SITUATION AWARENESS IN REMOTE CONTROL CENTRES FOR UNMANNED SHIPS

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SUMMARY

The feasibility of unmanned, autonomous merchant vessels is investigated by the EU project MUNIN (Maritime Unmanned Navigation through Intelligence in Networks). The ships will be manned while departing and entering port and unmanned during ocean-passage. When unmanned, the ships will be controlled by an automatic system informed by onboard sensors allowing the ship to make standard collision avoidance manoeuvres according to international regulation. The ship will be continuously monitored by a remote shore centre able to take remote control should the automatic systems falter. For the humans in the shore control centre the usual problems of automations remains as well as a pronounced problem of keeping up adequate situation awareness through remote sensing. The big challenge for the project will be to show that an unmanned system is at least as safe as an manned ship system, and to provide the shore control operators with adequate situation awareness.

1. INTRODUCTION

Maritime Unmanned Ship through Intelligence in Networks, abbreviated MUNIN, is the name of a three year EU, 7th Framework research project started in 2012. The aim of the project is to set a 200 m long dry cargo vessel under unmanned and autonomous control from pilot drop-off to pilot pick-up point. In this project a simulated conventional vessel will be retrofitted with technology required for an unmanned trans-oceanic voyage. The project consortium consists of 8 research and industry partners from 5 European countries: Fraunhofer Center for Maritime Logistics and Services, CML, in Hamburg, Germany; Marine Technology Research Institute, MARINTEK, in Trondheim, Norway; the Maritime Human Factors group at Chalmers University of Technology in Gothenburg, Sweden; The Department of Maritime Studies at Hochschule Wismar in Rostock-Warnemünde, Germany; Aptomar AS, Trondheim, Norway; MarineSoft Entwicklungs- und Logistik-gesellschaft mbH in Rostock-Warnemünde, Germany, Marorka ehf in Reykjavik, Iceland, and the Faculty of Law at University College Cork, Ireland.

An overview of the different technical research areas are illustrated in Figure 1.

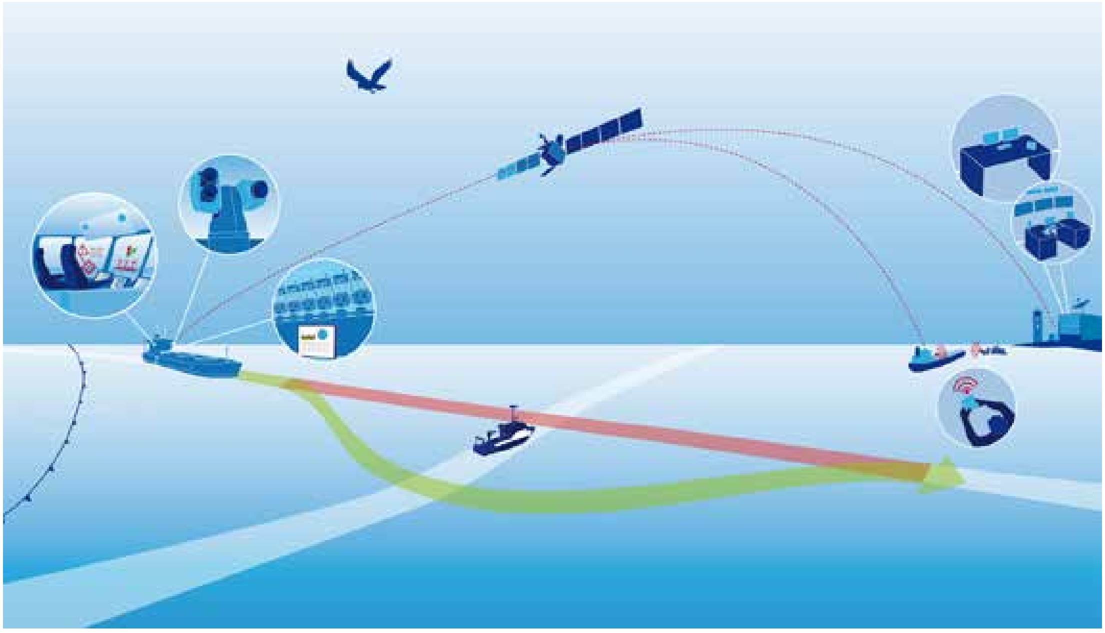

Figure 1: A schematic drawing of the features of the MUNIN project. To the left the unmanned ship with its Autonomous Ship Controller and engine system, and the IR and daylight gyro stabilised video system that had detected a stand on vessel and is preparing to do an evasive manoeuvre. The ship is remotely monitored by the operators of the Shore Control Centre to the far right. In case of emergency they have the possibility of taking remote control of the ship. Also the approaching pilot boat with pilot and boarding crew can take remote control of the vessel. Image by the MUNIN project.

1.1 WHY UNMANNED SHIPS?

One may wonder what drives an investigation of the feasibility of unmanned ships. Four reasons are presented here: the human work environment onboard and a risk of future shortage of seafarers; the strive for reducing costs of transportation; the global need of reducing emissions, and a strive for increased safety in shipping.

1.1 (a) Work environment

In a recent blog a consultant at a major shipping company revealed his listing of the three, in his opinion, biggest threats for the company in the coming five to fifteen years. As number one came “the unattractive industry”. His doubt was wheatear the shipping industry would be able to attract the generation Y, the millennials those born between the early 80s and the early 00s [1]. In a report to the International Maritime Organization (IMO) in 2010 the Baltic and International Maritime Council (BIMCO) and the International Shipping Federation (ISF) reported that “our results indicate that the industry will most probably face a tightening labour market, with recurrent shortages for officers, particularly as shipping markets recover” [2]. At the maritime college at the department of Shipping and Marine Technology at Chalmers University of Technology we have indications that the time newly examined master mariners expect to stay at sea is shrinking. Is it that the idea of being confined in relative isolation in a steel box for months together with a decreasing number of maybe culturally heterogenic crew is not so attractive for the younger generations of seafarers? Before the recession in 2009 the shipping industry experienced a problematic shortage of trained officers. Due to the recent economic recession this is not so now, but what will happen as the economy recovers? It could be that unmanned ships (or few-manned ships supported with autonomous technology) might be necessary in the future if we want to keep trading.

1.1 (b) Cost reduction

The shipping industry has for decades reduced costs by cutting down on the size of ship’s crews, this in turn leading to stress, safety issues and less attractive working conditions. Automation is a major driver in most industries, replacing manpower with machines. On the individual level this might be a painful, but on the general level it mostly means improved economic conditions for the society as a whole. One of the challenges for the MUNIN project is to show cost efficiency for an unmanned ship system.

1.1 (c) Reduction of emissions

EU has promised to reduce greenhouse gas emissions by 80 % to 2050 [3]. Findings summarised by United Nation’s Intergovernmental Panel on Climate Change [4] also indicate an urgent need to reduce the emissions of greenhouse gases. One way of reducing the footprint of the shipping industry is to apply *slow steaming*. By reducing the speed of a typical container vessel by 30 %, a 50 % reduction in fuel consumption and thereby also fuel costs and emissions can be achieved [5]. However, if ships go slower, more ships will be needed to keep up the transportation capacity. And these ships will need fuel, so the equation is more complex than that. But according to the calculations for container shipping by Pierre Cariou [5] slow steaming has the potential of reducing emissions by around 11%, taken the increased number of ships into account. This is close to the target of a 15% reduction by 2018 that was proposed by the International Maritime Organisation’s Marine Environment Protection Committee, 2009 [6].

But slower ships mean longer voyages with increased salary costs as well as socially less attractive extended stays onboard.

1.1 (d) Increased safety

According to many reports human error is involved in 65-96 % of all accidents at sea, e.g. [7], [8],[9]. Could it be that by removing the human from the direct control of the ship, accidents to some extent can be prevented? "The big benefit of having a driverless system is the safety - the element of human error is taken out completely," said Copenhagen unmanned Metro chief executive Piero Marotta in an interview 2009 [10]. Given some time, it remains to be seen if this is right for the Copenhagen metro. However, it is probably not so simple. Humans still program automation. For example in 1999 NASA’s Mars Climate Orbiter disintegrated entering the March atmosphere due to a simple programming error (software giving instruction in Imperial units while the orbiter expected instructions in SI units) [11]. And human will still be involved in monitoring, remote control, and maintenance. And on the high seas unmanned ships will have to coexist with manned systems. But if we ever so slightly can move decisions from the operator onboard, where stress and fatigue play a vital part, to less stressful programming and maintenance work, some safety benefit might be gained. It is one of the major goals of the MUNIN project to show that an unmanned system can be at least as safe as a manned system.

More on this later, as this discussion will be the focus of this paper. But first a brief look at the unmanned and autonomous system.

1.2 UNMANNED AND AUTONOMOUS SHIPS

An autonomous ship is a ship that is controlled by automatic systems both for navigation and for engine control. These systems will be preprogramed, just as we today can have a track pilot follow a pre-recorded voyage plan. But the autonomous system will also contain a certain level of artificial intelligence and will be able to detect and identify other vessels and do collision avoidance manoeuvres according to the International Regulations for Preventing Collisions at Sea (COLREGS). However, an autonomous ship is not necessarily unmanned. From time to time maintenance teams might be onboard during parts of the voyage to make service or repairs on systems onboard, and as mentioned above, the ship is expected to be manned during port approach and departure.

An unmanned ship is, as the name implies, a ship with no one onboard. It is expected that the vessels will be unmanned for the trans-oceanic phase of a voyage. However, an unmanned ship is not necessarily autonomous. The vessels will be remotely monitored from a Shore Control Centre (SCC) receiving crucial information via satellite with short time intervals (once every 4 seconds is envisioned) and the SCC will have the ability to take remote control if called for, or if in doubt of the autonomous system.

Reliable communication systems will be a challenge for the system and as a last resort if the autonomous system cannot find a solution with concurrent loss of communication the ship will be able to go into a fail-to-safe mode (e.g. drop anchor or heave-to, as applicable). For more details on the architecture of the systems and technical details see [12], and [13].

Many of the technical systems developed in this project might also be used to enhance safety in manned vessels.

This paper will now focus on the human factors issues concerning monitoring and control of the unmanned vessel from the Shore Control Centre.

1.3 THE SHORE CONTROL CENTRE

The vision is that a fleet of unmanned vessels will be continuously monitored from a control centre. The operators will be notified when threshold limits are passed, for instance, if the ship leaves its predefined path and time schedule, or if the onboard sensor systems pick up an object that cannot be identified. In the case that intervention is needed this can be done in three levels:

1. Indirect control. By updating the voyage plan during voyage, e.g. regular updates due to weather routing, or to avoid a declared NoGo zone, e.g. an oil spill operation. The autonomous system is still in control.

2. Direct control. By ordering a specific manoeuvre to the vessel, e.g. heaving to give lee for a search and rescue operation. The autonomous system is still in control.

3. Situation handling. In this case the autonomous system is bypassed. The shore based Officer Of the Watch controls rudder and thrusters directly. This will be done form a “situation room” looking much like a present full mission bridge simulator on a maritime achademy.

A great challenge for the project will be to determine precisely what information is needed, and how to portray this information in the Shore Control Centre to give the operators enough situation awareness to be able to, in worst cases, apply direct control of the remote vessel.

2. THEORY

On the manned ship bridge officers constantly work on building their *situation awareness*. The term was coined by Mika Endsley in 1988 [14] and is defined as “The perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”. Perceiving, comprehending and projecting. On the bridge this is done by monitoring instruments like radar and electronic chart system, but also by looking for cues outside of the windows and by sensing the vessels motions and vibrations. Prison 2013 used the term *ship sense* to describe the knowledge of the bridge officer in shiphandling [15], [16].

2.1 SHIP SENSE

The skill of ship sense contains so much more than collecting and making use of information presented by the navigational instruments. In close distances to other objects, such as when navigating through an archipelago or when engaged in harbour manoeuvres, i.e. situations when there are many available objects that can be used as reference objects, the task is mainly visual. Making use of information collected from the outside environment.

But focusing on the trans-oceanic phase of a voyage, this is usually a phase when the work of the navigational crew takes the form of a more monitoring state. Because the lack of visual reference objects, it is also the part of the voyage where mainly information from the nautical instruments is used as sources for achieving situational knowledge. But when the weather gets rough and the sea-state high, this is also when the situation on the bridge is transformed from being largely a monitoring job to being a very active task [15]. The autopilot is often disengaged and the ship is steered by hand with the goal to get a smoother ride through the seas. In such a situation the job of the shiphandler is about, among many other things, to get a feel for the ship’s movement in the present sea state. To know when it is time to slow down or to slightly alter course in relation to the direction of the oncoming waves to better care for the safety of the ship, its cargo and its crew.

This situational knowledge is not something that is collected through information presented by the nautical instruments onboard. It is rather something that is gained by the shiphandler using his senses, i.e. feeling the heaving motions of the vessel in the sea state, listening to and feeling the slamming when the bow falls into the through after being raised high by the last passing wave, and by visually studying the wave patterns [16].

The shiphandler can as a result of the above be pictured as balancing the task prerequisites and the resulting environmental factors. By letting his ship sense and his knowledge of the ships manoeuvring characteristics activate manoeuvring actions to reach the overarching goal of a safe voyage for both his ship, its crew and its cargo – to keep the ship in harmony with its environment [16].

2.2 HUMAN FACTORS

Human factors is a scientific discipline concerned with the understanding of the interactions among human and the other elements of the system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance [17]. In the social technical model "The Septigon Model" [18] which was developed from "The SHEL Model" [19][20], there are seven interrelated elements that made up one sociotechnical system: Individual, Group, Organizational Environment, Society and Culture, Practice, Physical Environment, Technology.

The targeted goal of such models is always aiming at reaching the harmonious state between the people and the environment. For manned ships, the interactive harmony between people and environment as well as people and the vessel (both software and hardware), depends on what level of situation awareness one can achieve during manoeuvring, as these effects make up the gut feeling described earlier as ship sense.

In essence, perception and cognition are the keys in ship sense from the perspective of human factors. When fulfilling the task of manoeuvring, the information is gathered through seafarers' senses via different perception receptors like the retina, which represents the first level of situation awareness. Then the seafarer goes through his/her experience and knowledge to comprehend the situation at hand, and finally uses mental models to judge what information is more crucial than other information.

Although it is true that the limit of human perception and attention constrain how good situation awareness can become, it is almost impossible to miss some information when people and the vessel share the same spatial movement, e.g. information brought by kinetic perceptions. Slamming will induce the high load to the ship and is therefore treated as the one important factor during risk assessment. Besides, the auditory receptors which will either actively or passively receive the sound of the strong wind while the visual image of the sea rage and foam is hard to miss if one just keeps his or her eyes open. However, by introducing the concept of unmanned ships, maintaining a high-level of situation awareness will be a big challenge. The factors causing ship sense onboard needs to be relocated to the shore side for an unmanned ship system.

First of all, there will be no physical connection between the human and the vessel, and no directly perceived information from the ship's environment. Specifically the visual perception of the environment, a vital sense in ship-handling for bridge crews, will be lost. This missing interaction highlights several human factor issues concerning both monitoring and controlling, e.g., it will be difficult for the operators in the Shore Control Center to perceive how the ship is behaving thousands of miles away, and what surrounding environment the vessel is facing at that moment. One solution is to build the connection between ship and shore by collecting and delivering dynamic information related to safety and navigation to shore. However it does not necessarily resolve the issue regarding the effect of absorbing information via different perceptions as the initial stage of situation awareness.

Secondly, the intuitive mental model that is used for maneuvering manned ships is no longer available. Mental models are used to decide the priority of information for humans [21]. In the task of remote monitoring and controlling, the users on shore need to build a new mental model to take them into a higher level of awareness, otherwise they will become blind to the environment, let alone the actions that need to be taken. There is a need to make people on shore understand the information more intuitively by lowering the burden of constructing the full picture. It is necessary to transform the conventional "onboard mental model" to the one that applies to shore management scenarios.

Thirdly, situation awareness is one accumulated product of the process [22] and therefore developing constantly. Although the data can be collected and delivered to shore instantaneously, the information acquired at one particular moment does not necessarily serve for high-level situation awareness, for the user needs to recall the previous related information to understand the situation thoroughly. But constantly providing information might not be the solution because there will be a huge risk of information overloading. Admittedly it is plausible to deliver needed information for the coming task by task detection, the user might still fail to keep pace to the rapid changing system and fulfil multi-threaded tasks. Cost-effectiveness is one crucial aspect when relocating human factors from ship to shore. What is more, it is not only what information is indispensable but also how dynamic the situation is changing in situation awareness needs to be reconsidered for Shore Control Centre. Maintaining situation awareness is more challenging than creating situation awareness for one moment since it is required to both keep track of the dynamic situation and keep users in the loop.

Overall, unmanned ship does not mean elimination of human factors but on the contrary, more attention needs to be paid to human factors with respect to developing and maintaining high-level situation awareness in dynamic systems. By relocating the human factors from ship to shore and considering them as the core goals, it will help to identify what information as well as what interactive approaches are really needed to develop the usable shore-based system.

3. METHOD AND RESULTS

In order to find out what information that will be necessary at the Shore Control Centre in order to acquiring adequate situation awareness a focus group interview was organized with 6 bridge officers with experience from different types of vessels.

The group came up with a list of 165 pieces of information that they felt was needed for providing situation awareness for a remote operator. The information was clustered into 9 different groups. Below are a summary of each information group.

1. Voyage. Information regarding the voyage plan and the itinerary list of reporting points etc. Also control of the voyage envelop, setting of threshold parameters for alarms that will change during a voyage (e.g. minimum allowed depth, minimum allowed distance to other vessels, land etc.). Updates of ship's static AIS message, fuel situation, etc. Daily updates from weather routing services will also be administered from this group.

2. Sailing. In this group all the standard information seen on a ship bridge would go: position, course over ground, heading, rudder angle, rate of turn, speed over ground and through water, etc. Here the main sailing alarm "inside nav box" also goes. The vessels planned voyage is represented by a "safe haven", a rectangle moving along the planned track. The box represents the expected position and time slot the ship is to be within if the voyage proceeds according to plan. If the ship for some reason leaves the box the operator is notified.

3. Observations. In this group the important information from of the autonomous object identification system is reported. The onboard sensor system fuses information from radar, AIS and the daylight and IR video cameras into an object identification system which will identify other ships, their course, speed and attitude and send this to the autonomous ship controller which will act according to COLREGS. The situation is also shown on the chart system in the Shore Control Centre. If the system fails to identify an object the image is sent to shore for identification. The object identification system is developed by the partner Aptomar AS and is expected to detect objects at least as well as a human lookout, but with a 24/7 vigilance that probably exceeds human capabilities. Tests with this system will be dune during the spring of 2014.

A challenge for the autonomous system as well as the remote operator will be the terms "restricted visibility" and "safe speed" which is not numerically defined in the COLREGS. In "restricted visibility" there is no stand-on ship (with right-of-way), but both ships are compelled to take evasive manoeuvre, while in "good" visibility the stand-on vessel is compelled to keep course and speed.

In this group the navigators also requested information about the ships motions. With no one onboard to sense heave, roll and slamming, these motions would have to be monitored by sensors and sent to the shore centre and displayed in some intuitive way to give some ship sense to the operator. Maybe in some kind of ship's equivalent to an airplane's gyroscope (see Figure 2).

Figure 2. A flight gyroscope showing roll, and pitch. A proposed *vessel gyroscope* can be used to transmit some "ship sense" to the remote officer of the watch.

The gyroscope would need to indicate average and peak roll and heave, but also vibrations dangerous to the hull's structural integrity driving from slamming and taking green water on deck.

4. Safety and emergencies. In this group information about firefighting, water ingress, bilge pumps, watertight doors, etc. is presented. Also handling of anchors, indoor PA systems to communicate with maintenance crews etc.

5. Security. This group contains information of the security sensitive log-on to the ship (an unmanned vessel will be an attractive target for computer hackers). It will also contain logs of door status etc. allowing the operator to keep track of authorized personal onboard (e.g. maintenance team), but also of possible intruders or stowaways onboard that could compromise the ISPS (International Ship and Port Facility Security) integrity of the vessel. CCTV camera images from the ship can also be requested by the operator (e.g. engine room, pilot ladder, cargo holds as well as common indoor and deck spaces).

6. Cargo, stability and strength. In this group information about the autonomous stability system and lists of tank levels is presented. Manual ballast water handling is also managed from here. This group also contains information about cargo conditions. The target vessel for the MUNIN project is a dry bulk carrier so it is envisioned that monitoring of temperature, humidity and ventilation for all cargo holds will be important as well as displacement monitoring.

7. Technical. In this group the engine parameters go. The engine is controlled by an onboard autonomous engine control system and when everything is working all right only a very limited amount of information is sent to shore. However the Shore Control Centre also include an engineer that can request and monitor all available parameters and control accessible points as well as plan maintenance and repair.

8. Shore Control Centre. There are some things that the autonomous vessel will not be able to handle itself. One of them is voice communication with other vessels. Although an unmanned vessel will have to be clearly recognizable as such, maybe thought paining, special lights, special AIS designator, etc., the unmanned vessel will be obliged to listen and respond to all radio and distress channels just like a manned ship, but the incoming calls will have to be linked to the shore operator. The calculated lag will be the same as in a normal satellite call and could be handled. Navtex, navigational warnings, AIS text messages etc. will also be forwarded within this group.

This group also contain information about the operational mode of the unmanned vessel. From the shore perspective the ship can be either in a) manual onboard, b) autonomous, c) remote, or d) fail-to-safe mode. Manual mode is when the ship is handled by the onboard control team or the pilot going from port to the point of autonomous voyage. Autonomous is when the ship is controlled by the autonomous onboard system. Remote control is when the ship is controlled from the Shore Control Centre and finally the Fail-to-safe mode is an emergency mode which the ship will go into after a certain time if communication with shore is lost or should some other emergencies happen. Fail-to-safe can mean different things sin different waters, e.g. drifting on the high seas, heave-to in constrained eaters, or drop anchor if close to leeward land.

As communication costs using satellite link is as a very expensive service today the shore operator also need to keep track of not only available satellite links and bandwidth, but also communication costs. We estimate that costs can reach 150,000 US dollars per month with today’s prices, if real-time communication of all parameters were to be practiced. (However, communication costs are expected to fall in the future.) Therefore information will only be sent on need-to-know bases.

For trust-building in initial stages of the unmanned system provisions for sending the event log of the autonomous ship controller can also be made.

9. Administrative. An administrative group containing information that a ship needs to log was also identified, such as different log books and crew list, etc. VDR (Voyage Data Recorder) is one such type of information.

Other exceptional situations difficult to tackle on unmanned ships, that was brought up during the focus group was such things as vessel icing (a not uncommon problem in Scandinavian waters winter time) and displacement of cargo. And maybe not to be underestimate: a plethora of small trivial problems like a dripping tap, a door not properly shut, a bin that has fallen over, that on a manned ships would be trivial to fix, but which on an unmanned vessel might grow to serious trouble.

4. DISCUSSION

Although the autonomous vessel might be unmanned, humans will continue to play an important part in the unmanned ship system. And with humans comes the possibility errors. Issues identified include:

1. Situation awareness in the SCC: mistakes due to not understanding the true situation of the vessel.
2. Misunderstandings in interaction with manned vessels: lag in VHF communication, bad communication links, language issues same as for manned systems, but worsened by lack of situation awareness. (e.g. references to local conditions not known by SCC operator.)
3. Delays in decision making due to lengthy time for operator to get into the loop (human-out-of-the-loop syndrome).
4. Stress and information overload because several ships might need the operators attention at the same time.
5. Human error due to “carry over effects” between two vessels as operator monitors several vessels at a time.
6. Weather situations too difficult for the automation to cope with and video link not good enough to allow for proper ship sense for manual ship handling.

This and other issues will be risk factors for an unmanned ship system. Let’s look at some of these issues.

How can we expect operators thousands of miles from the actual vessel to be aware of the situation, to gain adequate situation awareness? Three tools are the main pillars in this respect: the electronic chart, the radar and the video image (see Figure 3).

Figure 3: Three tools deliver the bulk of situation awareness to the remote operator: a camera system (top), radars (bottom left) and the electronic chart with AIS information and predicted maneuverability parameters (bottom right).

The vessels position and the position of other vessels in the vicinity is constantly transmitted to the shore control and displayed on an electronic chart system (see Figure 3, bottom right). On this system the vessels voyage plan (intended track, and intended time slot, the "navbox") as well as manoeuvring envelope are also shown

Under normal operation information from radars and AIS data is computed onboard by the object identification system. But on request radar images from the ships radars can be transmitted to the shore control (see Figure 3, bottom left).

One of the partners in the project, Aptomar AS, has developed a gyro stabilized camera platform equipped with IR and daylight video cameras and search light. This system conducts automatic image recognition and will do autonomous watch keeping. The camera platform can also be remote controlled from the shore centre sending stills or video images with a quality depending on the available connection link. Test with remote controlled manoeuvring of the vessel using the video system is planned for later this year. One of the real big challenges: remote hand steering in heavy weather would be the optimal goal of such a test but will be dependent on prevailing conditions on the test site.

A major goal of the project is to be able to show that an unmanned ship is at least as vigilant as a manned vessel. The vigilance of manned systems on ocean passages is not optimal, as many ship offices confess in conversations face-to-face. It is also reflected in accident reports. In 2004 a chemical tanker collided with a fishing vessel in the North Sea. The accident investigation report summarises: "As a power-driven vessel, Reno, [the tanker] was required to keep clear of Ocean Rose [the fishing vessel], but did not do so because her OOW had left the bridge and gone to his cabin. The AB lookout saw Ocean Rose and, realising that she was potentially a problem, tried to contact the OOW. He was unsuccessful." [23]. And this was on the North Sea. We can expect vigilance to be even lower on the oceans.

Watch keepers are humans and human error is part of the human condition and watch keeping on lonely ocean passages when other ships might not be seen for days in a row will be less than optimal. The automatic watch keeping on an unmanned ship is expected to keep the same high level at all times. Test will be done to determent the limits to what can be detected and identified, what needs to be sent to the shore centre for identification, and what will remain unseen. A crucial point for the project will be to show that no castaway floating on a piece of debris is left unspotted in the open sea. (And then another problem will arise: how can an unmanned ship come to help?)

5. CONCLUSIONS

The goal of the MUNIN project is not only to show the technical feasibility of unmanned vessels, but also to show that an unmanned system is at least as safe as a manned system.

To say that an autonomous system will remove human error as a cause of accidents is to grossly misunderstand the complexity and human involvement also in autonomous systems.

Technical breakdowns will probably play a big role in the beginning, as in most new systems, but can be expected to be overcome as experience is gained. Human error will continue to be the biggest challenge and must be addressed carefully and melodiously.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

1. WICHMANN, J., 'The power of social and sharing', Maritime CEO, 2013. http://maritime-ceo.com/focus_content.php?fid=3w3c27 [acc. 2014-01-04]

2. LANG, D.., 'Update on the Worldwide Supply and Demand for Seafarers', *Report from the Baltic and International Maritime Council (BIMCO) and the International Shipping Federation (ISF)*, 2010.

3. EUROPEAN COMMISSION. 'A Roadmap for moving to a competitive low carbon economy in 2050'. 2012. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52011DC0112:EN:NOT [acc. 2014-01-04]

4. UNITED NATION'S INTERGOVERN-MENTAL PANEL ON CLIMATE CHANGE, http://ipcc.ch/ [acc. 2014-01-25]

5. CARIOU P. 'Is slow steaming a sustainable means of reducing CO2 emissions from container shipping?', *Elsevier, Transportation Research Part D: Transport and Environment*, 16 (3), pp. 260–264. 2011.

6. MARINE ENVIRONMENT PROTECTION COMMITTEE. 'Analysis on the Appropriate Values of the Reduction Rates of the Required EDDI'. 60/4/36, 2009'. Submitted by Japan, 15 January 2010.

7. SANDQUIST, T. F., 'Human Factors in Maritime Applications: A New Opportunity for Multi-Modal Transportation Research', *Proceedings of the Human Factors 36th Annual Meeting*.1992.

8. BLANDING, H. C., 'Automation of Ships and the Human Factor', *Ship Technology and Research Symposium of The Society of Naval Architects and Marine Engineers, Philadelphia, PA*, 1987.

9. ROTHBLUM, A. M., 'Human Error and Marine Safety', US Coast Guard. http://www.bowles-langley.com/wp-content/files_mf/humanerrorandmarinesafety26.pdf. 2002. [acc. 2014-01-04].

10. FISCHER, E. (2011), 'Justifying automation', *Railway-technology.com*, 2011. http://www.railway-technology.com/features/feature127703. [acc. 2014-01-04]

11. STEPHENSON, A. G., LAPIANA, L. S., MULVILLE, D. R., RUTLEDGE, P. J., BAUER, F. H., FOLTA, D.; DUKEMAN, G. A., SACKHEIM, R.; NORVIG, P. 'Mars Climate Orbiter Mishap Investigation Board Phase I Report'. NASA 2010.

12. RODSETH, O. J., KVAMSTAD, B., PORATHE, T., AND BURMEISTER, H.-C., 'Communication Architecture for an Unmanned Merchant Ship', *Proceedings of OCEANS, Bergen, 2013 MTS/IEEE*, 2013, pp. 1-9.

13. MUNIN PROJECT. Technical reports at the MUNIN web site: http://www.unmanned-ship.org/munin/ [acc. 2014-01-04]

14. ENDSLEY, M. R., 'Design and evaluation for situation awareness enhancement', *Proceedings of The Human Factors Society 32nd Annual Meeting* 1988.

15. PRISON, J., '*Ship sense – exploring the constituents of shiphandling*'. Licentiate thesis, Technical report no. 13:146, ISSN 1652-9189, Chalmers University of Technology 2013.

16. PRISON, J., DAHLMAN, J., and LUNDH, M. 'Ship sense – striving for harmony in ship manoeuvring. *WMU Journal of Maritime Affairs*, 12(1), 115-127, World Maritime University, 2013

17. INTERNATIONAL ERGONOMICS ASSOCIATION: http://www.iea.cc/whats/index.html [acc. 2014-01-10].

18. KOESTER, T., 'Terminology work in maritime human factors. Situations and sociotechnical systems', *Copenhagen: Frydenlund Publishers*, 2007.

19. EDWARDS, E., 'Man and machine: Systems for safety', *Proceedings of the British Airline Pilots Associations Technical Symposium*, 21-36. 1972.

20. HAWKINS, F. H., 'Human factors in flight', Aldershot, UK: Gower Technical Press. 1987.

21. ENDSLEY, M. R. (2012). *Designing for Situation Awareness: an Approach to User-Centered Design*. Boca Raton, FL: CRC Press.

22. ENDSLEY, M. R. Theoretical underpinnings of situation awareness: A critical review. In M. R. ENDSLEY & D. J. GARLAND (Eds), *Situation awareness analysis and measurement* (pp. 3-32). Mahwah, NJ: Lawrence Erlbaum. 2000

23. MARINE ACCIDENT INVESTIGATION BRANCH. 'Report on the investigation of the collision between Reno and Ocean Rose off Whitby, North Sea 6 March 2004'.

9. AUTHORS BIOGRAPHY

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