YRKESHÖGSKOLAN NOVIA

Unmanned merchant vessels in Man Over Board (MOB) operations

Sami Korppi

Master's Thesis

Master of Engineering, Autonomous Maritime Operations

Turku 2019

MASTER'S THESIS

Author: Sami Korppi
Degree Programme: Master of Engineering, Autonomous Maritime Operations - Turku
Supervisor: Johanna Salokannel

Title: Unmanned merchant vessels in Man Over Board (MOB) operations

---

28.11.2019 53 pages

Abstract

The aim of this work is to evaluate, how an unmanned ship could assist other vessels and persons in the sea in Man Over Board (MOB) situations. According to the International Convention for the Safety of Life at Sea, all ships have to assist other vessels or persons in distress regardless of the circumstances. Unmanned vessels cannot have an MOB situation themselves, but they can be of assistance to other vessels.

The development of unmanned ships has so far concentrated largely on navigation and situational awareness. The technology developed for navigation could be used also for managing distress situations. Distress situations require information of the surroundings of the vessel, communication and navigational functions.

In this work, the whole chain of events in a distress situation is evaluated: recognizing exterior distress signals or identifying a MOB situation, search of a person or life raft in the sea and assisting persons. The evaluation is based on international regulation, earlier research, expert views on technical and regulatory development and the writer's own experiences of working at the sea.

Language: English Key words: Autonomous, unmanned, shipping, man over board, MOB, distress

---

Table of Contents

1 Introduction ... 1
1.1 Research questions ... 2
1.2 Research methods ... 3
1.3 Commissioner ... 4
1.3.1 Kongsberg ... 4
1.3.2 Kongsberg Maritime ... 4
1.3.3 Yara Birkeland ... 5
2 Regulation & Classification ... 6
2.1 Regulatory bodies ... 6
2.1.1 IMO ... 6
2.1.2 National regulatory organizations ... 7
2.2 Classification societies ... 7
2.3 Existing regulation's applicability to unmanned vessels ... 8
2.3.1 Definition of an autonomous ship ... 8
2.3.2 COLREG ... 9
2.3.3 STCW ... 10
2.3.4 MARPOL ... 10
2.3.5 Other matters ... 10
3 Unmanned vessels' sensors and their characteristics ... 12
3.1 Radar ... 12
3.2 Lidar ... 14
3.3 Cameras ... 15
3.3.1 PTZ camera ... 15
3.3.2 Night vision cameras ... 16
3.4 GNSS ... 17
3.5 Inertial navigation system ... 17
3.6 Dynamic Positioning Systems ... 18
3.7 Microphone array ... 18
4 Distress signals ... 19
4.1 Digital signals (l, m, n, o) ... 20
4.2 Pyrotechnic distress signals (c, h, i, j) ... 21
4.3 Visible signals other than pyrotechnics (f, g, k) ... 21
4.4 Voice signals (a, b, d, e) ... 21
5 Automated identification of distress signals ... 22
5.1 Optical identification of distress signals ... 22
5.1.1 Pyrotechnic distress signals ... 22
5.1.2 Other visual distress signals ... 25

5.2 VHF/MF/HF distress signals 25
5.2.1 DSC call 26
5.2.2 Voice call 27
5.3 Voice signals 27
5.4 SART 28
5.5 Identification of an actual visible MOB situation 28
6 Unmanned vessel in a search operation 29
6.1 Management of a distress situation 29
6.2 Communication 30
6.3 Technical accessories applicable for search operations 31
6.3.1 Radar 31
6.3.2 Lidar 31
6.3.3 Camera 32
6.3.4 Drones 33
6.4 Autonomy level during a search operation 35
7 Rescuing humans from the sea 36
7.1 Helping persons in the sea 36
7.2 Helping persons recover from the sea 37
7.3 Other ways of assisting the overall rescue mission 38
7.4 Organising remote control of an unmanned ship 39
8 Life Saving Appliances to be used in MOB situations 39
8.1 Remote launch of traditional Life Saving Appliances 39
8.2 Drones 40
8.3 Other means 41
8.3.1 Unmanned Search and Rescue vessel development projects 41
9 Conclusions 43
References 45

1 Introduction

This thesis is made for the Master's degree programme *Master of Engineering, Autonomous Maritime Operations* of Novia University of Applied Sciences (UAS) in Turku, Finland. Supervisor of the work is Johanna Salokannel from Novia UAS and the commissioner is Kongsberg Maritime Finland Oy.

Personally, I have quite a varying background in seafaring and engineering. In addition to a master's degree in engineering, I have a master mariner's degree and experience from various kinds of vessels. The smallest vessels I regularly use are kayaks, and the range of vessels I have experience from continues from recreational boats to waterbuses and merchant ships both large and small. I have also been an active member of the Helsinki Lifeboat Association, serving voluntarily on dedicated Search and Rescue boats. Further considering my present-day work in a safety oriented environment, I have always been interested in the safety of seafaring and operations in distress situations. This all led me to consider the use of autonomous vessels in distress situations. As I investigated the area, I found that practically there is no existing research in the field done.

The topic of distress situations and even just one type of distress, man over board (MOB) situations is a broad area and there are multiple separate subjects within the topic that could be master's thesis topics themselves. Therefore, the topic has to be discussed on a somewhat general level and it is not possible to dive as deep into nuances as would be tempting. On the other hand, as there is no pre-existing research, some subjects have to be covered in quite a technical and theoretical level, as there is no information available of real-world applications in the maritime field.

The early development of autonomous vessels has concentrated in the area of navigation. Naturally, automated navigation is a prerequisite for autonomous vessels, it is the very core of seafaring. Nevertheless, before actual autonomous vessels can sail, there are also other requirements that need to be fulfilled and safety is one of them. There are strict rules of how vessels and their masters should behave in distress situations concerning their own or other vessels. Therefore, also unmanned vessels must fulfil safety related requirements. Actual regulations do not exist yet, hence the situation cannot be reflected to concrete requirements.

1.1 Research questions

The master of a ship at sea which is in a position to be able to provide assistance, on receiving information from any source that persons are in distress at sea, is bound to proceed with all speed to their assistance, if possible informing them or the search and rescue service that the ship is doing so. This obligation to provide assistance applies regardless of the nationality or status of such persons or the circumstances in which they are found.

(IMO, SOLAS, Chapter V, Regulation 33)

The quotation above, from the International Convention for the Safety of Life at Sea (SOLAS), combined with the development of unmanned vessels, is the basis for this work. Actually, the paragraph is a good example of one side of the work that needs to be done before unmanned vessels can sail the seas. The wording of SOLAS mentions the master of a ship, which an unmanned vessel will not have, at least not aboard the ship. Still, also future ships may be required to offer the level of assistance applicable to the vessel. The difficult part is to define what is applicable. Komianos (2018) proposes, that unmanned vessels could even be exempted from Search and Rescue (SAR) activities, but I will look a little deeper into the subject.

The fundamental question of this work is: How should and how can unmanned vessels offer assistance for persons in distress in Man Over Board (MOB) situations? As unmanned ships are unmanned by definition, the topic refers to MOB situations of other vessels. Aim of the work is to find out the requirements and possible means of giving assistance when there is no crew on board. I will also investigate how unmanned vessels could be considered in regulation and the development of life saving appliances. In the work, I will deal with the whole chain of events of a MOB situation. It will include the following steps:

- Identification of a distress signal
- Acknowledging and forwarding the distress signal to a relevant rescue organisation and other vessels
- Identification of a distress situation without an external distress signal
- Actual search operation
- Distress related communication with the rescue organization and other vessels
- Rescuing humans from the sea or assisting them if rescuing is not possible

In this thesis, I will go through present regulatory requirements and evaluate how they can be applied to unmanned operations. I will gather available information of future scenarios of regulation and the development of the industry.

There are numerous, widely varying possibilities of distress situations. They include but are not limited to fire, flooding, grounding, collision, sinking, etc. Real-life distress situations may be various combinations of two or more of these situations. This work will concentrate only on subjects related to MOB situations. Some aspects of the work, like identifying distress signals, are applicable also to other forms of distress. But any aspects which cannot be connected to MOB situations will be excluded.

Also, this work concentrates solely on unmanned vessels. Manned vessels, even if they could be remotely or autonomously operated, are not addressed in this thesis. Naturally, many of the findings will be applicable to manned intelligent vessels, but they will not be separately considered as they would resemble very closely traditional manned ships. The scope of the work will be limited to merchant ships. In other words, dedicated search and/or rescue vessels and other vessels and devices will only be discussed as a reference.

1.2 Research methods

Autonomous and unmanned vessels are still in an early phase of their development. There are very few autonomous merchant vessels existing today, and mostly they are modifications of traditional, manned ships. Hence, there is no experimental practice of building unmanned vessels and their life saving appliances (LSA). There is also a limited amount of research done in the field.

As there is no practical experience of LSA of unmanned vessels, I will dig slightly deeper into the technology in this work. I will evaluate the technical possibilities in distress situations of the devices used on unmanned ships. Both the traditional technology that is used also on manned ships and newer solutions characteristic for unmanned vessels. Technical possibilities are evaluated for their applicability for all phases of distress situations. Technology is assessed by its capability of use in distress situations like identifying different kinds of distress signals or search operations.

This work is mostly based on information from literature, regulations, earlier research and expert interviews and presentations. Existing knowledge and research results will be gathered and applied to a new area to construct knowledge of the subject. Practical experiments will not be done. The required amount of work and the usability of results do not justify the arrangements that practical experiments would require. Quantitative methods will neither be used. I will concentrate on the question of what aspects enable or on the other hand restrict autonomous vessels from taking part in assisting in MOB situations. I will analyse the information and evaluate what could and should be done to utilize unmanned vessels in MOB situations. As the scope of the work is quite broad, it is impossible to concentrate on specific details of different technologies and some areas will have to be researched later on a more detailed level.

1.3 Commissioner

The original commissioner of the work was Rolls-Royce Marine and its remote & autonomous operations unit in Turku, Finland. However, already at the time of signing the master's thesis contract, it was known that Rolls-Royce Marine would be purchased by Kongsberg Maritime. The purchase was completed on April 1st, 2019. Hence, at the time of writing, the commissioner is Kongsberg Maritime Finland Oy.

1.3.1 Kongsberg

Kongsberg is a Norwegian conglomerate, which was originally founded as early as 1814 when it started producing rifles for the Norwegian armed forces. It stayed solely as a weapons manufacturer until the 1950's. Kongsberg is still a significant producer of weapons for Norway and its NATO allies, but it has widened its portfolio to a wide range of products. (Kongsberg)

1.3.2 Kongsberg Maritime

Kongsberg Maritime employs approximately 7 600 persons worldwide and it has offices in 34 countries. It offers various solutions for different areas of maritime business such as offshore construction and production, fishery, passenger vessels and intelligent shipping like autonomous vessels. Kongsberg Maritime's products include, but are not limited to:

- Navigation: radars, gyrocompasses, Voyage Data Recorders (VDR), Information Management Systems
- Automation & control: automation and safety systems and loading & cargo monitoring computers
- Sensors: pressure, temperature and tank liquid level sensors and transmitters, motion and heading sensors

- Propulsion control systems
- Condition monitoring systems
- Electrical switchboards
- Fleet management systems
- Dynamic positioning systems
- Positioning systems
- Fish finding equipment
- Marine robotics: remotely controlled and autonomous underwater vehicles, unmanned surface vehicles and their equipment

Existing wide product portfolio helps the development of autonomous vessels, as there already are various products, which are applicable also in unmanned ships. (Kongsberg)

1.3.3 Yara Birkeland

Kongsberg Maritime has been a key player in planning the widely known autonomous container ship Yara Birkeland. It is said to be the world's first autonomous and zero-emission container vessel. The plan is to launch the vessel in 2020 and have it running autonomously by 2022. At first, the vessel will have a containerised, manned bridge. When the vessel will be run autonomously, the bridge will be lifted off (Komianos 2018). Yara Birkeland's length overall is 80 m, cargo capacity is 120 TEU and it is totally electrically driven. Its battery capacity is 7 MWh and propulsion consists of two Azipull pods 1200 kW each. The vessel's route will be 31 nautical miles on the Norwegian coast.

Figure 1. Illustration image of Yara Birkeland (Yara)

2 Regulation & Classification

Within the maritime field, there are various organizations, which affect the technical solutions aboard vessels. There are solely regulatory actors like IMO, and private organizations like classification societies, which also have a large impact on vessels' technical solutions.

2.1 Regulatory bodies

2.1.1 IMO

The International Maritime Organization (IMO) is a specialized agency of the United Nations. IMO was formally established in 1948 by name Inter-Governmental Maritime Consultative Organization (IMCO). The name was changed to its present form in 1982. (IMO, Brief history of IMO)

The members of IMO, through IMO conventions, have agreed and published the most important regulatory documents affecting international shipping. IMO regulations cover practically everything related to shipping, starting from ship design and construction to manning, operations and environmental questions. IMO conventions are the acronyms that all seafarers worldwide are well aware of, including but not limited to:

- International Convention for the Safety of Life at Sea (SOLAS)
- International Convention for the Prevention of Pollution from Ships (MARPOL)
- International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)
- Convention on the International Regulations for Preventing Collisions at Sea (COLREG)

The pace of IMO work and its results is quite slow, due to multiple reasons. It is a large organization and the members include states that have different interests in the development of shipping. Quite naturally, differing interests may have an influence on the states' authorities' desire to change regulations.

Even if there are no conflicts between member states, the decision process in IMO is still considerably time-consuming. New proposals can be proposed by member states, non-governmental and intergovernmental organizations or by the secretary general of IMO. New proposals are reviewed, compared to existing guidelines and strategy, and considered politically, policy-wise and technically. A proposal and its form are developed in subcommittees and approved in a committee. If the proposal affects the areas of multiple committees, adoption is approved by the assembly, which is the highest governing body of IMO. New texts are circulated to the member states before the adoption and after the final decision, there is still time reserved for the entry into force. All these phases take time, hence every new proposal of IMO regulation takes years to come into effect. (Timonen 2018)

2.1.2 National regulatory organizations

IMO regulations per se are just agreements between its member states, not legally binding rules. When IMO regulations have been formed, they need to be implemented nationally. IMO conventions do not specify how they should be implemented in national laws. The implementation is organized in its own way in each member state. It is not within the scope of this work to study the worldwide national organizations individually. As an example, In Finland, the ministry of transport and communications is the responsible organization for the development of legislation in this area. Traficom is an agency of the ministry and it has a large role in the development, expert discussion and research work in the field of maritime regulation. (Timonen 2018)

2.2 Classification societies

Classification societies have existed since the 18th century when merchants, shipowners and captains gathered at Edward Lloyds' coffee house in London. (Wikipedia, classification society) Classification societies are non-governmental organizations that establish, maintain and control the compliance of technical standards for the construction and operation of ships. Classification societies are an important part of the shipping business as they set the practical guidance and limits for the operations and technical condition of vessels.

Seppo Liukkonen of DNV GL Helsinki describes classification societies role "The classification is based on a voluntary mutual agreement between the classification society and the owner of the ship, offshore installation or other classified object. Thus, principally the classification of a ship, for instance, is not mandatory, but in practice in the international trade it is a "must". Without classification a ship in the international trade cannot get freight and insurances, for instance." (Liukkonen)

The role of classification societies is monitoring, supervising and inspecting that designing, building and operating of a ship complies with applicable technical and safety standards

(Goh & Yip 2014, Kannos). The most well-known classification societies include organizations such as Lloyd’s Register, Bureau Veritas and DNV GL.

2.3 Existing regulation’s applicability to unmanned vessels

There are various treaties, which include regulation that is not perfectly valid in a world of autonomous ships. These issues may be minor details, which can be solved by changing the wordings according to common sense. Many treaties like these are discussed in literature. However, I will not cover them in this text on a detailed level as required changes will mostly be intuitive and self-explanatory.

Autonomous vessels are not considered in existing maritime regulation. There is research done in the field (for example Danish Maritime Authority 2017) and they clearly show that the writers of the regulation have not even thought about the possibility of unmanned vessels. One example of this is the wordings in STCW. Article III of STCW states that the STCW rules apply to seafarers "serving on board seagoing ships entitled to fly the flag of a Party". (IMO, STCW) This could be interpreted that a remote operator's skills and certificates would not be covered by STCW requirements, as he / she does not serve *onboard* ships. On the other hand, STCW chapter VIII states that officers in charge of the navigational watch "… shall be physically present on the navigating bridge or in a directly associated location such as the chartroom or bridge control room at all times." (IMO, STCW)

This paragraph (2.3) is largely based on the report “Analysis of regulatory barriers to the use of autonomous ships”, which is published by Danish Maritime Authority and made by two Danish companies: consulting firm Ramboll and law office CORE Advokatfirma. The report is based on the Danish maritime cluster, Danish legislation, and Danish regulatory bodies, but practically the significance of national characteristics in the field is minimal, as seafaring is mostly covered by international treaties. I will cover the subjects on an international level and not go into details of any national players in the field.

2.3.1 Definition of an autonomous ship

There are different ways of determining the levels of autonomy in shipping. The report uses the following categorisation (Danish Maritime Authority 2017):

- M: manual navigation with automated processes and decision support. Officer of the Watch is present aboard the ship but not necessarily continuously on the bridge as navigation can be controlled by automated systems.

- R: remote-controlled vessel with crew on board. The vessel is remotely controlled. There is a qualified person on board to take control of the navigation if necessary, but this will not be done routinely, only when special circumstances require it. In that case, the autonomy level will be shifted to M.
- RU: remote-controlled vessel without a crew on board. The vessel is solely controlled from outside, e.g. shore-based remote control center or another vessel.
- A: autonomous vessel. The vessel will operate totally autonomously and will alert a human remote controller only in exceptional situations like system failures. In that case, the autonomy level will be shifted to RU.

As mentioned earlier, I will concentrate on unmanned vessels, which in this classification means autonomy levels RU and A. SOLAS states that "The Administration may exempt any ship which embodies features of a novel kind from any of the provisions of chapters II-1, II-2, III and IV of these regulations the application of which might seriously impede research into the development of such features and their incorporation in ships engaged on international voyages." (IMO, SOLAS). This means that individual states may grant permits for testing of various technical solutions, for example testing of autonomous shipping. This has already happened e.g. in Finland. Testing autonomy in international traffic requires more effort, but likely national waters will be sufficient for testing purposes in the near future.

2.3.2 COLREG

The Convention on the International Regulations for Preventing Collisions at Sea (COLREG) is one of the most, if not the most challenging set of rules to be implemented in an autonomous ship. In today’s shipping, uncertain situations are often confirmed by VHF voice calls between officers of the watch of related vessels. VHF voice calls are challenging to arrange if a ship is controlled by machines. Other means of communication need to be arranged or the situations where voice calls have been needed have to be avoided before they happen.

Present rules explicitly demand a physical lookout on the bridge of the vessel. For remotely controlled ships (autonomy levels R and RU), the requirements of remote look-out have to be defined. Technical solutions to be defined include camera and microphone systems, communication technology and required redundancy and fault tolerance levels. Qualification requirements of the remote operator also have to be agreed on. The technical requirements of look-out will also affect an unmanned vessel's capabilities in search operations. Regarding fully autonomous ships, the question is even more complex. There will not be a human watching images from the cameras of an unmanned vessel. Look-out will be managed by artificial intelligence and other computerised systems. It has to be carefully considered, what situations have to be relayed to a remote operator.

2.3.3 STCW

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) basically defines what the title says: what kind of training and certification is required from the crew of a vessel. (IMO, STCW) As mentioned before, the wording of STCW limits its regulations to persons serving onboard a vessel. Therefore it is technically invalid for any questions regarding remotely controlled vessels. However, practically the requirements of STCW can quite easily be applied to persons performing the same functions remotely as they would do locally on board a vessel. STCW includes also regulations regarding the use of life-saving appliances and other operations in distress situations. There is no crew aboard unmanned vessels to operate devices like rescue boats, hence some parts of the STCW are invalid for the vessels of the future. On the other hand, remote operations may easily lead to a multi-level organization in the remote operations centre. Simple questions, no matter which traditional department of the ship they are related to, could be solved by a "remote operator of the watch". If an issue requires more technical knowledge, it could be delegated to an individual or a team of technical experts who may physically be somewhere else than the operator. (Danish Maritime Authority 2017, Komianos 2018)

2.3.4 MARPOL

International Convention for the Prevention of Pollution from Ships, known as MARPOL, defines the limits of waste disposal and pollution from ships. (IMO, MARPOL) Mostly MARPOL's regulations cover everyday functions of a ship and are not related to distress situations. An area where MARPOL requirements could or should be observed related to distresses, is the possibility of accidents. For example groundings or collisions could lead to environmental consequences. However, these aspects are outside of this work's scope.

2.3.5 Other matters

In this chapter, I will briefly cover various topics, which affect autonomous shipping, but I have considered to be of minor importance, or the rules are scattered in numerous regulations and / or they can likely be easily resolved by changing the wordings of regulations intuitively. A simple example of these could be the requirement of SOLAS chapter V, regulation 19 to have all necessary nautical charts for the intended voyage aboard the vessel (IMO, SOLAS). In the case of an autonomous or a remote-controlled vessel, it is obvious that the charts are still needed for navigation, but the actual place where they exist may be outside the vessel.

2.3.5.1 Representative of a vessel

Under various regulatory matters, including the United Nations Convention on the Law of the Sea (UNCLOS), an interesting question is who will represent the ship in case of an autonomous vessel. Traditionally the master of the ship has been the one to be in charge. Various rules define explicitly the master to be the representative of the vessel and require him / her to make reports to authorities and answer questions and act on behalf of the vessel. (United Nations, ILO) Even in distress situations it is the master that SOLAS requires to assist the ones in distress. If there is not a master on board the vessel, regulations have to be adapted to the new situation. Depending on the situation, a ship's representative may be the shipowner, remote operator or a specifically agreed representative, who could be e.g. contracted from a local agent company in a port. This requires quite many changes to the wordings of regulations. However, I consider the matter to be a question of negotiations and an agreement between different parties of the business.

2.3.5.2 Safe manning

There are requirements of safe manning in different treaties, including SOLAS (by IMO), UNCLOS (by the United Nations), and MLC (by the International Labour Organization). However, they do not include explicit numbers of seamen on board, the requirements only dictate that the manning must be sufficient to carry out all ship's operations, including distress situations, safely. Practically, the actual limits of safe manning are also today defined by the flag state's assessment. If flag state officials consider reduced manning or even unmanned vessels to be safe, international regulations do not present a barrier to that.

2.3.5.3 Assisting humans in distress

It is a fundamental principle that all vessels (masters) must give assistance to anyone who is in distress at sea (IMO, SOLAS). On the other hand, there are practical limitations of how especially an unmanned vessel can offer assistance. However, the wordings of SOLAS and UNCLOS state that the master of a vessel must give assistance if the vessel is ”in a position to be able to provide assistance” (IMO, SOLAS) and ”in so far as such action may reasonably be expected of him" (United Nations). Fundamentally, this covers all the aspects that may limit the possibilities to help, including that the vessel may be unmanned. For real-life situations of the future, it would be good if a basic level of assistance could be agreed on internationally. This could mean for example remotely launchable life rafts. Matters related to this question are discussed further in later parts of this work.

3 Unmanned vessels' sensors and their characteristics

Autonomy brings a new range of sensors to a vessel. Basically, all traditional sensors are still valid also in an autonomous vessel, but there are some sensor types or uses of sensors that are typical for unmanned vessels. The sensors can be divided into three different groups, based on their significance on autonomous vessels and their difference of use when comparing traditional and autonomous vessels. Sensors that are used both in traditional and autonomous ships and their use cases do not differ in any way, will not be covered on a detailed level. An example of this group is the Automatic Identification System, AIS. The next group are sensors that have been used also in traditional ships, but interpretation and processing of the data are reasonably different in autonomous operations. A radar is an example of such a device. When a radar image is processed by an algorithm instead of a human, it has to be converted to a digital format (Poikonen 2019b). The last group is sensors that have not been widely used in traditional ships, like lidars or navigational cameras.

Project Icarus (Matos et al. 2017) developed an autonomous vessel for patrolling limited areas like harbours and delivering help for persons in the water. It offers information about sensor selection for search and rescue purposes. The largest vessel of project Icarus (a 7-metre rigid hull inflatable boat) is equipped with:

- Radar
- Lidar
- Weather sensors
- Daylight camera
- Thermal camera

These sensor types will be discussed in the following chapters.

3.1 Radar

Radars (RAdio Detection And Ranging) have existed, in some form, for over 100 years. German physicist Heinrich Hertz invented the basic idea of a radar already in the 1880's.

However, radars were not found practical or necessary enough until the 1930's and military needs for long-range detection of objects. (Skolnik) Since then radars have been developed substantially and they have been extremely important instruments in maritime navigation for decades.

On a modern manned ship, a radar and an ECDIS (Electronic Chart Display and Information System) are the two most important sources of information for the navigator. Radar information may be viewed separately or it may be overlaid with chart data from the ECDIS. Interpreting the radar's information, combining it with chart data and the optical view from the bridge is one of the most important, or even the most important skill of a navigator.

Even being over a century old invention, radar is still superior in detecting objects from a long distance. The theoretic maximum range of a modern marine radar is usually 48 nm. Such a range requires perfect conditions, like antenna positioned in a high mast, large object to detect and good weather. According to Matika & Grzan (2013), a small fishing boat can be seen from a ship at a maximum 14 nm range, due to radar horizon. Practical radar range varies due to external conditions, but usually, large ships can be seen at least from a 10 nm distance. Modern devices like lidar are far better in accuracy, but their working range is considerably shorter than radar's.

A radar image is normally very simple and therefore also quite easy to understand. Different colours can be used to represent stronger or weaker signals, but basically, the image can be thought as a two-dimensional monochrome image. Hence, a radar image can be considered quite easy to interpret for computer vision.

Everybody, who has used a marine radar, understands that the accuracy of a radar is coarse. Poikonen uses an example of a radar signal converted to Asterix Cat 240 digital signal. At a range of 2 km (1,1 nm) one pixel equals an area approximately the size of 2 x 6 m and at 10 km range, the area is about 10 x 30 m.

One aspect of radar is to help in the positioning of the vessel. For an experienced navigator, this happens intuitively, when a nautical chart and the radar image are continuously compared. For a computerized system, the function has to be built separately, but it is quite an effective way of crosschecking sensor data.

3.2 Lidar

Lidar (LIght Detection And Ranging) works technically by the same principle as a radar. A signal is transmitted, and reflected signals from external objects are received and processed to form an image of the surroundings. Radar uses radio wavelength signals, lidar sends light signals. Lidar typically works on frequencies near infrared. This means that the light is absorbed by water, hence a lidar cannot see the surface of calm water. However, small droplets like the ones in the wake of a ship or in fog do reflect the lidar rays. (Poikonen 2019b)

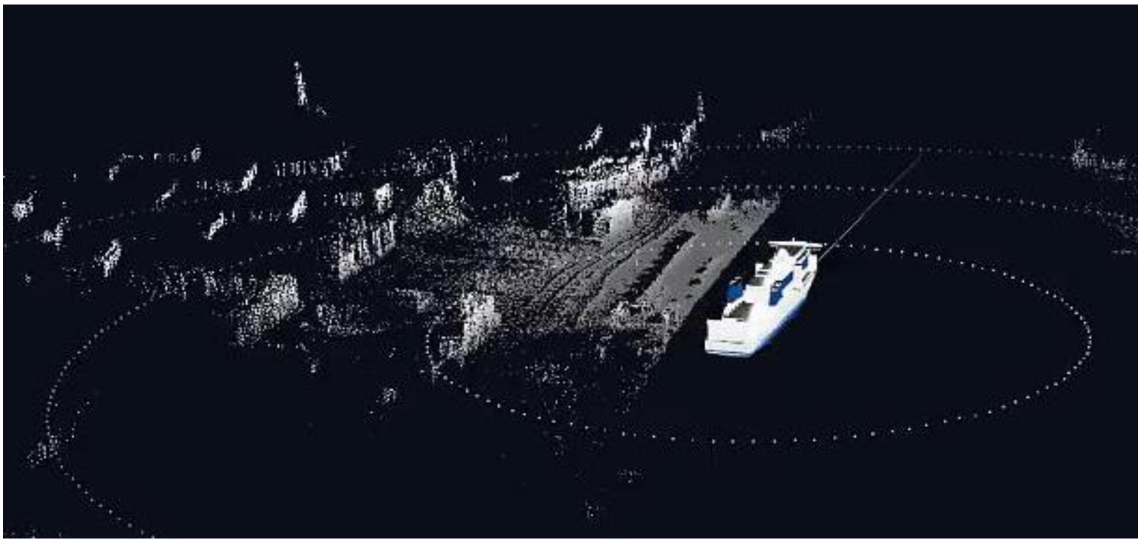

Figure 2. Example of a lidar image

The effective range of a lidar is far shorter than that of a radar. On the other hand, lidar accuracy is superior compared to radar. Lidar forms a 3D point cloud of its surroundings. Figure 2 shows an example of a lidar image with an actual ship and surrounding point cloud (Poikonen 2019b).

Lidar's accuracy is very high, it measures the distances in the scale of centimetres (Dix, Abd-Elrahman, Dewitt & Nash 2012). Therefore, it is highly usable in object detection and classification. As ships at sea usually roll more or less, the lidar image changes constantly, even if there would not be any factual changes in the environment. Therefore lidar requires good integration with ship's INS (Inertial Navigation System) to get accurate data of the ship's position and motion. The maximum range of a present-day lidar device is approximately one kilometer (0,54 nm) (Poikonen 2019a). This is a handicap in marine use at open seas, as navigational decisions have to be made far earlier than within a lidar's range.

3.3 Cameras

3.3.1 PTZ camera

The acronym PTZ stands for Pan-Tilt-Zoom. Basically, the camera per se is quite an ordinary digital video camera, the difference is particularly its ability to turn 360 degrees and up and down and also zoom, just as the acronym advises. PTZ cameras are very common in various solutions like surveillance cameras. Figure 3 demonstrates a typical PTZ camera.

Figure 3. A typical PTZ camera. (Wikimedia commons)

In autonomous vessels, PTZ cameras could be regarded as auxiliary cameras to fill in the sectors that are not covered by the ship's main navigation cameras and to offer a technically different view. PTZ cameras' resolution and technical quality may not be as high as of the navigation cameras, but they supplement well the areas that are usually not of high interest, such as the side and stern sectors of the vessel. In addition to the lower interest level sectors, PTZ cameras can also be used to supplement the detections of static cameras and help in identifying objects. When a static camera finds something interesting, a PTZ camera can be zoomed to the object and used in identifying it. The features and capabilities of PTZ cameras are demonstrated in this work with the examples of two existing cameras suitable for autonomous vessels. The example cameras are Reliant 640 HD and Flir M400 (Teinilä 2019). The Reliant's price is approximately 16 000 $ (opticsplanet.com) and Flir's 59 000 $ (thegpsstore.com). The prices mentioned were found in online stores in spring 2019 and are not to be interpreted as optimal prices of the devices, they are merely mentioned to give an idea of the price range.

PTZ cameras' resolution is usually not very high. Typical resolution is Full HD, which is 1920 x 1080 pixels. So, it is far from modern still cameras or even general use video cameras, where 4K resolution (3840 x 2160 pixels) is nowadays quite common. Their strength is their ability to zoom. Typical PTZ cameras used in autonomous vessels feature a 20-30 times optical zoom (Teinilä 2019). When considering search operations, the PTZ cameras could be programmed to continuously scan the sea area and feed the images to AI to interpret them and find possible persons in the sea.

3.3.2 Night vision cameras

To build up a photo, or video, which is basically a series of photos, some kind of light is always needed. In daytime, the light is usually easily available as there is enough sunlight, even if clouds block the direct view of the sun. When daylight starts to dim, technical solutions become more complex. There are three main solutions to enable taking pictures in low light:

- Amplifying the light captured on the camera sensor
- Thermal camera
- Infrared camera

A low-light camera uses the same technology as is used in daylight imaging. The received light is technically amplified to get a brighter picture. To some extent, low light cameras can be enhanced by using larger camera sensors and/or lower resolution, which interprets to larger pixels if the physical sensor size is maintained equal. Technical amplification of the received signal leads to gradually inferior image quality when the amount of light diminishes. Also, this technology always requires at least some light: if there is no light, it cannot be amplified.

Thermal cameras do not require any visible light. Their sensors react to heat emitted from objects. Hence, even though a thermal camera is often an integrated part of a daylight camera, the thermal camera uses its own separate components. Thermal camera's lens usually has a shorter zooming capability and its resolution is lower than the one in the daylight camera. According to their product brochures, the aforementioned example PTZ cameras both have a 640 x 480 resolution in their thermal camera system.

Infrared (IR) camera sensors react to longer light wavelengths than visible light. They require an infrared light source, which is normally a set of IR led lights positioned around the camera lens. The PTZ camera in the example photo above has 9 infrared LEDs around its lens. Regarding maritime use, the range of IR LEDs may become an issue. Based on product presentation materials, in normal surveillance cameras designed for industrial or home surveillance, the maximum range of IR LEDs is only a couple of hundreds of metres, which is far from sufficient in maritime use.

3.4 GNSS

GNSS stands for Global Navigation Satellite System. The best-known example of such is the US-originated Global Positioning System, usually known as GPS. Other highly similar systems are Russia’s GLONASS, China’s BeiDou and EU’s Galileo. GNSS are used, in addition to seafaring, in car navigators, mobile phones, smartwatches, etc.

The basic principle of all these systems is the same. GNSS have approximately 20-30 satellites orbiting the earth, and their orbits are precisely known. They transmit satellite-specific data, which is received, recognized and timed by a receiver. Based on the satellite identification and receiving time differences the receiver can compute its distance from the orbits of multiple satellites. As the orbits are precisely known in advance, the position and altitude of the receiver can be calculated. A GNSS compass measures the received phase difference of multiple antennas and calculates their geographic direction which is shown to the user as a compass heading. GNSS's are vital in the navigation of all vessel, both manned and unmanned. In distress situations, they are needed for example for informing the position of the vessel or following a search pattern.

3.5 Inertial navigation system

Inertial Navigation System, INS, supplements and enhances reliability and accuracy of GNSS data. INS uses sensors such as accelerometers, gyroscopes, and magnetometers to sense the movements of the vessel. INS does not provide a geographical position per se, just a relative, but very accurate, position compared to a previous moment in time. (van Graas 2013) INS also gives information of the motion of the vessel like roll, yaw, and heave. Figure 4 demonstrates the motions (Wikipedia, Ships motions). Although the data of an INS system in short time intervals is very accurate, its position data does tend to drift as time passes. Therefore INS data has to be compared to GNSS data and reset on a regular basis.

INS data is important in MOB operations as it supplements and enhances the accuracy of GNSS data. In addition, INS data is essential in stabilizing and fusioning of data from cameras and other types of sensors. Different movements of the ship cause the camera images to change constantly. For effective tracking and identification of objects, camera images have to be stabilized with the input from the INS system.

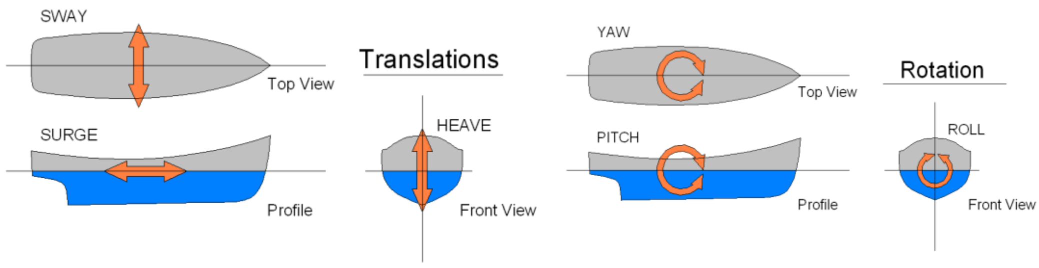

Figure 4. Ships motions. (Wikimedia commons)

3.6 Dynamic Positioning Systems

Dynamic positioning (DP) systems are widely used in present-day applications on oil fields, offshore construction sites, and other demanding use cases. Usually DP systems require quite an expensive and laborious set-up of infrastructure to operate, at least on the vessel side, and still, their operating range is very limited, even at maximum only kilometres. DP systems employ technologies such as acoustic transponders, taut wires, and locally assembled radar systems (Lusto 2013). If there is a need for a DP system in an unmanned vessel, it offers superior accuracy for positioning also in distress situations, if the vessel is within the DP system range. Otherwise DP systems do not offer substantial value compared to their technical complexity and price.

3.7 Microphone array

Microphone arrays are something that is clearly needed onboard autonomous vessels to substitute humans. Just by listening and turning his/her head, a human can identify the direction of a sound quite well. The accuracy is not perfect, but on a coarse level, it is an easy task for a human.

With just one microphone, external sounds can be recorded and stored, but it cannot tell anything about the direction of the sound. The more microphones are installed, the better is the accuracy of the sound’s direction. Even technically simple arrays with less than five microphones offer a good estimation of the sound direction. (Al-Sheikh et al 2013; Poikonen 2019a)

The data from a microphone array may be fuzzy, but its value is its uniqueness. The surrounding sounds give information that is not affected or interconnected with other sensors. Also, sounds are not significantly affected by fog, rain, snow or other phenomena that limit the capabilities of other sensors like cameras and lidars. An open sea is a good environment for accurate sound reception. As there are few obstacles in the surroundings, received sound is not affected by reflections or echoes. (Poikonen 2019a)

4 Distress signals

Distress signals are defined in annex IV of the Convention on the international regulations for preventing collisions at sea, COLREGs (IMO, COLREG). The whole list of distress signals, as it is written in the COLREGs, is presented below. In this chapter, I will group them into categories based on the technical solutions used and present them briefly. Identification of the signals in an unmanned vessel in a more detailed level is discussed in the next chapter.

I would say that some of the signals in the list are obsolete today and that a large share of present-day deck officers would not notice them in real-life circumstances or possibly even identify them as distress signals. One example of such a signal is the use of a combination of signal flags N and C. But, the list is included in the COLREGs and therefore also autonomous vessels should be capable of identifying them. The letters in parentheses of this chapter's subtitles refer to the lines of the COLREGs list.

List of distress signals (IMO, COLREG)

(a) a gun or other explosive signal fired at intervals of about a minute

(b) a continuous sounding with any fog-signalling apparatus

(c) rockets or shells, throwing red stars fired one at a time at short intervals

(d) a signal made by any signalling method consisting of the group · · · — — — · · · (SOS) in the Morse Code

(e) a signal sent by radiotelephony consisting of the spoken word "MAYDAY"

(f) the International Code Signal of distress indicated by N.C.

(g) a signal consisting of a square flag having above or below it a ball or anything resembling a ball

(h) flames on the vessel (as from a burning tar barrel, oil barrel, etc.)

(i) a rocket parachute flare or a hand flare showing a red light

(j) a smoke signal giving off orange-coloured smoke

(k) slowly and repeatedly raising and lowering arms outstretched to each side

(l) a distress alert by means of digital selective calling (DSC) transmitted on:

(i) VHF channel 70; or

(ii) MF/HF on the frequencies 2187.5 kHz, 8414.5 kHz, 4207.5 kHz, 6312 kHz, 12577 kHz or 16804.5 kHz

(m) a ship-to-shore distress alert transmitted by the ship's Inmarsat or other mobile satellite service provider ship earth station

(n) signals transmitted by emergency position-indicating radio beacons

(o) approved signals transmitted by radio communication systems, including survival craft radar transponders

4.1 Digital signals (l, m, n, o)

Some of the signals are sent originally in digital format. These include DSC (Digital Selective Call) alerts sent on VHF or MF/HF frequencies, satellite-based EPIRB (Emergency Position Indicating Radio Beacon) signals and other satellite systems, like Inmarsat, distress alerts. They are digitally identified as distress signals already in present-day receivers, hence they do not require any new technology in unmanned vessels.

A Search And Rescue Transponder (SART) is a transponder that sends radio signals in the 9 GHz radar frequency band when it discovers a radar signal. 9 GHz (3 cm band) radars are obligatory on all ships of 300 gross tonnage and upwards (IMO, SOLAS), so every ship should be able to receive the SART signal. Below is a mockup of the display of a radar with a SART in its coverage area. When a radar receives a SART signal, it is not digitally identified as a distress signal, as the radar "sees" it as an ordinary reflected signal from any object. However, in my classification, I will include SART in digital signals as radar signal is easily converted to digital data (Poikonen 2019b) and hence can be processed in digital format.

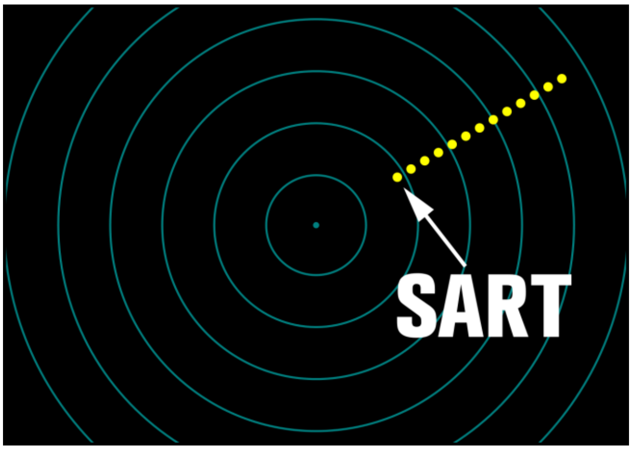

Figure 5 Mockup of a radar display with a SART (Craggs 2011)

4.2 Pyrotechnic distress signals (c, h, i, j)

Pyrotechnic signals include smoke signals, handheld and parachute flares, and devices that shoot red stars. Flames on a vessel are also considered a distress signal. It does not necessarily mean that the vessel itself is on fire, the fire can also be intentionally lit for example in a barrel. Some of the pyrotechnic signals are designed for day use, others for night time. In drill situations, I have seen over a hundred flares both parachuted and handheld. Flares are hardly visible in well-lit day conditions, but they are effective in darkness. For smoke signals it is vice versa, they are good during the well-lit hours of the day, but practically useless at night.

4.3 Visible signals other than pyrotechnics (f, g, k)

These signals are mostly historic, from the times when flag signals were the only way of communication between two ships or a ship and the shore. They can be difficult to identify as distress signals even for an experienced seafarer today. Especially list item G: “a signal consisting of a square flag having above or below it a ball or anything resembling a ball” is extremely challenging.

4.4 Voice signals (a, b, d, e)

Voice signals can be divided into two groups: radio calls and other voices. A distress radio call must be started on VHF channel 16 and it has to include the word "Mayday" repeatedly. Other voice signals, like a continuous sounding with a fog-signalling device or a gun fired at one-minute interval could be regarded as practically obsolete signalling methods even in today’s world with manned vessels. Ship bridges are usually closed and so the officer of the Watch (OOW) cannot hear external voices unless they are exceptionally loud. Even if there is a separate lookout, he/she is usually also at the bridge inside the walls.

5 Automated identification of distress signals

There is a common understanding, that technical solutions substituting safety related human work on ships can be approved, if the system can perform the task at least as well as a human. All unmanned vessels will most likely have at least some ways of operating them and their technical systems remotely. For example, radio communication with humans in other vessels is difficult to automate. Decision making in complex situations will probably also require human intervention. Therefore, I will presume in this work that autonomous systems are required to identify distress signals and potentially analyse data like images from cameras, but they will not be required to perform complex decision making in challenging situations or be able to fully understand and analyse human natural language. When these kinds of situations are identified, control is supposed to be transferred to the remote operator.

5.1 Optical identification of distress signals

5.1.1 Pyrotechnic distress signals

Pyrotechnic distress signals include, as their name suggests, burning materials. They are made to burn even in conditions where there is no oxygen available, for example underwater. Pyrotechnic signals have some characteristics which can help in identifying them using machine vision and artificial intelligence.

Utkin et al. have researched the use of lidars in detecting wildfires. They have found out that lidar is comparatively efficient in detecting smoke in the air (Utkin, Piedadea, Beixigaa, Motaa and Lousãa 2014). This is good news regarding the detection of pyrotechnic signals, as they all produce more or less smoke. Another characteristic feature of burning pyrotechnic signals is that they are by far hotter than their surroundings and hence they should be easy to identify using thermal cameras.

The actual rocket of a parachute rocket is a small and fast-moving, hot object going almost vertically upwards. The rocket's rise from sea level to its peak height takes only a couple of seconds and it produces a smoke trail. When the rocket has risen to its peak, which is minimum 300 metres (IMO, LSA Code), the parachute is opened and the actual flare is ignited. Its descent takes at least 40 seconds (IMO, LSA Code). Just like the rocket, the flare is a small and hot object. It descends in a predictable manner and emits a very bright, but physically small light. These characteristics are quite unique, there are practically no other phenomena at sea that would have these kinds of fingerprints. Therefore, they should be fairly easy to identify using the vessel's cameras, especially if thermal cameras and lidars can be applied. Technically, also the sound of a fired parachute rocket could be identified. Nevertheless, it would require the rocket to be quite near the microphone and hence the use of microphones is probably more of a theoretic than a practical solution for identifying a parachute rocket.

Figure 6. Descending parachute rocket in dim daylight. (Markku Tamminen)

The actual flare in a handheld flare is practically similar to the one used in parachute rockets. It is small and very bright and hot. But it does not descend from the sky but stays stationary near the sea level. Practical maximum height is the height of a ship's deck, some tens of metres above sea level. Otherwise, its characteristics and identifiability are practically the same.

An orange smoke differs slightly from other pyrotechnic distress signals. It is also a small and hot object. However, when it is fired, depending on the wind, the actual burning material may be covered with thick smoke within seconds. A smoke signal generates very thick smoke, which is of an exceptional colour. The smoke stays in the air for a couple of minutes. Based on the research of Utkin et al, the smoke could be used as an identifiable object using a lidar and AI technology to interpret the image.

Figure 7. Orange smoke in windy conditions. (Markku Tamminen)

Devices shooting red stars as distress signals are rare and their efficiency is weak. Based on personal experience of approximately 30 fired devices, the visible time of the stars is only a couple of seconds and the intensity of the light is weak. It could even be said, that the sound of shooting them raises more attention than their visible characteristics. They are extremely difficult for a human to identify, as they are visible for such a short time. Hence, if the goal of a computerized system is to be as effective in noticing the red stars as a human, it does not require much. However, also in these cases, thermal cameras are probably practical in detecting them.

5.1.2 Other visual distress signals

The variety of distress signals is broad and many forms are more of historical leftovers than true means for alerting other seafarers. These include signals such as signal flag combination N and C or "a signal consisting of a square flag having above or below it a ball or anything resembling a ball". These kinds of signals could be identified with camera systems using artificial intelligence or traditional computer vision methods (Poikonen 2019a). Whichever method is used, it requires substantial amounts of work to teach or otherwise define how the system can identify the distress signals. Poikonen suggests that there should be international co-operation on the development of the systems (Poikonen 2019a). For example, an international community could offer an image database of visual distress signals. Teaching an AI system to identify them requires hundreds and thousands of images (Nielsen 2015), and it is not sensible in any way for every developer to acquire their own image repertoire. As industry parties probably do not consider distress signal identification to be an area of a significant competitive benefit, industry-wide co-operation could be arranged. However, it is also essential to include regulatory bodies for the work, as they will be the ones to finally judge whether the systems are effective enough.

5.2 VHF/MF/HF distress signals

There are two types of radios used for communication aboard vessels, VHF (Very High Frequency) and MF/HF (Medium / High Frequency) radios. Technically there are no major differences between them, the most important differing features are the frequency band and transmitting power. Marine VHF works in frequency band 156-174 MHz (Wikipedia, Marine VHF Radio). MF (2 MHz band) and HF (4, 6, 8, 12, 16 MHz) frequencies are normally combined in the same device (egmdss.com).

VHF is, by far, more widely used than MF/HF in everyday situations. It is used for daily communication between ships for example in agreeing navigational manoeuvres to avoid close-quarters situations. VHF is also used for communication between ships and shore-based operators like ports, VTS services, and pilots. All ships are required to listen to VHF channel 16, which is the international calling and distress channel used for broadcasts of marine safety information (IMO, SOLAS).

A VHF radio is applicable only on short distances. The theoretic maximum range of VHF calls depends on the height of the transmitting and receiving antennas. For example, between two antennas at 30 m height, the theoretic range would be approximately 21 nm. (Kasum, Cvjetkovic and Stanivuk 2013). By my own experience as a deck officer, practical maximum range of a VHF call between two ships varies significantly and is approximately 5 to 20 nautical miles depending on the circumstances.

MF/HF radios are obligatory on most seagoing vessels (IMO, SOLAS). MF/HF radio uses lower frequencies and higher transmitting powers compared to VHF radios. With a MF/HF radio, calls can be made, at least theoretically and in optimal atmospheric conditions, without geographical limits. Long distance calls, even to the other side of the globe, require the right time of the day, selecting a suitable frequency band and good atmospheric conditions. This is enabled by higher transmit powers and especially radio propagation of lower frequency radio waves. Further details of radio wave characteristics are beyond the scope of this work. In everyday situations aboard ships, MF/HF radio is seldom used. Ships are required to keep DSC watch on MF/HF radios, but listening to voice call frequencies is not obligatory. Most ships today have comprehensive satellite communication systems, hence long distance radios have become almost obsolete.

5.2.1 DSC call

Earlier times, distress traffic was carried out by voice communication from start to finish. Modern DSC-enabled (Digital Selective Calling) devices enhance the pace of communication and add reliability. DSC is a system used on VHF and MF/HF radios for digitally calling other stations and sending distress signals. Specific MF/HF/VHF frequencies / channels are reserved for DSC traffic. DSC can be and is used for routine calls to other ships, but I will concentrate on its use in distress situations.

DSC devices are connected to a GNSS or it is built-in in the radio. Some basic parameters of the vessel are saved in advance to the DSC controller, including vessel’s dimensions, its type, number of persons onboard, etc. When a distress call is sent, the DSC device sends the vessel’s identity (MMSI number) and all fundamental data of the vessel in seconds in text format, which is automatically saved to the receiving devices. DSC alerts are easy for unmanned vessels, as the information is already in digital format. After the initial DSC alert, the rest of the distress traffic is executed by voice traffic. It can be assumed that the actual distress traffic after a DSC call is handled by a remote operator.

5.2.2 Voice call

DSC radios are obligatory on all merchant vessels and a DSC call should be the primary way of sending a distress alert via radio. However, smaller vessels may not have DSC devices and even if there is a DSC radio on a vessel, a traditional mayday voice call is still a valid distress signal (IMO, COLREG). There is only one VHF channel that is required to be listened to at all times, the international calling and distress channel 16. As it is a normal calling channel, there is a lot of non-distress traffic on the channel, especially in coastal areas where there is plenty of vessel traffic and the transmissions of coastal stations are within the VHF range.

Distress traffic on VHF channels should always include the word "mayday". Therefore, when wishing to automatically identify a distress call, the task is to find this one word from the voice flow. Automatic processing of the following information would be beneficial for the operations, as fundamental information could be presented to the remote operator in a pre-processed form, but reliable voice recognition systems are still difficult to implement (tutorialspoint.com). Practically all calls including the word mayday should be immediately forwarded to the remote operator to evaluate the need for further actions.

5.3 Voice signals

Voice distress signals include a gunshot or other explosive fired at the interval of one minute, continuous sounding of any fog signalling device or morse code SOS (· · · – – – · · ·) signalled with any sounding device. Like pyrotechnic distress signals, these signals have some very specific characteristics, which ease their identification.

It is hard to believe, that these days repeating gunshots would be used as a distress signal. However, gunshots have two attributes that ease their identification: duration-wise they are very short and the frequency spectrum of a gunshot is wide (Poikonen 2019a). These characteristics make them fairly easy to distinguish from other sounds at sea. An international and public library of sound samples, in the same way as mentioned earlier regarding visual distress signals, could ease their identification (conversation with Poikonen 2019a).

Compared to gunshots, fog signalling devices are substantially different, practically opposite, in terms of the sound's frequency band. The frequencies of a vessel's sound devices are defined in COLREG. For example, the frequency of the whistle of a vessel more than

200 m long must be between 70 and 200 Hz (IMO, COLREG). The navigation systems of an autonomous vessel have to listen and identify the sound devices of other vessels in all situations, even without considering distress signals. Sounds used in navigational purposes are combinations of short (1 s) and long (5 s) signals. Hence, different sound patterns identified to be vessels' signalling need to be listened to and analysed in any case. If a fog horn signal is continuous, it should be easy to identify, with the same systems as navigational sounds, to be a distress signal. Then the information just needs to be passed from the navigation system to the vessels other systems and remote operator.

SOS signal is also quite unique and unlikely to be mistaken for any other sound. Even if the SOS sound can be given with any device, the combination of three short, three long and three short sounds is apparently easy to differentiate from natural sound sources at the sea.

5.4 SART

A SART transponder transmits its specific echo pattern to the radar of another vessel. In unmanned vessels, the radar signal has to be digitized for the navigations systems and therefore it is practically processed as a digital signal from the beginning. In addition to navigational analysis of the radar signal, the systems need to run an algorithm capable of detecting a SART signal.

5.5 Identification of an actual visible MOB situation

Watchkeeper of any vessel, in addition to identifying the defined distress signals, should be able to identify an actual visible distress situation. Recognizable distress situations include for example a burning or sinking vessel, an obviously grounded vessel or a person over board. Identifying a MOB situation in a normal situation does not fundamentally differ from a search operation where the goal is to find and identify a person in the sea.

In a conventional, manned ship, there is normally one or two persons at the bridge doing the tasks of navigation and lookout. Their goal is not to specifically find persons in the sea, but to keep themselves up-to-date of anything and everything happening or existing in the vicinity of the ship. If there is knowledge of a potential person in the sea, the lookout will be strengthened and probably at least two more lookout persons are added to the bridge or another position aboard the ship optimal for the lookout.

Concerning unmanned vessels, it could also be thought that in normal situations, the situational awareness algorithms are used in a standard mode, which is able to notice persons in the sea, but are not optimized for it. In standard mode, the use of cameras and processing of the images could be less thorough and less processed compared to a full efficiency search operation.

6 Unmanned vessel in a search operation

6.1 Management of a distress situation

All the sea areas of the world are divided into search and rescue regions between the world's coastal states. The exact borders of responsibility areas are agreed by neighbouring countries. These and other principal rules of search and rescue management are defined in the International Convention on Maritime Search and Rescue. All search and rescue operations are always managed by a shore-based rescue co-ordination centre or a rescue sub-centre. They may designate an on-scene co-ordinator to lead the operations in the distress area. (IMO, International Convention on Maritime Search and Rescue) The on-scene co-ordinator may be the master of an authority vessel or also a merchant vessel's master who has completed a special course for on-scene co-ordinators. For example, many of the masters of passenger ferries have conducted the course.

Figure 8 shows a simplified model of distress situation management in a case where an autonomous ship's algorithms have detected a distress signal or a distress situation. The vessel's systems send an alert to a remote operator. The alert includes information of the situation such as images of a possible visible distress signal, video or voice recording or other information that is interpreted as a distress signal or situation. The remote operator inspects the received data and evaluates whether the algorithm's detection is correct. If the situation is evaluated, with sufficient accuracy, as a non-distress situation, the alert can be cancelled. Otherwise the alert is forwarded to a Maritime Rescue Co-ordination Centre (MRCC) in whose area the vessel is located. MRCC evaluates the situation and gives orders for the remote operator or releases the vessel from the operation. The remote operator acts as a representative of the vessel, answering questions, giving information and controlling the vessel to fulfil the requirements of the MRCC. The operation is continued until the MRCC decides to cease it.

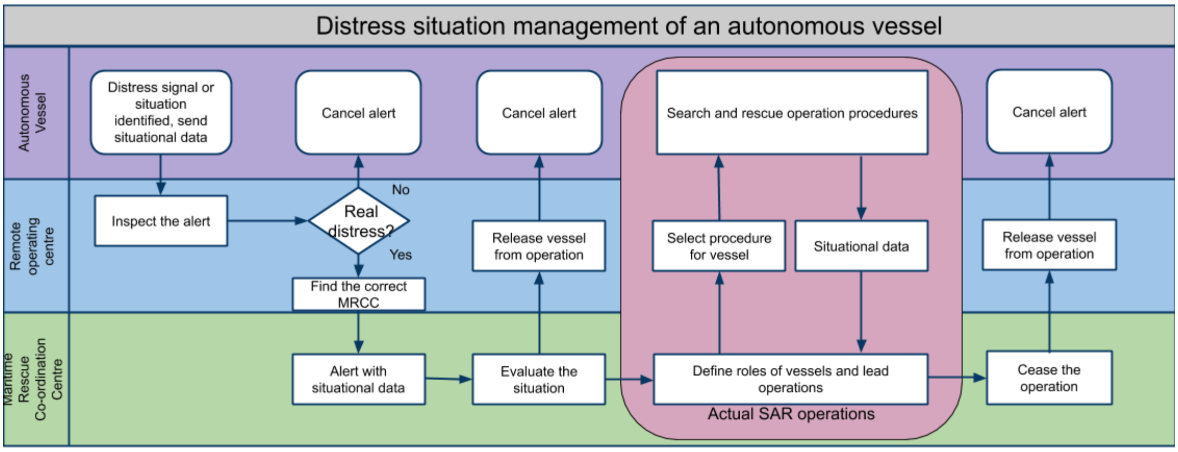

Figure 8. Distress situation management derived of an autonomous vessel's automatic detection.

The remote operating centre should be able to easily apply basic search and rescue operations procedures to the unmanned vessels. These could include for example a software capable of generating search patterns according to guidance received from the MRCC. When thinking about the future with large fleets of unmanned vessels and centralised remote operating centres, there could even be dedicated devices, spaces and teams to manage distress situations. Remote operations could be covered anywhere in the world, so technically it would not be a problem to establish even just one, globally acting distress operations centre for a large remote operations enterprise.

6.2 Communication

Distress situations often require intense communication, where parties of communication may include two or more of the following (Aboa Mare 2011):

- The vessel from where person(s) have gotten into the sea
- Person(s) in distress
- Other assisting merchant vessels
- Dedicated Search and Rescue vessels
- On-scene commander
- Maritime Rescue Co-ordination Centre
- Airplanes
- Helicopters

In a distress situation, there usually is a lot of communication between different parties of the operation. Communication is practically impossible to automate, hence a dedicated communications person is needed in the remote control centre. Presumably, autonomous vessels will have at least all the same communications devices as a manned vessel, and they can be remotely controlled. Therefore an unmanned vessel does not differ significantly from a traditional ship communication-wise.

6.3 Technical accessories applicable for search operations

6.3.1 Radar

Each liferaft and lifeboat is required to be equipped with a radar reflector unless it is equipped with a SART radar transponder (IMO, LSA Code). Therefore a radar, in addition to its use in navigation, can and should be a vital tool in actual searching. A radar has its weaknesses, for example, it cannot be used to identify objects, but it is superior in detecting objects from a distance. Noting the LSA Code’s requirement, life rafts and boats are reasonably well visible on radar. On the other hand, a single person with or without a life vest can hardly be seen by a radar, unless the person has some technical aids for radar visibility.

6.3.2 Lidar

Lidar has its own characteristics in what it can see and what it cannot. Lidar cannot detect a calm sea surface (Soloviev 2019). When considering a search operation at sea, this could be assessed a positive feature. A ship at sea is surrounded by water, and no technical devices are needed to confirm that. Other objects in the sea could be better detected when reflections from the water do not disturb the measurements. However, waves and especially stormy conditions form water droplets above sea level, and they produce reflections of lidar transmissions (Soloviev 2019). As lidar uses light for detection, its capabilities depend on the object's and its material's ability to reflect light. Life saving appliances have to be of highly visible material and colour and need to have retro-reflective materials (IMO, LSA code), which enhances lidar's possibilities of detecting life rafts or life vests in the sea.

There are features in lidar detection that affect its capabilities in search operations at sea in different, and in some cases opposite ways. This is an area where further research is needed to clarify the advantages and disadvantages in actual search and rescue operations. A better understanding of lidar's capabilities requires practical experiments in differing weather conditions. Lidar could be an effective tool in MOB search operations.

6.3.3 Camera

Forward-looking cameras of unmanned vessels are primarily designed to give an overview of the vessel's surroundings for navigational purposes. They can be used to detect and identify other vessels, land areas, and navigational aids. Usually, there are no optical zooms, hence they cannot be used for detailed detection. PTZ cameras do have optical zooms, and therefore they are better equipped to identify smaller objects like humans in the water.

A typical example of a forward-looking camera is Allied Vision Prosilica GT 1930. It is a 2 megapixel (1936 x 1216 px) camera and often there are multiple cameras installed in a row to offer a wider view to the vessel's surroundings. (Teinilä 2019)

To evaluate PTZ cameras' capabilities in detecting objects, I calculated a rough estimate of how far a small object like a human wearing a life vest could be observed. There are numerous assumptions in this calculation, and it is not meant to give an exact limit of the camera's capabilities. For example, the effect of the angle between the camera view direction and the sea surface would have to be calculated on a more detailed level. The most important assumptions made in this calculation are:

- The camera's technical details (1/2.8'' sensor with 1920 * 1080 pixel resolution, max 94 mm focal length) are based on the Reliant 640 HD model fully zoomed
- Object to detect is 0,5 * 0,5 m in size
- The minimum detectable and identifiable object size in pixels is 30 * 30 pixels (Poikonen 2019b). Poikonen mentions, that even smaller objects could be identifiable, but I have used the 30 * 30 pixel limit to compensate for the camera view angle.

With these assumptions, an object of 0,5 * 0,5 m could be identified by machine vision algorithms at the maximum distance of approximately 3 800 m (2,05 nm). As mentioned, this result requires that the camera optics are zoomed to its farthest end, which means that the area covered with one image is substantially limited. However, as the speed of a ship is rather slow, it would not be technically a problem for a modern camera + AI system to continuously scan the visible area by taking consecutive photos and processing them. (Poikonen 2019a) In practice, each single spot on each side of the vessel can be scanned multiple times as the vessel proceeds along its search pattern. This helps in finding humans in the sea as small objects can be hidden behind waves for a considerable part of the time. Taking multiple photos of the same spot at different times enhances the possibilities of finding the object.

In search operations, sweep width is an important parameter of actual searching. Sweep width is the computational value of how wide an area can be covered from one vessel in the search operation.

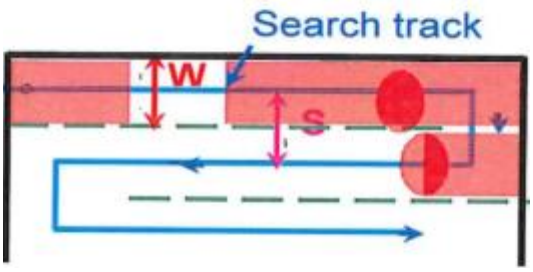

Figure 9. Sweep width and track spacing of a parallel sweep search. W=sweep width and S=track spacing (Finnish Border Guard 2014)

Sweep width is affected by multiple factors: (Finnish Border Guard 2014)

- Size of the searching vessel (physical height from sea level of the lookouts)
- Size of the searched object (person in the water, life raft, boat, etc.)
- Visibility
- Weather

According to search operation guidelines of the Finnish Coast Guard, sweep width for a merchant vessel searching for a person in the water, in good visibility is 0,7 nm. Sweep width is the whole width of the searched area, i.e. actual distance from the ship to the far end of the sweep width is half of the value. (Finnish border guard 2014)

As mentioned earlier, these calculations of camera capabilities include numerous assumptions and they cannot be considered to be exact figures of their possibilities. But based on this simple analysis, if PTZ cameras and their control and processing software can be used to continuously scan the sea area by highly zoomed images, an unmanned vessel can be at least as capable in a search operation as traditional ship with human lookouts.

6.3.4 Drones

Generally speaking, drones are more or less a synonym for Unmanned Aerial Vehicles (UAV). Civilian use cases include for example surveillance, supplying goods into difficult terrains or inspections of high structures. Military organizations use UAVs for example in surveillance or in combat situations where they could be equipped with missiles and bombs. The largest UAVs are fixed-wing vehicles, which weigh several tons and cost millions of euros. In this study, the word drone refers to small, unmanned multi-rotor aerial vehicles. Even within the area of small multi-rotor copters, there are numerous possibilities and the range of features varies significantly. Naturally, technical details also affect the price of the device.

Figure 10. Typical recreational use drone, a DJI Phantom quadcopter. (Josh Sorenson)

It could be said, that the usage of drones in professional applications is still in its development phase. There are already established applications like inspections of high-rise structures or dangerous areas in industrial facilities. However, the business is still quite new, and there are plenty of new ideas and attempts for products in the field. Only experience will tell, what kinds of products will be sensible and cost-effective in the future. In any case, there are interesting ideas for the use of drones also in the maritime environment and in MOB situations. Drones could be used for example in search operations and to bring aid to persons in water.

The flight time of rotary-wing drones is limited. Typical flight time is between 20-60 minutes, which must be considered quite short in a search operation. Fixed winged aerial vehicles are more energy-efficient and could offer longer flight times like 2 hours (Lomonaco, Trotta, Ziosi, Avila and Diaz-Rodriguez 2018), but fixed wings require quite constant and fast horizontal speed to stay airborne and their take-off and landing from a ship require purpose-built structures. When considering a situation where humans are present, an easy way to prolong the effective flight time is to quickly change the battery for a drone and then send it flying again. However, in unmanned ships, the task is more challenging. There are technical applications for wireless charging and even battery swap systems, but naturally, they require more complex technology and hence more money (Twining 2019).

There are fixed-wing drones that are also capable of vertical take-off and landing in the same way as rotary-wing drones. These kinds of hybrid drones may have flight times of over 8 hours (Twining 2019). However, they are more complex and expensive products. It is doubtful, whether they would be financially reasonable on an unmanned vessel. Rotary-wing drones could easily be employed also in other kinds of operations, like external inspections of the vessel or its surroundings.

Hence, even though drones can cover large areas in comparatively short times, the usefulness of drones in actual searching, which can take hours, is limited. However, drones could be very beneficial in shorter duration tasks like checking possibly interesting objects and validating them. When something interesting is found by other sensors (fixed cameras, lidar, radar), a drone could easily be sent to hover near the object and deliver higher quality images of it. When drones would be used only occasionally and for reasonably short intervals, one charge of their batteries could last for longer times.

6.4 Autonomy level during a search operation

A search operation is a distress operation by definition. Hence, all possible means to ensure successful operation should be utilized and the manning level of a remote control center should not be a limiting factor. However, there are practical limits of what can be done remotely. The sheer amount of data received from various sensors is huge, and practically it is not possible nor feasible for a human to process it all. It is not sensible to keep a remote operator tied to monitoring a video feed. A live video feed of high enough technical quality would also be challenging for communication services in use, especially if the communication is routed via satellites. Therefore, the data has to be processed and classified automatically in the vessel, and the remote operator should be used only to analyse and verify the findings of the vessel’s AI systems. To ensure an undelayed operation, enough manpower should be reserved for checking the detections.

7 Rescuing humans from the sea

7.1 Helping persons in the sea

IMO has published a circular (IMO, Guide to recovery techniques) about saving people from the sea, from survival craft such as lifeboats and life rafts, and from other ships. The circular is written for traditional, manned ships, but its content can and should be carefully considered also when designing unmanned vessels. A major part of the guidance could be applied to vessels without a crew. However, noting the scope definition of this study, I will omit the recovery directly from other ships.

One of the easiest ways for an unmanned vessel to assist persons in the sea is to make lee for them. Usually, accidents happen in harsh weather conditions, and survival in the sea can be troublesome even if there is good equipment, like life rafts, available. A large vessel may ease the environmental conditions substantially just by sheltering from the wind and waves. In addition to the persons in distress, also smaller SAR vessels may benefit greatly if a larger vessel shelters them. The ship is needed to get close enough for those in distress, but on the other hand far enough so that the ship will not run over them. This task may be difficult, especially when the ship and the recovery object are likely to be affected by wind, sea state and current in different ways. Manoeuvring possibilities can be affected by other recovery objects, debris, other survival craft or people in the sea. The approaching direction should be evaluated by assessing different affecting factors like wind, sea, swell and possible navigational restrictions. (IMO, guide to recovery techniques)

Persons in the sea may also be assisted by offering them buoyancy aids such as lifebuoys, lifejackets and life rafts. In addition, detection aids such as high-visibility / retro-reflective materials, lights, a SART or an EPIRB could be supplied to those in distress. In some cases, also survival aids like shelter, clothing, drink, food and first aid supplies and communications equipment would be beneficial equipment. I will get into more details of the technical possibilities in the next chapter. If there is a throwing line or equivalent that can be used to connect the vessel and the aiding equipment, it would lessen the possibility of them drifting away from the ship because of wind or other circumstances. (IMO, guide to recovery techniques)

7.2 Helping persons recover from the sea

A technically easy way to help persons in the sea by an unmanned vessel would be to launch climbing devices like rope ladders or a rescue slide to the side of the vessel. However, the practicality of such a solution is limited. When humans fall to the sea from a ship, they can be physically hurt already before they even hit the water. Also, when MOB cases happen, external conditions like the weather are usually harsh. In addition, being in the sea takes a lot of energy even from a physically fit person. Climbing from the sea to a ship, which could easily mean 10 metres of vertical climbing on a rope ladder, is physically challenging even in easy conditions. Reduced body temperature, exhaustion, and stormy conditions make it even harder. Therefore it is unlikely that persons in the sea could recover themselves to an unmanned vessel without assistance.

Getting exhausted persons from the sea to the vessel would practically require some kind of a lifting device, for example a rescue basket. Making a lifting device capable of operating without a human operator is naturally possible, but I find it unlikely that such a system would be required from unmanned ships or that shipowners would be interested in investing in them if they are not mandatory.

There are also various aspects, which should be considered when those in distress are climbing to the ship, if that could be arranged in the first place. These include the risk of persons getting hit against the side of the ship when they are on a ladder or getting hit by a life raft they have just left, when the life raft and the ship are moving unequally. (IMO, guide to recovery techniques)

If helicopters are available, they could be used only as winches, using them to hoist people from the sea to the ship, without lifting them inside the helicopter. (IMO, guide to recovery techniques) This is a method worth considering if there are a lot of people in the sea and they are in a considerably good condition physically. If the distress site is far from land, recovering people to a ship is naturally significantly faster than transferring them to an evacuation point ashore.

An aspect to consider further is to evaluate the need and possibilities to give assistance or at least give access to shelter to persons who have been recovered from the sea or survival craft by other vehicles. These may be e.g. dedicated search and rescue vessels or helicopters. At the moment existing autonomous vessels, the very few that exist, are traditional, manned ships that are equipped to enable unmanned operations. Their structures and interior areas have not been modified to optimize their use in autonomous mode. Hence we factually do not know yet, how the exterior and interior spaces of dedicated autonomous ships will be designed. If we, for example, take a look at the illustration image of an autonomous ship from Kongsberg in figure 11, it is noted that its exterior areas are significantly different from traditional ships. Even with a helicopter, it would be challenging to lower humans, especially ones that are limited in their ability to help themselves, safely to the deck. If they manage to get aboard the vessel, access to interior spaces and their suitability to recovered humans remains unanswered at this time.

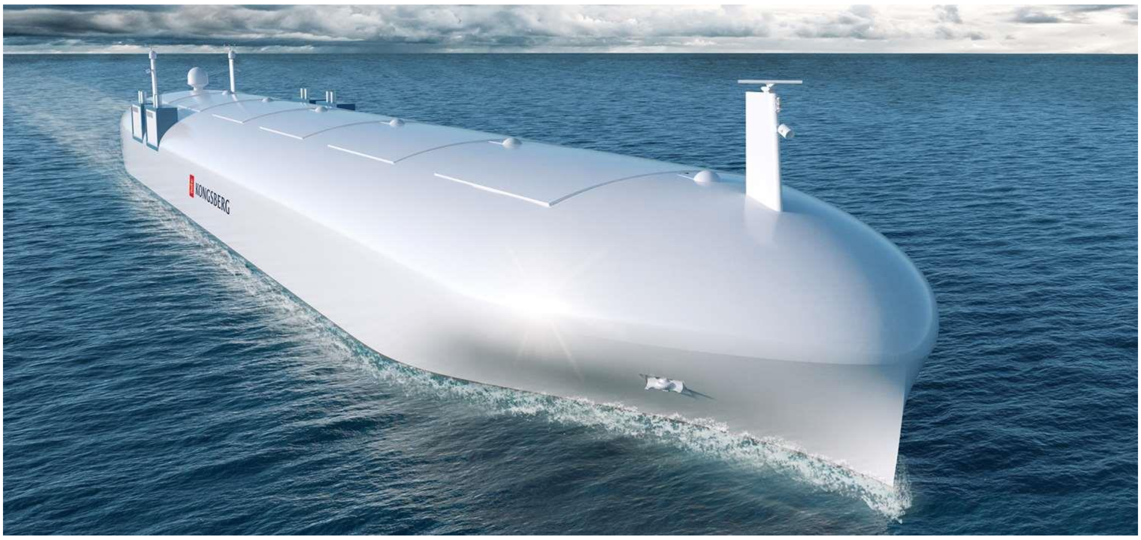

Figure 11. Demo photo of an autonomous ship. Photo Kongsberg.

7.3 Other ways of assisting the overall rescue mission

Apart from actually saving the persons in the sea, there are ways of assisting the rescue mission generally. Most of them are not strictly related to the vessel being manned or not.

An unmanned vessel can act as a communication hub in the scene. If the persons in distress are lucky, they may have handheld radios. The effective range of VHF walkie-talkies is short, and in most cases, their operation range is not sufficient for communication with a shore-based Maritime Rescue Co-ordination Centre. An unmanned vessel can help this issue by relaying the messages with its versatile communication devices including satellite communication systems.

Unmanned vessels also have good sensors for gathering information of the surroundings: weather, sea state and still and video images of the situation. This information can be crucial to the persons managing the rescue operation. If an unmanned vessel has already found the persons in distress, even if it cannot offer tangible help, it can help other ships to locate the accident scene. A large ship is significantly easier to find than a life raft or even a single person in the sea.

7.4 Organising remote control of an unmanned ship

When designing autonomous vessels and their remote control centres, handling of distress situations needs to be taken into consideration in an early phase of the development. In a normal situation, one remote operator may be in charge of several vessels, especially if the vessels operate autonomously. If a vessel encounters a distress situation, operator requirements are drastically changed. Just like aboard a vessel, a distress situation requires separate persons in charge of the tasks. Active tasks include (Aboa Mare 2011):

- Communications
- Navigation
- Keeping situational awareness of the distress situation
- Decision making
- Control of the actual recovery operation

All of these may not require a separate person, but all tasks need to be handled and the workload has to be managed carefully.

8 Life Saving Appliances to be used in MOB situations

According to my interviews of Life Saving Appliances (LSA) manufacturers and other experts, at the moment they have not made any plans of producing specific products for unmanned vessels. (Kannos 2019, Lundholm 2019) Therefore, in this chapter, I will only personally evaluate the possibilities of using present-day products in unmanned vessels.

8.1 Remote launch of traditional Life Saving Appliances

There are already today systems for remote launching of life saving appliances such as life rafts. Figure 12 shows the control panel of CM Hammar’s electronic remote operation system. It is intended for remote use within the vessel, like releasing a life raft from the bridge. But, naturally, as the system is totally electric, the system is easy to adapt also to remotely controlled vessels. If there is a person in the sea with or even without a life vest, a life raft would help substantially both in terms of actual survival and the possibilities of locating the person.

Figure 12 Hammar liferaft remote release panel. Photo CM Hammar

There are some experiences of launching a rescue slide and using it the opposite way as usual. If there are persons in the sea who are in good condition, they can use the slide and its integrated raft to climb up to the ship. However, as there will not be humans in an unmanned ship, it is unlikely that there would be a rescue slide installed in an autonomous ship. If it were, remote launching would be as easy as remote launching of a life raft.

8.2 Drones

Independent or remotely operated drones could be used for assisting people at sea. Already in 2013, there have been prototypes of a drone capable of delivering lifebuoys to persons in the sea (Kelion 2013). An inflatable lifebuoy could also be considered, like the one used in project Icarus (see chapter 8.3.1). Inflatability would save physical space aboard the drone. A powerful drone could even help a person by towing the person near the ship or a life raft. There has been also other tests and prototypes, but commercial products in the field are still difficult to find. Therefore, more detailed technical information or schedules of off-the-shelf products were not available.

8.3 Other means

There are also modern inventions that could be of help to the persons in the sea. A few manufacturers produce self-propelled lifebuoys. They are supposed to be thrown into the water and steered remotely near the person in the sea by using its electrically powered propulsion. They are made to be controlled by a person seeing the casualty, not from a distance. (uSafe, OceanAlpha Group) Possibilities of controlling them from a remote operating centre could be evaluated.

8.3.1 Unmanned Search and Rescue vessel development projects

There are some projects which have researched and developed unmanned vessels for searching and rescuing persons in the water. These projects have not concentrated on operations from unmanned ships, rather on operations near shore like harbour areas. Still, they have interesting findings and the principal ideas used could be evaluated also regarding autonomous vessels.

Project Icarus is a European project aiming to find new ways of using unmanned devices to be used in search and rescue missions. The project scope includes operations in the air, at sea and on the terrain. There are over 20 partners in the project from countries like Belgium, Portugal, Italy, France, and Germany. (Project Icarus)

Project Icarus has tested three different vessels to be used in man over board situations, of which two are developed to be used together. The largest is a 7-metre rigid hull inflatable boat, equipped with radar, lidar, weather sensors and daylight and thermal cameras. It is designed to deliver a smaller device to the vicinity of a person in the water. The smaller device is called an Unmanned capsule (UCAP). It is 1,45 m long vessel with an electric motor and 15 kg payload capacity. The UCAP carries an uninflated life raft that can be inflated remotely near the person(s) in distress. (Matos et al. 2017)

Figure 13. Project Icarus vessel with two UCAPs on their launching pads. (Icarus)

Project AGaPaS has introduced another kind of an unmanned search and rescue vessel, which is designed to be used e.g. aboard offshore platforms. It is based on a twin-hull rescue vessel, which navigates by the Galileo GNSS. The system is launched by an automated system that identifies a person falling to the water. This system requires persons to wear a special life vest that is equipped with an automatically activating AIS transmitter. The rescue vessel navigates near the position of the person in the sea and autonomously stops within a safety margin of 5 or 10 metres. After that, it is remotely but manually steered to pick the person from the sea by a rescue basket between its hulls. Then the vessel returns to its parent ship and both the vessel and the person are picked up by specially designed devices. (Kurowski, Korte, Lampe 2012)

Figure 14. Project AGaPaS rescue vessel (Project AGaPaS)

Both these projects are interesting, but also face some problems when considering their usability in unmanned ships. Project Icarus vessels are designed to be on water constantly, there are no planned means of getting the vessels to the sea and back. Also, two separate vessels in addition to the actual life raft form quite a complicated system. Project AGaPaS vessel is planned to be a free-fall boat, hence it would be easier to launch. But its navigation is totally based on AIS signal from the life vest of the person in the water. Therefore it would be more suitable to offshore platforms and other places where all persons can be required to wear the vest. Hence it cannot be considered as the only means of rescuing persons in a merchant vessel.

9 Conclusions

My original research question is "How should and how can unmanned vessels offer assistance for persons in distress in Man Over Board (MOB) situations?" As discussed in earlier chapters, there are ways and most of them are not difficult to implement. When they will be implemented? I think it is not a question of distress handling, but other areas of development.

Unmanned vessels are still in their early development phase. Practically everything we have seen so far is prototypes and demos. They have proved that the technology already exists, especially for navigation. New solutions like PTZ cameras, LIDARs and microphone arrays bring new data of the vessel's surroundings and offer vital information for computerized systems or remote operators for navigational decision-making. These technologies could also be utilised to enhance the safety of manned ships.

Receiving of distress signals and identification of distress situations can be achieved by the same technical equipment that will be deployed aboard unmanned ships for navigation. Data processing software has to be developed, but most likely there will not be a need for dedicated technical devices only for distress recognition. Further technical research is needed to evaluate the possibilities of cameras, microphone arrays and lidars in identifying distress signals and search operations.

Life saving appliances (LSA) have not yet received much attention in autonomous ship development. It is quite logical, as they are not at the core of the field. Surely all ship owners recognize the importance of safety and they want to keep their crews and ships safe. But still, it is the regulation that defines the types and amounts of LSA to be carried on board. As all LSA requires frequent servicing and regular renewals, they are usually kept to the minimum level defined by regulation. As there are not yet any regulations about the LSA of unmanned ships, there are not any specific applications for unmanned vessels either.

The amount of LSA equipment has so far been dictated by the number of persons onboard the ship. If a ship is in a position to assist people from other ships, the crew of the assisting ship is supposed to use everything usable they have on board, including the LSA. If and when unmanned ships exist, it is a vital question whether there should be LSA to be able to assist others, even though there are no persons aboard own ship. As discussed earlier, applicable technical solutions already exist or they can be easily developed from present-day equipment. But if they are not required from an unmanned ship, they will likely not be bought from the manufacturers. Regulatory authorities have started their work in defining the requirements of autonomous vessels. However, they have started their work, understandably, mostly from a navigational point of view.

My research question covers a wide area of operations and there are various technical systems that can be used in distress situations. Autonomous vessels can be made to identify distress signals. However, some of them will be challenging to detect, as the regulations allow very different ways of expressing a distress. Distress-related communication can be operated with the same technical solutions that are used for navigational communication. For searching, an unmanned vessel with a highly developed detection systems, including cameras and lidars can be at least as effective as traditional ships.

Actually rescuing persons from the sea is a difficult question. Vessels specifically built to be unmanned will probably not have suitable spaces for rescued persons or even suitable ways of entering the ship. But otherwise there are various ways of helping persons in the sea, especially if remotely lauchable life-saving appliances will be developed and deployed. This could give more time for the persons in the sea and other vessels to enter the site and rescue them. To express my findings very shortly, I would say that unmanned vessels can be capable of identifying distress situations, searching for persons in the sea and assisting them, but some technical limitations exist.

The future of shipping is, inevitably, a world of less manned or unmanned ships. Probably it is slightly further than the most optimistic commentators today believe. But it is there, sooner or later. If there comes a time that I fall overboard from my own boat, I hope the nearest ship is able to help me, even if it is not controlled by a human, but by algorithms.

References

Aboa Mare 2011. Course material from Bridge Team Training course organised for Neste Shipping.

Al-Sheikh B., Elshebli A., Al-Assaf A., Almashaqbeh S., Alrawabdeh W., Al-Tahat A., Abu baker A., Batayneh J., Jabra F. 2013: Sound Source Direction Estimation in Horizontal Plane Using Microphone Array, online, retrieved 26.10.2019, https://www.researchgate.net/publication/269689001_Sound_Source_Direction_Estimation_in_Horizontal_Plane_Using_Microphone_Array

CM Hammar, Hammar ERRS (Electronic Remote Release System) product info document, online, retrieved 3.4.2019, https://www.cmhammar.com/wp-content/uploads/ERRS_product_information.pdf

Danish Maritime authority, 2017, Analysis Of Regulatory Barriers To The Use Of Autonomous Ships, https://www.dma.dk/Documents/Publikationer/Analysis%20of%20Regulatory%20Barriers%20to%20the%20Use%20of%20Autonomous%20Ships.pdf

Dix M., Abd-Elrahman A., Dewitt B. and Nash L. 2012. Accuracy Evaluation of Terrestrial LIDAR and Multibeam Sonar Systems Mounted on a Survey Vessel. In *Journal of Surveying Engineering* 138 (4), 203 -213.

egmdss, The basis of MF/HF radio, online, retrieved 24.6.2019, https://www.egmdss.com/gmdss-courses/mod/resource/view.php?id=2262

Finnish Border Guard 2014. SAR pictures and tables. Received by email from Tommi Karppi, Finnish border guard.

Goh L-B, Yip T.L. 2014, A Way Forward for Ship Classification and Technical Services. In *The Asian Journal of Shipping and Logistics* 30 (1), 51-74.

van Graas, F. 2013. Inertial Navigation Systems. Presentation material on *Workshop on GNSS Data Application to Low Latitude Ionospheric Research*. Online, retrieved 11.11.2019. http%3A%2F%2Findico.ictp.it%2Fevent%2Fa12180%2Fsession%2F23%2Fcontribution%2F14%2Fmaterial%2F0%2F0.pdf&usg=AOvVaw28mW4z8KXUOAb1eqZp-XlR

ILO, International Labour Organization, MLC, Maritime Labour Convention, accessed through Regs4Ships service offered by Novia UAS library

IMO, Brief history of IMO, online, retrieved 3.6.2019, http://www.imo.org/en/About/HistoryOfIMO/Pages/Default.aspx

IMO, COLREG, Convention on the International Regulations for Preventing Collisions at Sea, accessed through Regs4Ships service offered by Novia UAS library

IMO, Guidelines on maritime cyber risk management, MSC-FAL.1/Circ.3, accessed through Regs4Ships service offered by Novia UAS library

IMO, Guide to recovery techniques MSC.1/Circ.1182/Rev.1 "Guide to recovery techniques", accessed through Regs4Ships service offered by Novia UAS library

IMO, International Convention on Maritime Search and Rescue, accessed through Regs4Ships service offered by Novia UAS library

IMO, LSA Code, Life Saving Appliance Code, accessed through Regs4Ships service offered by Novia UAS library

IMO, MARPOL, International Convention for the Prevention of Pollution from Ships, accessed through Regs4Ships service offered by Novia UAS library

IMO, SOLAS, The International Convention for the Safety of Life at Sea, accessed through Regs4Ships service offered by Novia UAS library

IMO, STCW, The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, accessed through Regs4Ships service offered by Novia UAS library

Kannos, S. Safety Surveyor, Bureau Veritas Finland. Email conversation 26.8.2019.

Kasum J., Cvjetkovic S. & Stanivuk T 2013. Dynamic Model for Calculating the VHF Radio Horizon at Sea. Online, retrieved 11.11.2019. https://hrcak.srce.hr/file/164620.

Kelion L. 2013. Iran develops sea rescue drone prototype in Tehran. BBC News article, online, retrieved 11.11.2019. https://www.bbc.com/news/technology-24929924

Komianos, A., 2018, The Autonomous Shipping Era. Operational, Regulatory, and Quality Challenges. In *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, 12 (2), 335-348.

Kongsberg, 200 years of determination, online, retrieved 25.4.2019, https://www.kongsberg.com/who-we-are/200-years-of-excellence/

Kurowski, M., Korte, H., Lampe, B., 2012: AGaPaS - a new approach for Search-and-Rescue-Operations at sea. In *IFAC Proceedings Volumes*, 45 (27), 73-78.

Liikenne- ja viestintäministeriö, Remote pilotage allowed, press release, online, retrieved 3.8.2019, https://www.lvm.fi/-/remote-pilotage-allowed-995692

Liukkonen S. (w.y.), Role of classification society in arctic shipping, online, retrieved 25.8.2019, https://www.environment.fi/download/noname/%7BE8AA2BDC-10AF-41BD-AA68-EE0F5E9BBD59%7D/108823

Lomonaco V., Trotta A., Ziosi M., Avila J. and Diaz-Rodriguez N. 2018. Intelligent Drone Swarm for Search and Rescue Operations at Sea. Online, retrieved 11.11.2019. https://arxiv.org/pdf/1811.05291

Lundholm M. Technical sales manager, CM Hammar. Email conversation 17.4.2019.

Lusto L. 2013. Dynamic Positioning basic course material. Aboa Mare.

Matika D., Grzan M. 2013, Optimizing Marine Radar Performance in Enhancing the Safety of Navigation. Online, retrieved 10.11.2019, https://hrcak.srce.hr/file/162587

Matos A., Silva E., Almeida J., Martins A., Ferreira H., Ferreira B., Alves J., Dias A., Fioravanti S., Bertin D. and Lobo V. 2017: Unmanned Maritime Systems for Search and Rescue. From *Search and Rescue Robotics - From Theory to Practice*. Online, retrieved 8.11.2019. https://www.intechopen.com/books/search-and-rescue-robotics-from-theory-to-practice/unmanned-maritime-systems-for-search-and-rescue

Nielsen, M. 2015. Neural networks and deep learning. Determination Press.

OceanAlpha Group Ltd. Dolphin 1 smart lifebuoy product web page, retrieved 23.11.2019. https://www.oceanalpha.com/product-item/dolphin1/

Opticsplanet.com, PTZ camera product page, online, retrieved 19.6.2019, https://www.opticsplanet.com/nvts-reliant-640hd-gyro-stabilized-thermal-and-hd-visible-camera-system-for-mari.html

Poikonen, J. 2019a. AI development lead, Kongsberg Maritime Finland, personal conversation on 12.4.2019.

Poikonen, J. 2019b. Video recording of lecture "Sensors and signal processing in remote and autonomous vessels", 16.5.2019.

Project Icarus, Project Overview, online, retrieved 8.11.2019, http://www.fp7-icarus.eu/project-overview

Skolnik, Merrill I., History of radar, Encyclopedia Britannica, online, retrieved 7.5.2019, https://www.britannica.com/technology/radar/History-of-radar

Soloviev V., Specifics of using lidar and ir-camera for detecting obstacles on maritime vessels, 2019, Novia UAS.

Teinilä, A. Technical product manager, Kongsberg Maritime Finland. Email conversation April 2019.

Thegpsstore.com, PTZ camera product page, online, retrieved 19.6.2019, https://www.thegpsstore.com/FLIR-M400-Thermal-Camera-with-LED-Spotlight-P4484.aspx

Timonen R., presentation on Novia UAS's Autonomous Maritime Operations course Introduction to Marine Operations 16.3.2018

Tutorialspoint.com, Artificial intelligence tutorial. Online, retrieved 11.11.2019. https://www.tutorialspoint.com/artificial_intelligence/artificial_intelligence_quick_guide.htm

Twining D., Chief Operating Officer, Planck Aerosystems. Email conversation 16.7.2019.

United Nations, United Nations Convention on the Law of the Sea, accessed through Regs4Ships service offered by Novia UAS library

uSafe, uSafe smart lifebuoy product web page, retrieved 23.11.2019. https://usafe-global.com/

Utkin A. B., Piedadea F., Beixigaa V., Motaa P. & Lousãa P. 2014. Scalable lidar technique for fire detection, online, retrieved 17.10.2019, https://www.researchgate.net/publication/269313375_Scalable_lidar_technique_for_fire_detection

Wikipedia, Classification society, online, retrieved 18.6.2019, https://en.wikipedia.org/wiki/Classification_society

Wikipedia, Ship motions, online, retrieved 12.6.2019, https://en.wikipedia.org/wiki/Ship_motions

Wikipedia, Marine VHF Radio, online, retrieved 24.6.2019, https://en.wikipedia.org/wiki/Marine_VHF_radio

Yara, Yara Birkeland press kit, online, retrieved 28.6.2019, https://www.yara.com/news-and-media/press-kits/yara-birkeland-press-kit/