than 3m, see figure 7.

4.5.4 Sea marks. Seamarks are in general hard to detect at sea. The problem is that they are small, and in rough weather, it is time-consuming to first find the seamark in the sea chart, then try

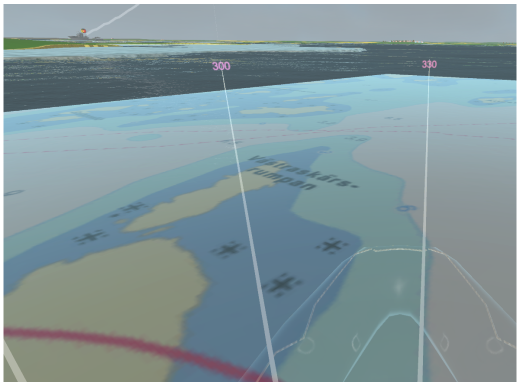

Figure 7: The area in the sea chart with depth below 3m are lifted up above surface as icebergs, so that the operator easily understands that it is a dangerous area.

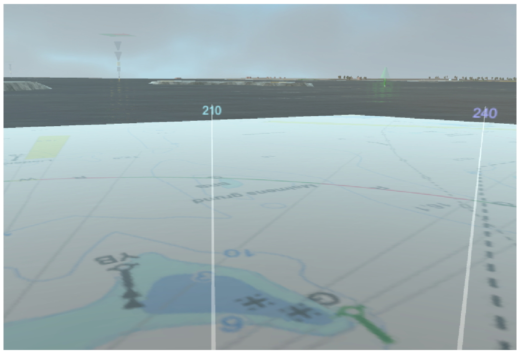

Figure 8: The sea marks are increased in size to be more easily detected. By following the lines from the compass rose, it gets easier to find out which sea marks that match which symbols in the sea chart.

to estimate in what direction they are located in, and then finally trying to detect it when still far away.

By having a sea chart that is always rotated in the correct way, it is easy to estimate which sea marks that belong to which in the sea chart, see figure 8. The sea marks are also ten times bigger than reality, which makes them easier to detect.

Cardinal marks are sea marks which mark out in what compass direction there is a grounding. In the VR GUI, they are complemented with a red-green area above them, indicating in which direction the grounding is located. This is shown in figure 9, as well as that the iceberg marks the same grounding.

4.5.5 Tracking of ships. The Automatic Identification System (AIS) is mandatory for bigger ships. The system provides information about, e.g., identification, position and heading, to nearby ships. By receiving this information directly to the GUI, it is possible to present real-time information about the bigger ships in the surrounding to the USV.

In the GUI, the information from the AIS is presented in three ways:

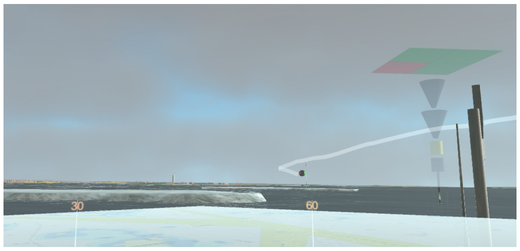

Figure 9: The South Cardinal Mark marks the grounding north from the Cardinal Mark (to the left in the image). The grounding is also marked with an iceberg.

Figure 10: From the AIS data, the ship type, position and heading is extracted. From the ship type, a suitable 3D-model is chosen. The sphere is positioned above the position, and is colored according to the heading.

Figure 11: The bright bearing-lines in the sky indicates that both visual ships are steering to the right. The ship to the right is farther away, which is visualized with the thinner line. The ship to the left is going at a constant speed but has made a turn approximately 25 seconds ago. 30 seconds of history is presented in the CEP.

- The type of ship is translated into available 3D-models of various types of ships. The 3D-model is then presented in the VE, see figure 10.
- The heading from the AIS is used for coloring a sphere according to standard ship lantern configuration, see figure 10. If e.g., most of the sphere is green, the operator can instantly conclude that the ship is moving to the right.
- A *Contact Evaluation Plot* (CEP) is normally used to present fusioned bearing tracks when at least one of the sensor data originates from passive sensors, such as cameras or passive sonars [20]. The CEP presents the bearing tracks in a time-bearing format. In the VR GUI, the CEP lines at this time

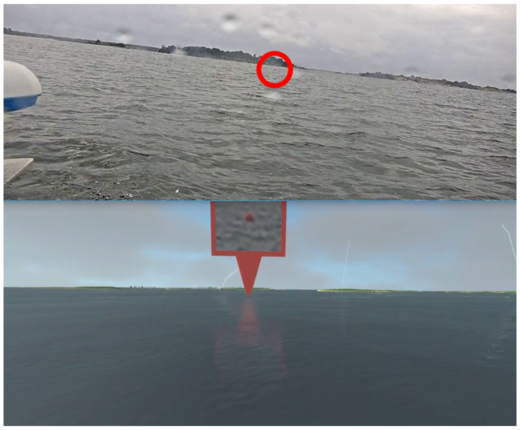

Figure 12: Above, an image from the sea-trials is shown. From this image, the buoy was detected. Below, the cropped image is presented in the VR GUI.

only originate from the AIS. The CEP provides the operator with an overview of all the surrounding ships, where the relative motion, as well as ship maneuvers, can be detected, see figure 11.

4.5.6 Presenting real-world images. An algorithm for detection of buoys has been developed for the USV, where the buoys simulate people in the water with life vests. The algorithm uses the camera images and can calculate the bearing and range to the detected buoys. By using this information, the images can be cropped to only contain the object of interest, and send this cropped image through the low bandwidth connection for presentation in the GUI, see figure 12. The operator can then study the image, and decide if the USV shall move closer to examine the object more carefully.

4.6 Usability Evaluation

The GUI has been evaluated by two experienced naval operators. They both found the cognitive load to be reduced by serving the operator with all available information, as the operator e.g., does not need to mentally translate an AIS target to the sea chart, and then to the real world. Other functions that were mentioned to reduce the load were the enlarged sea marks, the NoGo-areas, the spheres and the CEP-lines. The CEP-lines where pointed out to be able to serve the operator with valuable information, such as when passing the *Closest Point of Approach*. One of the operators was skeptical whether the colored compass rose would increase the orientation ability. More textual information from the AIS is also requested.

5 DISCUSSION AND FUTURE WORK

We have designed a GUI for remote control of a USV. Special attention has been given to reduce the cognitive load while maintaining safe navigation. It is important to have a good situational awareness, which is given by augmenting the surrounding ships and objects.

To be able to operate a USV remotely in a safe manner, it is important that the USV can detect all hazardous objects such as ships, and share this information with the GUI. By that, a function for automatic detection and classification of nearby objects would boost the functionality of the GUI.

In the near future, the GUI will be evaluated by experienced naval operators, in order to enhance the usability even further. New sea-trials will be conducted with new features to steer the USV directly from the GUI.

ACKNOWLEDGMENTS

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