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The Human Element and Autonomous Ships

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ABSTRACT: The autonomous ship technology has become a "hot" topic in the discussion about more efficient, environmentally friendly and safer sea transportation solutions. The time is becoming mature for the introduction of commercially sensible solutions for unmanned and fully autonomous cargo and passenger ships. Safety will be the most interesting and important aspect in this development. The utilization of the autonomous ship technology will have many effects on the safety, both positive and negative. It has been announced that the goal is to make the safety of an unmanned ship better that the safety of a manned ship. However, it must be understood that the human element will still be present when fully unmanned ships are being used. The shore-based control of a ship contains new safety aspects and an interesting question will be the interaction of manned and unmanned ships in the same traffic area. The autonomous ship technology should therefore be taken into account on the training of seafarers. Also it should not be forgotten that every single control algorithm and rule of the internal decision making logic of the autonomously navigating ship has been designed and coded by a human software engineer. Thus the human element is present also in this point of the lifetime navigation system of the autonomous ship.

1 INTRODUCTION

The idea of an autonomous ship is not a new one. In fact, automatically controlled surface vessels have existed already for decades. Fully automatic dynamically positioned vessels became common in the offshore industry in the 1970's and the use of on autonomous cargo ship was studied and demonstrated in Japan in the 1980's. Today fully autonomous Unmanned Surface Vessels (USV's) are widely used in ocean research, coast guard and military applications.

The technology of an autonomous and unmanned ship has been a subject of lively discussion in recent journals, conferences and seminars on development of marine technology. An autonomous ship is a sea-going surface vessel which is capable of operating without any crew onboard. The interpretation of an autonomous ship by the MUNIN-project is a combination of fully autonomous operation and remote human control. The ship's own control system can ask for assistance by the remote operator in such situations where the onboard decision making system cannot solve the situation for one reason or other. The autonomous ship can thus operate fully independently or it can be in some situations remotely operated.

The autonomous shipping is seen as a possibility for maritime transport to meet tomorrow's challenges. The most important arguments are the improvement in safety and the reduction of costs, i.e. improvement in competitiveness. Recent European research and development projects on this field are the MUNIN-project, financed by the EU, and the Norwegian ReVolt project by DNV GL supported by Transnova, Norway. The third major European project on this subject is AAWA, financed by a group of Finnish companies and the state-owned Finnish Funding Agency for Innovation, TEKES.

One of the fundamental outcomes of the MUNIN-project was the finding that the unmanned vessels can indeed contribute to the aim of a more sustainable maritime transport industry and that the autonomous ship bears the potential to reduce operational expenses, reduce environmental impact and attract seagoing professionals. Also the fully autonomous, unmanned, battery powered and electrically driven concept ship ReVolt was estimated to have a considerable potential for cost savings compared to an ordinary diesel-run ship, over a million euros annually.

It is a very often repeated claim that about 80% of marine casualties are caused, at least in part, by some form of a human error. However, this claim has been challenged by many researchers. The main weakness about this claim is the interpretation of the human error. Why humans behave in the way they do and what can kind of behaviour can be expected from a human operator? It was argued already by Rasmussen (1982) that ”human error” is not a useful term and should be replaced by considering such events to be ”human-task mismatches”. One could think that the autonomous ship would be the solution to this kind of unlucky events, because it is unmanned. Wouldn't it eliminate completely the human error – or the human-task mismatch - from the navigation process? Unfortunately the answer is no. The assumption is clearly not correct, even though the operation of the ship takes place without any human involvement. The human factor is still very much present, but in another form.

It is apparent that when the ship is unmanned, certain types of human errors are not possible. Such as errors due to operator fatigue, due to forgetting something important or due to wrong attitudes. Also such basic operator errors as slips and lapses would be avoided. But still, the human element is present and there is also room for human errors.

The human element is present on the unmanned ship, because it has been designed and constructed by a human being. The human factor has been shifted from the actual moment of operation to an earlier phase of the life-time of the ship, when the whole technical system was designed, built and tested. Leveson (1995) expresses this by stating that "removing dependence on an operator by installing an automatic device to take over the operator's function only shifts that dependence onto the humans who design, install, test, and maintain the automatic equipment – who also make mistakes."

Are the designers of the autonomous ship able to anticipate all different operational situations in order to make the ship behave always in a safe way? It must be taken into account that the autonomous ship interacts with other vessels, unmanned or operated by human beings. How the autonomous ship affects the behaviour of the deck officers of the other ships in the same traffic area? This interaction creates a new type of human element that also could lead to a human error.

The human element is present also in the remote control of the unmanned ship. How this should be taken into account? Is the remote control of the unmanned ship similar to the on-site control of the ship? These themes will be discussed in the following chapters.

2 THE AUTONOMOUS SHIP IS DESIGNED BY A HUMAN BEING

The autonomous ship including the computer equipment, that controls the operation of the ship are designed and constructed by a human being. The software, i.e. the behaviour of the system in different operational situations, is also designed by a human being. It is obvious that the human element is involved in every single act of the autonomous ship, even though it is unmanned. In case of an autonomous ship, the size of the total software package is huge and the structure of this package is very complicated. It is divided into subsystems and smaller entities inside a large amount of different devices communicating with each other.

Potentially there can be one or more software bugs caused by a human error in every single piece of the large system. The process of developing and testing the control software for the autonomous ship is therefore extremely critical. What kind of errors could the software engineers make? The development of a real-time software system is a complicated iterative process consisting of different phases, such as requirement definition and analysis, planning of data structures and operation algorithms, planning of data transmission, designing the structure of the software, defining the scheduling and priorities of the tasks, designing the self-diagnostics and the algorithms for exceptional situations, coding the modules, testing on the module level, integration, testing on the system level etc.

It is beyond the scope of this paper to discuss the methods of creating good software for safety-critical systems. There are hundreds of books and papers written on this topic and many international standards published to support the development of safety-critical systems, such as IEC61508, ISO 26262 and IEC 62304, just to mention a few of them.

There are simple human errors that can take place during the software development work, such as typing errors and common human carelessness during the coding phase, which could cause software bugs with a great variety of symptoms. A bit more irritating errors result from poor interface design and unpractical operating algorithms. But the good thing about this kind of software errors is that they are obvious and can be easily corrected. The more mature the software becomes, the less it contains this kind of errors, since the software does not wear out, i.e. the amount of errors will not increase because of aging.

The most difficult and dangerous software errors are those that are connected with abnormal situations and algorithms in exceptional circumstances. Many maritime accidents have resulted from a poorly designed algorithm leading to an unexpected and dangerous operation under exceptional circumstances. Nobody knew beforehand how the system would behave in such situation. Some accidents of this type are analysed in Ahvenjärvi (2009). The problem of this kind of software design errors is that they are very difficult to reveal beforehand. It may happen that the exceptional situation was not anticipated by the group of experts who wrote the requirement definition for the software. The operation of the system in such situation might be the result of decisions made by a software engineer, who is not an expert of navigation. There is a good reason to ask if the software engineer is able to navigate a ship. Ahvenjärvi (2002a) rises this question and gives some examples of software errors caused by poorly designed algorithms for exceptional situations: "Onboard a passenger ferry a navigating computer, after a sensor failure, kept on controlling the speed of the ship without knowing the speed of the ship. Onboard another ship the automation system controlled the pitch of the propeller to zero after a main engine clutch failure, despite the fact that the other main engine was still running." Another grounding of a passenger ship was caused by a curiosity in the software of the autopilot of the ship. None of the deck officers was aware of the behaviour of the autopilot before the fateful stormy night in December 2001 arrived, and the ship grounded with 820 persons onboard (Onnettomuustutkintakeskus 2001).

A difficult case for the designer of the software is to find out how the autonomous ship should act in a situation where only really poor alternatives are left. For example, should the ship intentionally collide with another ship or in stead sail aground? These are difficult questions and the human element is very much present in creating algorithms for solving such problems. The responsibility can not be laid on the computer system. It is the man-made software that makes the system do what it does. But who takes the responsibility of an accident caused by a poor decision algorithm of the autonomous ship? It is beyond the scope of this paper to discuss this matter.

All in all, it is more than likely that there will be more or less dangerous software errors in the control systems of autonomous ships. The good thing about software errors is that they do not multiply during the lifetime of the system. Instead, by testing and using the system errors will be revealed and the software can be corrected and updated. Anyhow, the human element is still there, even when all possible effort has been put into testing and correcting the software before the autonomous ship is put into traffic.

3 INFLUENCE ON THE CREW OF THE MANNED SHIPS

Although it may sound a little bit strange scenario, the crew on a manned ship might learn new operating habits when they are in regular contact with an unmanned ship. It is a commonly known fact that automation has the tendency to create new and risky habits for them who are in regular contact with it. It is not difficult to find examples of this. The grounding of M/S Royal Majesty (NSCB, 1997) is a classical one, but also in everyday life we can see examples of changes in human behaviour caused by automation. Just consider a car driver that has a new car equipped with a parking radar. In the beginning the car driver checks the possible nearby obstacles from the mirrors and the windows, even though the radar is there. But gradually the driver learns that there will be a warning given by the radar system whenever there is something behind the car. And after some time the driver learns to rely on the parking radar and begins to neglect looking at the mirrors. It can happen that the driver starts to use a little bit more speed during parking because of the reliance on the radar system!

It is possible, if not probable, that the autonomous ship will cause some kind of learning process among the deck officers of manned ships operating in the same traffic area. When the operation of the unmanned ship is known and predictable, it could be utilised in some way to make the navigation of a manned ship easier or more effective, for example in encountering and passing situations.

The potential dangerous utilisation of the predictable behaviour of the autonomous ship should be taken into consideration. In the worst case that could result in degrading safety and new types of hazardous situations in the shipping routes and fairways. The autonomous ships should be equipped with extensive recording capacity in order to make it possible to afterwards analyse the odd traffic situations and incidents caused by manned ships.

4 THE HUMAN ELEMENT IN THE REMOTE CONTROL OF THE UNMANNED SHIP

As mentioned above, the autonomous ship can also be remotely controlled. The human element is present in this mode of operation in the same way as it is on the bridge of the manned ship. Maintaining the situation awareness is essential for safe and efficient control of the ship. Therefore the quality of the information presented to the human operator in the remote control centre is crucial.

The operator needs to have up-to-date and essential information about the status of the ship itself and about the traffic situation around it. There is a lot publications about the ergonomics and other factors affecting the performance of the human controller of a technical system.

If the operator in the remote control centre gets exactly the same information as would be available on the bridge of the ship, there is virtually no difference between the remote control and the onboard control. This is technically quite possible, provided that the data transmission capacity between the ship and the remote control centre enables the necessary real-time information exchange.

According to the MUNIN project the Human-Machine-Interface (HMI) of the remote control centre must be developed using decision-making heuristics that compliment the operator's ability to obtain and maintain situational awareness and remain "in the loop". A user-centred design will be critical to develop the remote control centre good for safe passage of autonomous, unmanned ships.

A potential area of development of the HMI of the remote control centre would be the utilisation of auditory feedback in monitoring of the operation of the ship's equipment. In case of the remote control of the autonomous ship it could be a recorder real sound or an artificial sound describing the operation of the critical equipment. This topic has been discussed by Ahvenjärvi (2002b). Ahvenjärvi proposes that the monitoring of safety-critical signals could be improved by producing a suitable non-disturbing continuous background sound to the control room. The changes in the background sound would describe the operational changes of the rudders and the main propellers. By using auditory feedback the detection of critical faults in the navigation system would be enhanced and the safety of navigation be improved.

5 WILL THE BEST OF THE HUMAN ELEMENT BE LOST?

Obvious strengths of the human operator of a complex system are flexibility and creativity. The human ability to adapt to surprising situations has positive effects in the safety of the system, although the human ability to adapt - i.e. the ability to learn - can also be a weakness, as discussed earlier.

The problem of a surprising situation from the software developer's point of view is that it can not be anticipated. Particularly challenging situations for the autonomous ship could be for example multiple and simultaneous sensor faults, or faults in the communication equipment, intentionally caused to disturb the ship (by a group of pirates, for example). This kind of scenarios describe another type of human element influencing the operation of the autonomous ship.

The preprogramed computer system has a limited, if any, ability to adapt to exceptional and surprising situations. This could be a weakness of the autonomous ship compared to the traditional ship with a human navigator on the bridge. The need to be able to cope with unforeseen situations must be taken into serious consideration when the control algorithms, emergency procedures and the decision logic of the autonomous ship is being designed. Effective ways to manage such situations must be introduced and tested before the fully autonomous ship is ready for wider use in sea transportation.

6 CONCLUSIONS

Introduction of the autonomous ship does not mean that there is no more a human element involved in the navigation process. Although some types of operator errors will be eliminated, the human element and the human error in different forms have to be taken into account. In this paper, some aspects of the human element related to the autonomous ship technology have been discussed.

The human element plays a major role in the software development phase of the autonomous ship. It is of utmost importance to ensure that the algorithms and decision making procedures of the autonomous ship are carefully defined, correctly coded and thoroughly tested - not only for normal operation conditions, but also for exceptional circumstances and surprising situations.

It must also be taken into account that the predictable operation of the autonomous ship can influence the behaviour of human navigators on the conventional manned ships. Potential unwanted habits caused by this kind of learning process might be reduced by equipping the autonomous ship with comprehensive recording capabilities.

The role of the human element in the remote control centre of the autonomous ship is similar to the role it has on the bridge of a manned ship. A user-centred design of the HMI of the remote control centre is extremely important to minimize user errors and to maximise the safety of the remotely controlled ship. Audible feedback could be an additional means to enhance the monitoring carried out by the operator in the control centre.

The human element is often associated with human errors. The positive side of the human element is the human creativeness and the ability to adapt to unforeseen and surprising situations. This form of resilience is a strength, but sometimes also a weakness, of the human deck officer of a ship. The lack of similar ability to adapt to unforeseen situations is a potential weak point of the autonomous ship. There must be a lot of resilience built in the control system of the autonomous ship to make it a safe alternative for the marine transportation needs in the future.

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