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# Remote supervision of autonomous ships: principles for interaction display graphics

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In the maritime industry, there is a focus on efficient and sustainable "greener" transport. One concept, that is a means towards this goal, is to supervise a fleet of partly or fully autonomous ships from a shore-based centre, sailing with reduced speed and crew for a reduced cost and fuel consumption. There is, however, a need to perform more research into the operational concept maintaining a high safety level. This paper focuses on interaction design principles for display graphics within the Situational Awareness framework, asking: 1) Which information is needed in displays to supervise and operate ships? 2) How should the information be presented for efficient and rapid perception of the greater maritime picture? And 3) How should display graphics support operators to look ahead, projecting the near future situation? These research questions are explored through previous empirical simulation studies and a workshop with experienced navigators. In addition, experience from the field of human-computer interaction and Situational Awareness for complex systems are used as inspiration. The contribution of the paper is design principles, for information graphics content and visual presentation. As the proposed principles are not targeting a specific type of display or situation, further work should focus on make them more specific for actual operational situations and implementations.

*Keywords*: *Keywords*: Maritime, Autonomy, Operation Centre, Human Factors, Graphics.

## 1. Introduction

There is a drive toward reducing the environmental impact from the maritime transport sector, while performing cost reductions and to obtain a sufficient amount of maritime navigators. One way of approaching this is to operate a fleet of Maritime Autonomous Surface Ships (MASS), with reduced speed for saving fuel and reduced manning for cost reductions, however, longer sailing time can increase cost of manning. MASS can be monitored and supervised from a Remote Operation Centre (ROC). This transition is also referred to as Shipping 4.0 (Rødseth 2017).

Both the technology and operational transition challenge a long and rich maritime tradition, referred to as seamanship. The transition toward autonomy is therefore suggested to be a gradual process, (IMO 2018, Lloyd´s 2016, DNV GL 2018), with classification and legislation undergoing modifications. One area that needs attention, is how to support remote operators in efficient supervision and to perform intervention if necessary. Among topics are awareness; automation; and cognitive workload (Karvonen Martio, 2018). There is also a need to address transparency into decision making, particularly if automation is performing situational adaptations that deviate from international steering rules (Madsen et al., 2022).

There are several research and development projects into maritime autonomy. One is the Autoship project (Colella et. al, 2023), which" *aims at speeding-up the transition towards a next generation of autonomous ships in EU"*, building key technologies by operating two autonomous ships. A demonstrator report (Skogvoll, Foss, 2023) focus on collision avoidance through a setup with two vessels for assessing key technologies for Situational Awareness (SA) and Autonomous Navigation Systems. The previous research project, MUNIN (MUNIN, 2016) aimed *"to develop and verify a concept for an autonomous ship, which is defined as a vessel primarily guided by automated on-board decision systems but controlled by a remote operator in a shore side control station"*. Through the MUNIN project (Rødseth, Burmeister, 2015), it was learned how a shore-controlled center is important in reducing complexity in operational scenarios dealing with maritime autonomy. It does, however, also put constraints to the operational ROC concept.

In a systematic review of 42 studies regarding the use of Artificial Intelligence interaction in autonomous ship systems, it was found that human operators will have an active role in ensuring autonomous ship safety (Veitch & Alsos, 2022). It is further suggested how a remotely controlled vessel organization can affect safety management negatively through fragmentation, and that new roles are putting a heavy burden on these centers (Størkersen, 2021). A Human Factors analysis focusing on safety of remotely controlled merchant vessels suggests how operators' actions represent the final and most important barrier against accidents (Wróbel et al. 2021).

Based on this, there is a need for efficient Human-Machine Interfaces (HMI) within a ROC. There are a few research-oriented HMI concepts, such as: Ecological Interface Design (Vicente, Rasmussen, 1992), which is a multilevel analysis approach; the Open Bridge Design System (Openbridge, 2023), which offers a design concept for user interfaces; and Information Rich Design (Braseth, 2015), which is used for larger overview displays. However, none of these concepts are specifically aimed at MASS challenges.

It is therefore a need to develop interaction design graphics principles. As Situational Awareness (SA) is an important concept for safe and efficient operation, we apply the three-level framework (Endsley, 2013) (section 2.1) asking:

1. Which information is needed in displays to supervise and operate ships?
2. How should the information be presented for efficient and rapid perception of the greater maritime picture?
3. How should display graphics support operators to look ahead, projecting the near future situation?

The research is performed within a project financed by the Norwegian Research council of Norway through the project Land-based Operation of Autonomous Ships (LOAS). Participants are Kongsberg Maritime, IFE and NTNU. The project objective is to develop and test interaction solutions for a ROC, ensuring safe and efficient supervision of autonomous ships.

The next chapter presents research into computer graphics and visual perception within the SA framework. The rdesign principles and examples of use are presented, followed by a discussion and topics for further work.

## 2. Research for design principles

The first section explains the concept of SA, followed by research into computer graphics and visual perception. The last section summarizes findings from previous LOAS user studies.

### *2.1 SA levels and information processing*

Maintaining SA is important for safety-oriented operations in general, and therefore relevant for maritime operations. The framework (Endsley, 2013) explains how SA can be divided into three levels, and that all three levels should be supported. Level one is to perceive the elements in the environment, identifying the necessary data to understand the situation. Level two is to comprehend this data into meaningful information, into a picture. Level three is to make a projection into the near future. We suggest that all three levels should be supported for operators supervising the situation in a MASS environment.

It is explained (Endsley et al., 2003) how efficient information processing should be supported by being able to alternate between goal-driven (top-down) and data-driven (bottom-up) information processing. Among other relevant concepts are to keep operators-in-the loop (automation); building a correct mental model of the situation (consistency); avoid attentional tunneling (narrow focus) and to avoid data overload (excessive workload).

### *2.2 HCI & visual perception*

To design efficient graphics for displays, it is relevant to use research-knowledge developed for computer graphics. Healey & Enns (2012) performed research on attention and visual perception and investigated how we perceive information on computer displays. They explain the dynamic process as a saccadic cycle, which repeats itself several times each second, using top-down goal directed strategies to direct bottom-up low-level information processing.

Fewer visual properties are an advantage for rapid visual perception.

Healey & Enns (2012) explain further how to avoid visual confusion, referring to a priority. hierarchy: "*Feature hierarchies suggest that the most important data attributes should be displayed with the most salient visual features, to avoid situations where secondary data values mask the information the viewer wants to see.*" This explains how information should be prioritized through graphical attributes.

Ware (2008) explains how visual features can be made to "pop-out", supporting rapid visual perception: motion; color; orientation; size; and stereoscopic depth. Motion is a particularly strong visual attribute, but should be used with caution, blinking flashing can be tiring. He explains that search for information cannot be compensated by training: *"One might think that finding things quickly is simply a matter of practice and we could learn to find complex patterns rapidly if we practiced enough. The fact is that learning does not help much."* From this, we suggest using graphical features the right way from the ground-up. Referring to the concept of affordance (Gibson, 1986), uses the term "cognitive affordances" for perceived possibilities for action. This suggest that display graphics must have cues for carrying out actions.

Our visual working memory is short-lived (Ware, 2013), and "washed out" several times each second. This creates so called change-blindness, where changes in a display from one visual fixation to the is difficult to detect. This can be mitigated by making information explicitly available, referred to as "information-in-the-world" (Norman, 2002). Metaphors can be used for designing rapid perception graphics; however, it is generally challenging to identify widely accepted ones, and they can be both useful and harmful (Norman, 2004).

Although not intended specifically for display graphics, E. Tufte has published several books on how to present complex information He (Tufte, 2001), explains how: *"Data graphics should draw the viewer´s attention to the sense and substance of data, not to something else"*. Relevant design concepts suggested are a high data-ink ratio (maximize dynamic content) and to avoid unnecessary frames and ornaments that clutters the presentation. Darker color concepts are recently used in commercial applications (Apple, 2023, Microsoft, 2023 and Google, 2023). Considering eye strain, this is relevant for operators spending a long time in front of their operator displays.

### *2.3 LOAS user study results*

The first user studies (Kaarstad et. al, 2021; Braseth et al. 2022) found that:

- A "bird´s" perspective is preferred, seeing the maritime situation through a larger static map coverage.
- My own ships should be distinguished from other ships.
- Present speed, the planned route, and alarms and warnings.
- Weather information is relevant.
- Additional information can be "attached" to a text tag connected to the ship.
- Visualize connectivity, explaining if communication link has poor quality.

Based on these findings, an updated design was made for an unformal workshop summer 2022. Two navigators with long maritime experience participated. They were both knowledgeable about using advanced automated system such as automated route and docking systems. Discussions was initiated individually by presenting several design concepts for remote supervision of ships in different operational scenarios. The findings were:

- A projection of 20 min. leg time is reasonable to perceive ship intentions.
- The whole route should be made visible when needed (e.g., by "clicking" on it). The tail trailing behind the ship can be presented in different ways, like mist, or dots.
- Present Bow Cross Range (BCR), where do the ships meet on the virtual point on the map? Wheel-over (the estimated curved turns) on the legs should be presented.

## 3. The resulting Design Principles

### *3.1 SA 1 – Information content, necessary data*

Identify ships (not leisure crafts), include speed and heading, the use of Course Over Ground (effects of wind, waves and current) should be considered. Present the "health" situation regarding technical systems, loss of communication (connectivity), and automation status. Distinguish my own ships, and an active selected ship from other ships. Include environmental factors such as wind, waves, visibility and current. Use natural metaphor graphics if possible.

### *3.2 SA 2 – Comprehension – the picture*

Present the larger naval picture through a "birds-perspective" of ships, and their constraints (shore, land). Use a flat "stable-static" externalized map-picture (ships move in a static map) without a navigation hierarchy, avoid pop-up windows hiding information. Include leisure traffic or other reported challenges, work areas and no-sail zones. Match information priority and reduce clutter through visually layered graphics. Limit the use of colors; lines; frames; borders and bold fonts. A darker background is reasonable considering eyestrain.

### *3.3 SA 3 – Projecting the near future*

A map area covering a reasonable sailing distance for faster ships, 20 minutes or more is a suggested starting point for proactive top-down planning, visualize routes if available. Visualize time and distance to other ships and constraints (e.g., shore), include front vector and trail explaining behaviour. Warn of nearby potential incidents by strong bottom-up data-driven pop-out effects: motion; signal colours and shape.

### *3.5 Weaknesses and limitations*

The principles are so far only based on limited user feedback. They are also only applied to the studied cases in the outer Oslo fjord. The focus is limited to the crossing part, not specifically targeting challenges in harbour operations.

## 4. Illustrations: applying the design principles

The following presents examples of how the design principles can be applied in practical designs. Please note that the following figures only represent a suggestion, other researchers and designers are encouraged to make their own versions based on their skills, knowledge and users' needs in the specific application.

### *4.1 SA 1 Information content - necessary data*

This first category is related to the necessary data. An important aspect is to distinguish ships from each other. One way is variations over a directional metaphor, see Fig. 1:

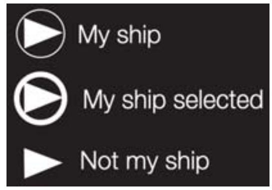


Fig. 1. The ship points (metaphor) in its sailing direction. Distinguishing between my own ship, a selected ship "click" and other ships.

Additional information about the ship, such as identification (name); automation level; direction (degrees) and speed (knots) can be grouped close to the actual ship (Gestalt proximity). Fig. 2 visualizes this information, we use a fictitious automation level A1 for a ship named AS 002:

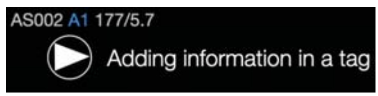


Fig. 2. My ship AS002, automation level A1, heading 177 degrees with a speed of 5.7 knots. Use standard word length, units are implicit understood.

The ship´s technical systems represents its "health" status, examples are propulsion; steering; connectivity and electrical systems. To avoid information overflow (data overload), we suggest presenting only aggregated or high-level alarms, leaving details for other applications. Visual consistency can be achieved by using a separate alarm symbol, thus avoid using the ship symbol itself for this purpose. In Fig. 3, we use a natural metaphor for alarms (red) and for connectivity problem (keep operator in-the-loop a Wi-Fi symbol):

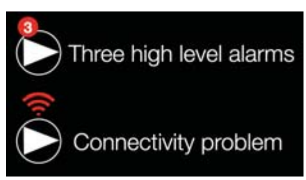


Fig. 3. Three high level alarms, connectivity (loss of communication) issue.

Since factors such as wind, waves, sight and current are properties of the environment, we find it reasonable to visualize them in the larger map, not as specific properties for each ship.

### *4.2 SA 2 Comprehension – the picture*

One affordance of the "birds-perspective" is that it supports building a correct mental-model of the situation with ships and constraints integrated into one operational picture. However, both color and contrast should support good readability. Signal colors are therefore reserved for alarms and dynamic information. Static information is suggested using a dull presentation without frames, thick lines, or borders (reducing visual complexity), the concept is visualized in Fig. 4.


Fig. 4. High visual priority on the alarm, mid-level is dynamic data. Wind is indicated with arrow, and place of measurement. Bottom visual level is the static environment with black sea, dark grey is less than 10 m depth, land has a faded beige color.

### *4.2 SA 3 Projecting into the future*

The purpose is to support operators being proactive. Ships should therefore have a vector and tail to perceive it´s motion, both scaled to qualitative indicate the speed and change of direction. Fig. 5 explains this concept through three vessels, one slow and one fast, the third is turning:

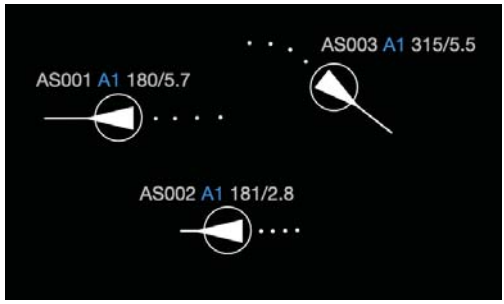


Fig. 5. Adding front heading vector and trailed tail for qualitative perception of heading, speed and turn. Using Course Over Ground should be considered.

To look further ahead, a visualization of the planned route is suggested. The concept is visually explained in Fig. 6:

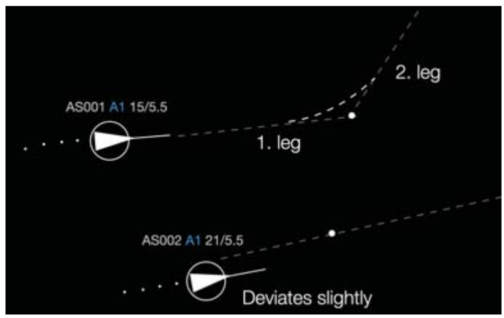


Fig. 6. Visualizing the planned routes to see ahead, AS002 deviates slightly from the route. Wheel-over is visualized between legs for AS001.

Urgent situations should be presented through strong visual pop-out effects. Blinking and flashing can be annoying and tiring, we suggest using a gentler dynamic alarm-spot (Braseth, 2015) to attract operators' attention. This "bubble" flashes up and shrinks in approximately 2 seconds "over the situation". Fig. 7 visually explains this using a Wi-Fi symbol for a connectivity problem:


Fig. 7. Dynamic alarm-spot to attracting attention, Here placed on top of a red Wi-Fi symbol for a connectivity problem.

The dynamic-alarm spot can also be used to warn for a potential collision. We suggest informing about the nearest point/time to contact for each ship (Bow Crossing Range BCR; Time to Closest Point of Approach TCPA). If the vessels do not take evasive action, the dynamic alarm -spot will flash up, see Fig. 8:

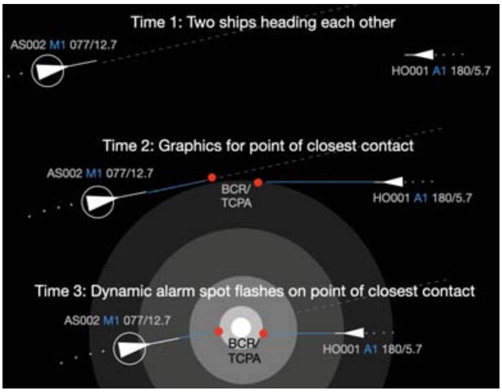


Fig. 8. The vessels do not take evasive action when the BCR/TCPA and vectors indicate close contact, red dots are nearest point of contact. The dynamic alarm-spot flashes up a large white bubble to attract attention.

## 5. Discussion and further work

The paper proposes design principles for graphics focusing on supervision of autonomous ships from a ROC. They are founded on theoretical and empirical findings with the purpose of providing direction and momentum into the design process for MASS. Regarding the first principle (SA1), we find the framework valuable for identifying key data, but we expect that this list will get more comprehensive as more information from further user studies are available. One example is how we present ships direction, do we show ships heading or Course Over Ground? However, we suggest keeping displays open and uncluttered for good readability, including only necessary information.

The second principle (SA2) explains how to design for comprehension of data. We found it useful to combine the "birds-perspective" with a non-movable map, with visual priority graphics, being cautious on use of high contrast, frames, and signal colors. One example is to include land areas as context through faded "dull" colors. One concept to strengthen SA2 is to make information explicitly available, avoiding loading operators' visual memory. However, our use of a darker background is not in accordance with the more traditional white/blue sea color used on naval maps. This can cause consistency problems and should be considered before implementation.

The third principle (SA3) is to make a projection into the future, planning ahead. Both the use of scalable front vector and a trailing tail helps to see the vessels immediate intentions, and combined with the planned route it strengthens the capacity to see further ahead. For our setup in the Oslo Fjord with fast maritime traffic in the north-south direction, a vertically arranged larger display could be helpful to perceive early information about approaching ships. We suggest exploring the actual naval environment before making decisions about actual design setup. However, if critical situations occur, attention grabbing graphics should be used. One possibility is the suggested dynamic alarm spot. This can also be combined with other input modalities such as sound for enhanced impact.

We found the combination of the three level SA framework and HCI research helpful in providing a direction and priority in the design process. However, we acknowledge that the level of detail in the design principles is vague, not comprehensive enough. The principles presented in this paper reflects our knowledge status at the moment, and we expect them to be modified and further developed as more research is present. Some of the proposed design principles are applied in a current user study in LOAS with results presented in separate papers.

Among topics that should be further explored is the need for specific "harbor, docking, departure" displays; should we have a checklist completed before docking and departure? Also, the use of larger overview displays for improved SA2 and SA3 should be considered. Other relevant research topics are: transparency about automation decision making and intentions, how many vessels can be monitored by one person, and what is needed for safe and efficient vessel hand-over between different operational sectors?

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