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Remote Monitoring and Control of Unmanned Vessels – The MUNIN Shore Control Centre

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Abstract

This paper presents work in progress within the MUNIN unmanned ship project. It will briefly discuss some points in a basic framework of design criteria for the Human-Machine Interface (HMI) of the Shore Control Centre where operators monitor, and have the ability to remotely control the unmanned vessels. The starting point will be the notion that unmanned ships might reduce human error. It also presents some example of simple interactive screens based on this framework. A prototype HMI for the Shore Control Centre will later this year be tested with users in a simulator based set up at Chalmers University of Technology.

1. Introduction

In March 2013 the executive vice president of the newly merged Det Norske Veritas and Germanischer Lloyd (DNV GL), Bjorn Haugland, wrote that unmanned ships was a potential game changer calling it "Unmanned vessels – the trump card". He linked unmanned ships to potentials of lower operational costs, elimination of on-board crew cost, risk associated with human error and threats to crew safety:

"Unmanned ships will revolutionize supply chain logistics and there will be no restriction on how much time a vessel can spend at sea, as there are no humans affected. Ships that do not carry time sensitive cargoes, such as perishable goods could, in theory, drift with sea currents, to move as energy efficiently as possible," *Haugland (2014*).

Unmanned ships will rely on automation and remote control and it is an interesting question if is possible to reduce accidents due to human error by automation. This paper will discuss some of the human factors issues concerning remote control of unmanned ships. First a brief introduction to the MUNIN unmanned ship project.

1.1. Maritime unmanned navigation though intelligence in networks

Maritime Unmanned Navigation though Intelligence in Networks (MUNIN), is a 3-year project in the European 7th framework program. The objective of the MUNIN project is to show the feasibility of unmanned, autonomous merchant ships. The ship will be under control of on-board crew approaching and leaving a harbour. The goal is that the ship will be autonomous and unmanned from pilot drop-off point to pilot pick-up point. However there might be maintenance teams or other personal on-board if necessary. The goal is also that the ship will be under autonomous control during the main part of the ocean voyage, remotely monitored from the SCC. Only in exceptional cases the shore control centre is expected to have to actually remote control the ship.

The consortium consists of different industry or research partners who work with different parts of the concept: data architecture, autonomous navigation, autonomous engine control, advanced sensor systems, and legal implications. The Department of Shipping and Marine Technology at Chalmers University of Technology is responsible for the Shore Control Centre.

In the Shore Control Centre a number of operators will monitor a number of unmanned vessels. We assume that one operator will be able monitor more than one vessel. How many is one of the points to be determined and much depends on the human-machine interfaces of the shore centre. An operator monitoring several ships will have to rely on automatic systems alerting him or her on irregularities of the operation. So the question is how much manual control we will actually have?

1.2. Autonomy and manual control

At one end of the spectrum we have the wave-goodbye-and-forget-call-if-you-have-any-problems type of unmanned system. This kind of system will need a very reliable technology that can cope with all eventualities and call for help if needed. In such a system the ship would be assigned a destination port and a set arrival time and would then be left to solve the task by its own. Should there be any problems, the vessel would call and report its whereabouts and the nature of the problem (and what kind of help it required).

At the other end of the spectrum we would have a ship system where each ship had a land based bridge team remotely controlling of the ship, just as had the bridge be lifted off the hull and placed on land and all the wiring prolonged by satellite links. The simplest (but also technically most difficult) would be to just copy the bridge ashore, and then stream all on-board information in real-time to that bridge: the vision through the wheelhouse windows via video cameras, the motions by a hydraulic system, etc. Done in this way the difference of control between unmanned and manned shipping would be small. There would still be an officer of the watch and a lookout/helmsman at the bridge of each ship. The technical challenge would be safe and secure transfer of very large data quantities, to cope with latency and to pay the satellite communication bill. (We have to some extent kept this idea is in the concept of the emergency "situation room.")

The concept investigated in the MUNIN project is one of autonomy and different levels of remote control if the autonomous system calls for help. We will rely on what we believe will be a robust autonomous system, once mature; meaning that we would expect human intervention to be an exceptional case in the trans-oceanic phase of the voyage. The hypothesis being that one operator can safely monitor several ships, given the right kind of integrated human-machine interface.

2. Human error

From many studies we know that the number of accidents caused (in part) by "human error" is in the range of 70-95%, e.g. *Sanquist (1992), Blanding (1987), Rothblum (n.d.*). We all know from own experience that humans make mistakes. We forget, we misunderstand, our thoughts can go astray, and we might even fall asleep when we are not supposed to. This is all part of the human condition. And this is also what can causes accidents. And frequently does. This has been the case ever since man appeared. In a complex technical society, humans need help to cope. That is why we have continuously worked on technical systems supporting the human decision-making. And successfully so, because accident rates do improve.

To provide perspective: In the three years 1833-1835, on average 563 ships per year were reported wrecked or lost in United Kingdom alone, *Crosbie (2006).* Today the total number of tankers, bulk carriers, containerships and multipurpose ships in the world fleet has risen from about 12,000 in 1996 to 30,000 in 2012. In the same time the number of ships totally lost per year (ships over 500 Gross Tons) declined from 225 in the year 1980, to 150 in 1996 and less than 60 in 2012 according to The International Union of Marine Insurance – and this worldwide. www.iumi.com/images/gillian/Spring2013/IUMI%20Casualty%20and%20World%20Fleet%20Statistics%20Jan%202013.pdf. We can assume that much of this safety improvement has to do with improvements in technical reliability. But we can also assume that this to some extent has to do with improvements in automation systems supporting human monitoring and decision-making. Within commercial air industry, automation has improved safety, *Billings (1997), Pritchett (2009), Wiener (1988*). We can assume that the same is true for the shipping domain.

2.1. Human error and automation

Automation can, if designed carefully, remove a lot of mental workload for the human operator. Just compare position fixing on the open sea using sextant and sun tables in the days before the global navigation satellite systems. Still automation may invite new types of errors into the work

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environment. Like automation bias.

Mosier and Skitka (1996), p. 205, defined automation bias as "a heuristic replacement for vigilant information seeking and processing". Meaning that if we know an automatic process is going to look for deviations, we will stop looking ourselves. Further we can look at the specific errors of omission and errors of commission, *Skitka (2000)*, where omission errors are when the human operator fails to respond to system irregularities because the automatic system fails to detect or indicate them, and commission errors are the human operator incorrectly follows an automatic advice or directive because they do not check and verify against other sources of information.

On the other hand, *Norman (1990)* already said that the problem was not one of automation, but one of inappropriate design of automation. He claimed that automatic systems instead of giving appropriate feedback tended to overuse alarms. He gave the example of the airplane captain that turned on the autopilot. When one of the engines then slowly lost power, the autopilot silently kept compensating for the unbalanced trust until it had nothing more to give and the plane rolled and went into a dive. He compared that to the captain that handed the controls over to the co-pilot, which, from the captain's point of view, was the same thing as handing the controls over to the autopilot. The co-pilot would then be expected to comment on the unbalanced power of the engine thrust long before it became a serious problem. He would say something like: "I seem to be correcting this thing more and more, I wonder what's happening?", *Norman (1990)*, p. 589, meaning that to keep the operator in the loop the automation needs to be more communicative, which is easier said than done. People form mental models of systems with which they interacts. The model is formed by the system image that the information displays of the system offers, *Norman (1986)*. If the information displays are not communicative, the operator will not know what is going on; he will be out-of-the-loop. *Norman (1990)*, p. 591, concludes: "To give the appropriate kind of feedback requires a higher level of sophistication in automation than currently exists." The question is: have we gotten any further since 1990?

From the maritime domain we hear the same thing: Automation is often used to help the bridge crews in complex tasks. But automation is risky as well. "It has been shown that operators will monitor less effectively when automation is installed, and even more so if the automation has been operating acceptably for a long period," *Lützhöft and Dekker* (*2002*). Automation creates new human weaknesses and amplifies existing ones. The question is how to turn automatic systems into effective team players? Feedback from the automation is important and Lützhöft and Dekker suggest that representations of automation behavior will have to be:

- Event-based: Representations need to highlight changes and events in a way that the current generation of state-oriented displays do not;
- Future-oriented: in addition to historical, human operators in dynamic systems need support for anticipating changes and knowing what to expect and where to look next;
- Pattern-based: operators must be able to quickly scan displays and pick up possible abnormalities without having to engage in difficult cognitive work (calculations, integrations, extrapolations of disparate pieces of data). By relying on pattern-based or form-based representations, automation has an enormous potential to convert arduous mental tasks into straightforward perceptual ones, *Lützhöft and Dekker (2002)*, p. 95.

3. Design framework

Hutchins et al. (1986) talked about interfaces built as a model world, as a metaphor for the real world, or the real system to be controlled. By having the user acting directly on the model world which in turn is connected to the real worlds and show the responses of the real world, a sensation of direct manipulation, *Schneiderman (1983*), and direct perception, *Flach and Vicente (1989*), is achieved. The goal was to make the psychological distance as short as possible. A conceptual model for such an interface framework is depicted in Fig.1.

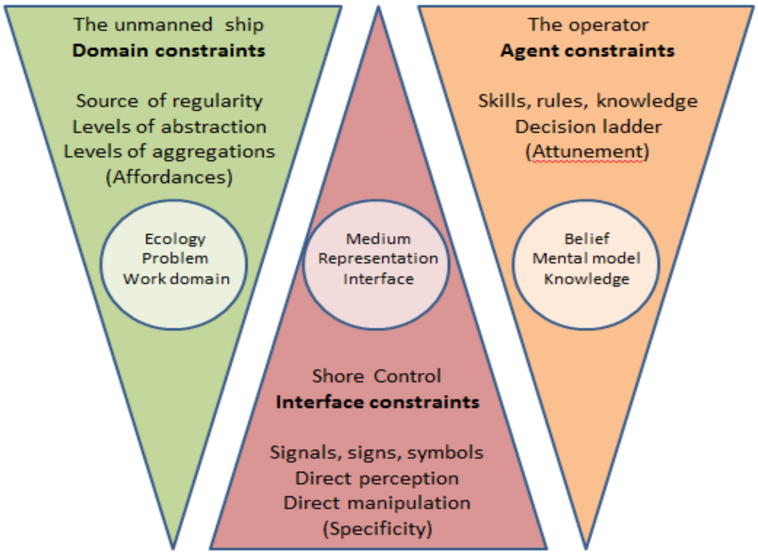

Fig.1: The three sets of behavioural-shaping constraints in a socio-technical system conceptualised as a tight fit between the three pieces of the puzzle; adapted from *Bennet and Flach (2011*)

Reducing psychological distance means improving the match between the structure in the real world (the pattern and the regularities in ship operation) and the belief structures (mental models) of the remote operators. The limited space does not allow us to go any deeper into this but to say that this is the real challenge for the development of the human-machine interface of the shore control centre. In the following a number of example interface prototypes will be show. These prototypes will be further developed and finally tested in simulations within the MUNIN project.

4. Design prototypes

The prototypes show below is some examples of the interfaces that must convey situation awareness to the monitoring operator of the shore control centre. We are now only looking at the monitoring interfaces. The interfaces for control are something else. The monitoring screens must afford both overview and detailed resolution. The traditional interface will be the map view.

4.1. The spatial overview

On-board ships the Electronic Charts Display and Information System (ECDIS) is the modern standard equipment allowing the bridge officer easy access to spatial information. It is natural that an ECDIS-like system also is available for the remote operator, Fig.2.

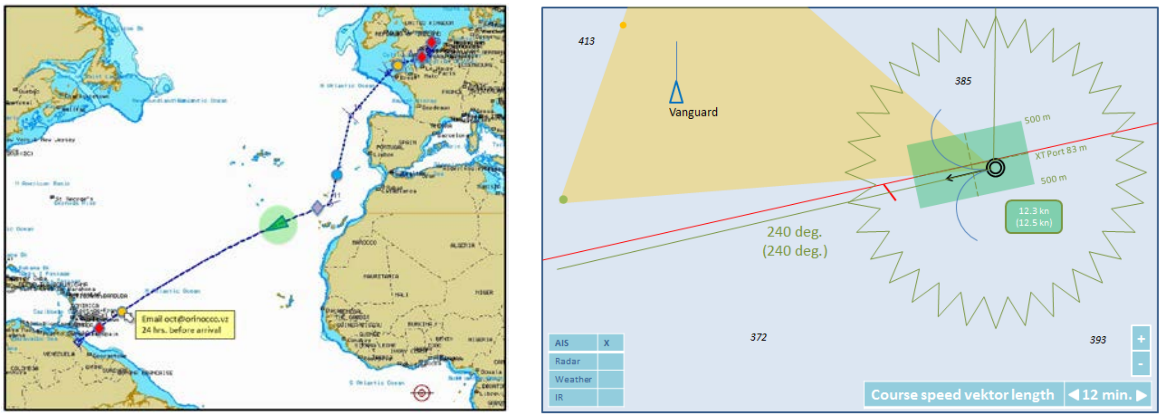

Fig.2: For spatial overview, traditional electronic chart is the natural interface. Left: zoomed out for overview; right: zoomed in for close vicinity of unmanned ship. Green box: planned position of ship

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4.2. Temporal overview

To allow the operator to overlook the whole voyage from a time perspective a temporal view showing different activities both in the ship time zone and in the shore centre time zone is offered. This view also affords event markers. These signify tasks the operator will have to attend to, e.g. send a mail to the pilot about next day's arrival time, or report to the Vessel Traffic Centre, Fig.3.

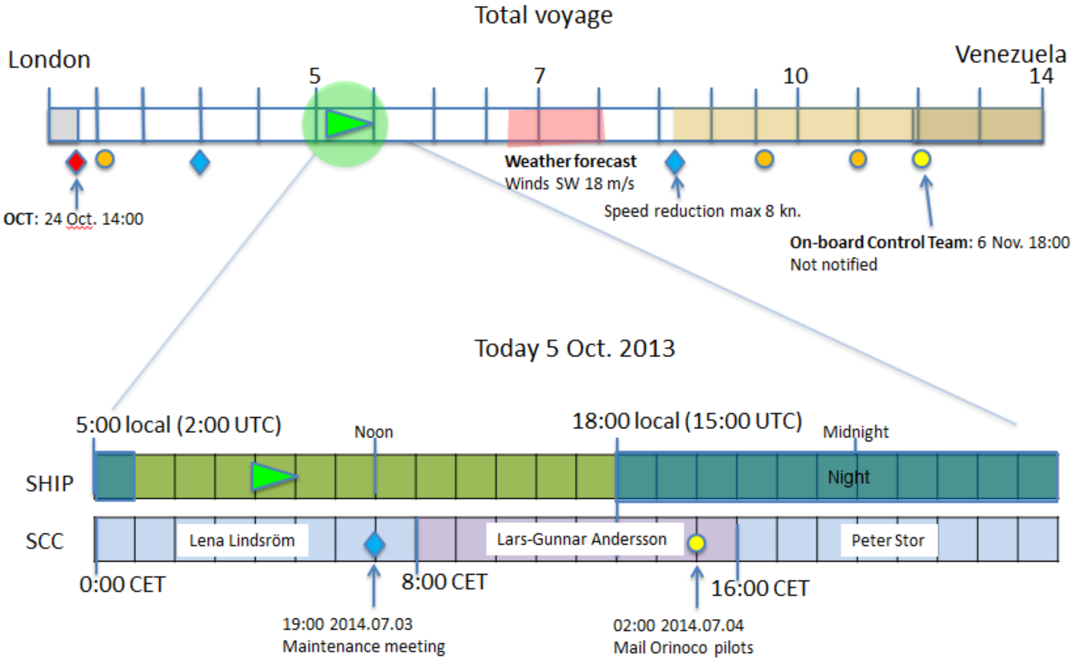

Fig.3: For temporal overview, a slot diagram is suggested, breaking down the voyage into days, and if zoomed in, into hours. The difference in time zones, showing day and night at the ships location and shifts in the shore control centre. Different coloured event markers (displayed both in the time view and on the chart) contain planned events, e.g. to email the pilot about arrival.

The allocation and notification of tasks also allows for an aggregated notification service that responds if two tasks of two different ships with the same operator collides, e.g. the pilot is stepping off one ship at the same time as another pilot is climbing on-board another ship under the same operators control.

4.3. Ship status indicator

From an operational point of view it is important for many stakeholders to know if the unmanned vessel is in good condition and that all systems probably will survive a long unmanned voyage. Insurance companies will be particularly interested.

Ship status can be aggregated from a very low, detailed level where every component and every pipe joint is assessed according to how many hours of expected life time remains until next maintenance session. Components, e.g. a fuel filter, can this way be aggregated to machine level, e.g. a generator, and then to higher system levels, e.g. the power system, and finally to the whole ship level. For very critical components where life-time assessments have proven difficult, redundancy has to be secured. Fig.4 shows an interface suggestion for such a ship status interface. It compares assessed remaining life-time until next service with remaining hours to destination and possible repair points. It also depicts redundancy levels, where yellow and red indicates lack of redundancy. The illustration shows the top, ship status, level. By clicking the status bar, lower system levels will be shown. Status assessments feeding information into the Status indicator display will be an important task not only during port visits, but probably also daily during the voyage by monitoring sensors of condition based maintenance.

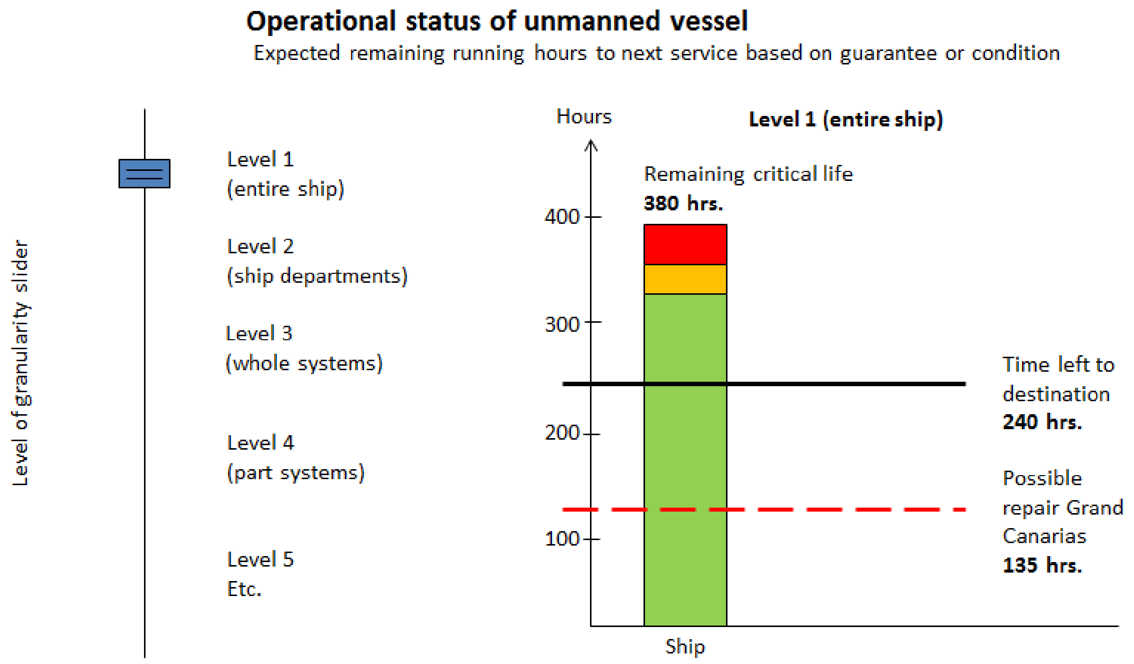

Fig.4: The Ship status indicator screen allows the operator to make an at a glance assessment of the ships present status, remaining life time compared to time to destination or port of repair. The picture shows the top, ship level. By clicking the bar, the operator can open lower levels all the way down to the individual components of the whole ship.

4.4. Trend lines

The use of trend lines is an important tool to allow the operator to see what is going on, but also to compare with what went on in the past and then to possibly extrapolate it into the future. Fig.5 shows an online weather application as a simple illustration of how a trend line display might look like.

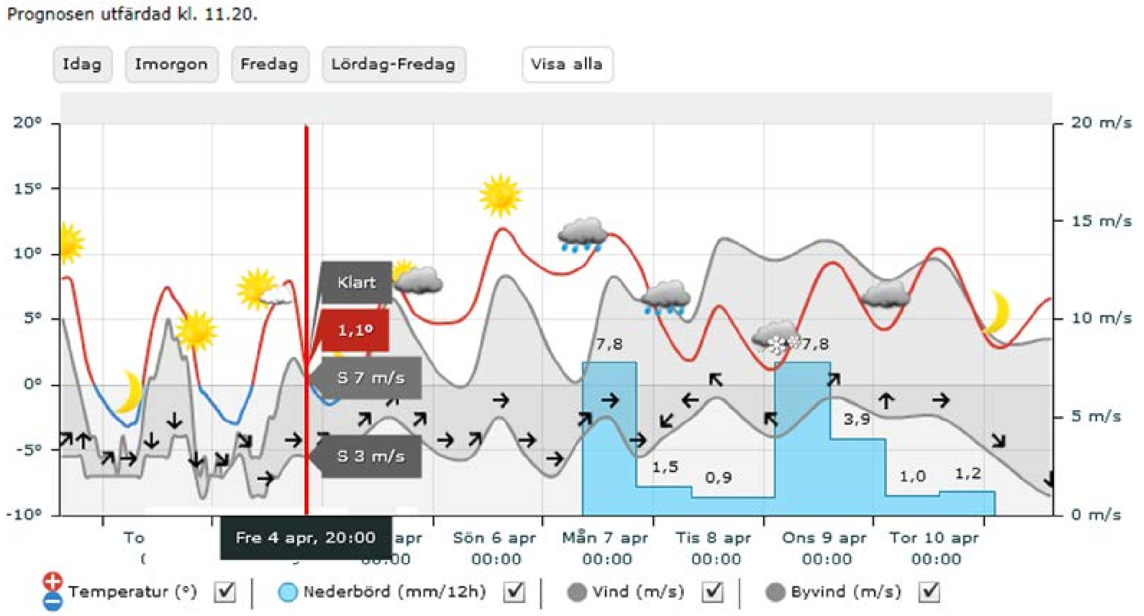

Fig.5: Use of trend lines in a weather screen. The red vertical line represents present time, curves to the left of that line is made up of real measurements stored into an historical archive, and to the right of that line is a prognosis of how the weather is going to be some days into the future. Example from http://www.smhi.se/vadret/vadret-i-sverige/land?pp=http://www.smhi.se/produktportal-1.0//chart.do&geonameid=2692633

This type of trend line diagrams can be used for a lot of parameters of the unmanned ship, particularly in relation to technical installations and engines.

4.5 Top level indications

On the top level, a dashboard screen alerts the monitoring operator about the condition of the unmanned vessel. All information sent from the ship to the shore control is accessible under the nine tiles in the square. They are clustered in a standardised way into 1. Voyage, 2. Sailing, 3. Observations, 4. Safety and emergencies, 5. Security, 6. Cargo, stability and strength, 7. Technical, 8. Shore control centre, and 9. Administration. If any of the parameters under each tile breaches a yellow or red alert level, the tile will change colour and the Top flag in the middle of the large circle will also change colour, alerting the operator about that something on that vessel is calling for his/hers attention, Fig.6.

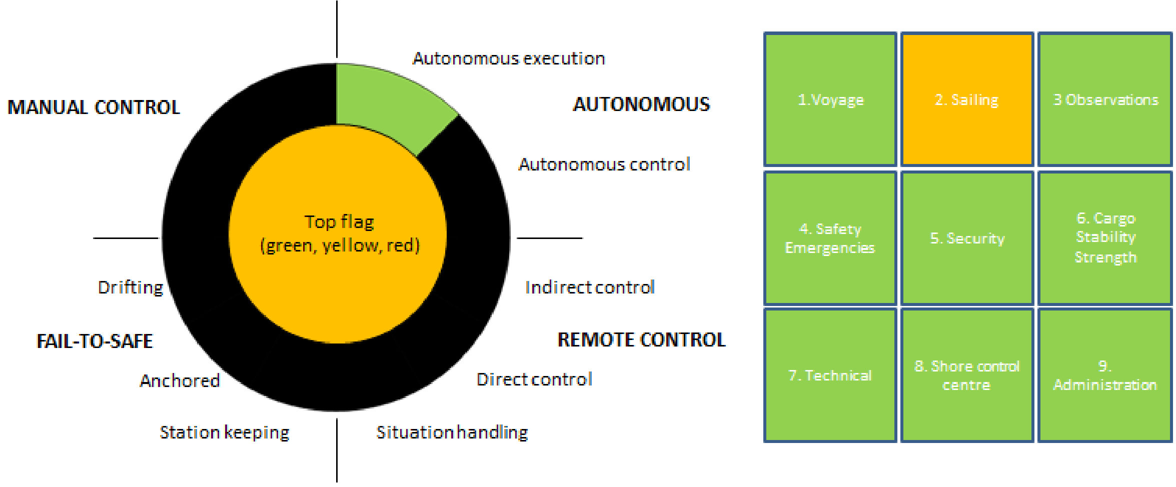

Fig.6: This dashboard shows the top level indicators alerting the monitoring operator if something is wrong on the unmanned vessel. Under each of the nine tiles of the square all information sent from the ship to shore can be found. The circle contains the top indicator light (green, yellow or red) as well as the mode indicators, signifying in which mode the vessel presently is in (manual, autonomous, remote or fail-to-safe).

There are more screens in the human-machine interface of the shore control centre which later will be presented in the deliverables of the MUNIN project. Particularly screens merging operational status of several ships into a simple interface for a single operator will be a challenge.

5. Conclusions

This paper has presented work by Chalmers University of Technology in the MUNIN unmanned ship project. This work concerns the display interface between the unmanned vessels on the high seas and the operator monitoring the ship's progress and status from ashore. Challenges such as human error and automation have been discussed as well as a design framework for the interface development. Finally some example screens have been shown. The development now continues and a first iteration of user tests will be conducted later this year and finally presented in a project report that later can be found at the MUNIN site http://www.unmanned-ship.org/munin/

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