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Smart ships – autonomous or remote controlled?

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Abstract

Nowadays the time of the smart ship is at the door. This is the result of the new, Fourth Industrial Revolution that is fast approaching. The Fourth Industrial Revolution is the result of an enormous increase in information being acquired, stored, processed, and transmitted The effect of this has been smart domestic appliances, robots, telephones, production machines, and other objects, visible everywhere in everyday life. There are obviously many advantages to the introduction of smart vehicles and attempts to introduce smart cars into traffic are already in progress. Smart ships are also currently attracting much attention. RINA organized three international conferences on this subject in a short space of time. An attempt to send a fully autonomous experimental ship across the Atlantic is already in progress. Although technically it would be possible to already build smart ships, there are many practical problems to be solved before they could be put into operation. Apart from purely technical problems there are problems of the economy, safety, security, and environmental protection as well as legal and political problems. There are also important problems regarding employment, training, and human relations. Questions are now being asked as to whether smart ships would be fully autonomous, remote controlled, or manned with a skeleton crew, and who will ultimately be responsible for the ship in question and how smart ships will affect sea traffic. Some of these problems have been discussed in this paper.

Introduction

Recently the introduction of smart products in almost all aspects of life has been clearly visible. The possibility of the introduction of smart ships in sea transport has also been widely discussed. The idea of building smart ships is not new; Bertram (Bertram, 2016) provided a short history of the development of the idea of smart ships and pointed out that this idea was proposed at the end of the nineteenth century.

Currently the global problem of overcapacity in shipping is clearly visible. This, according to the general opinion of the shipping world, cannot be solved within a short time frame. Global newbuild deliveries plummeted to just 18 million gross tonnes last year from over 83 million gross tonnes in 2015, which demonstrated that the crisis is important. In China almost half of the 1600 existing shipyards face closure. The contradiction between oversupply and demand will for certain last for a long time and will have an important impact on the ship manufacturing business. But such periods of recession are also times when all stakeholders are inclined to invest in innovations preparing for a future period of prosperity. That is why all around the shipping world calls for smart ships, smart manufacturing, and smart operation of ships is being heard.

Some years ago this call would have gone in vain because the technical possibilities did not exist. Now we are witnessing the coming of the Fourth Industrial Revolution. The Fourth Industrial Revolution (4IR) is likely to occur around the middle of the twenty-first century and will cause the world to become intelligent on the basis of an enormous increase in computing power.

The result of this is that the capability of building and operating of a smart ship is already in our hands. It is anticipated that by the year 2025 smart ships will regularly operate on international routes. The first autonomous experimental cargo ship will presumably be ready by the end of this decade.

Concept of the smart ship

It is important to define what is understood by the term smart ship. According to the general understanding the smart ship is a ship that is either:
- remote controlled or
- fully autonomous.

In both cases the ship could be unmanned or manned with a skeleton crew. Of course there may be many different solutions adopted in both cases with regard, for example, to the number and qualification of the crew (if any) or the method of remote control, either from the shore station or from an accompanying ship (master-slave concept, where the "master ship" may remotely control several accompanying "slave ships"). But even with fully autonomous ships humans will always be involved in some way or other to safely operate such ships.

If the ship is remotely controlled from a shore station or from the other ship we have the concept of the "shore captain" who will be controlling the ship via satellite and the control system will be transferred to shore or to another ship, where there is a navigation crew similar to the crew normally present on board, but assigned to several ships. If the ship is fully autonomous, then we have the concept of the "computer captain" and the ship will be equipped with a powerful computer and software that will take all the decisions themselves using artificial intelligence (Bertram, 2016). Certainly such a ship must be observed from the shore station, but the decision to override the ship's systems could probably be taken only in an emergency. In practice it is possible that a mixture of both systems may be used.

Recently many "smart" installations have been installed on board modern ships for different purposes such as making the operation of such ships safer and easier, for example, automatic mooring systems, automatic collision avoidance systems and similar, but such ships are not called smart.

According to the general opinion of technicians, the technology needed to construct and operate smart ships is already available or, at least, in the final stages of development. This applies to collecting, processing, and transmitting the data from sensors and appliances on board the ship and transmitting it to the shore station, to a unified bridge for remote-controlled unmanned ships, to effective autonomous collision avoidance systems, and to advanced sensor technology. In fact everything that is needed to run fully autonomous or remote controlled ships is already available.

Several advanced concepts for smart ships are currently under development, the leading company in this area being Rolls-Royce. The concept of a low cost container ship for the Baltic Sea, shown in Figure 1, was recently presented by Oscar Levander, head of the company (Levander, 2017).

Figure 1. Concept of low-cost smart container ship for the Baltic Sea (Levander, 2017)

Big data and the Internet of Things (IoT)

A smart ship will be equipped with numerous sensors monitoring the ship and its functions, as well as the close environment and the weather conditions in the area of operation and the weather forecast. DNVGL estimates that around 15,000 to 20,000 different sensors will be installed on board smart ships, which will be constantly monitoring the:
- Navigation systems,
- Safety systems,
- Machinery and automation,
- Cargo
- Environment.

As the price of sensors has reduced rapidly during the last few years (the average sensor cost is forecast to fall to $0.38 in 2020 from $1.30 in 2004), therefore the possibility to increase the number of sensors onboard is almost unlimited (DNVGL, 2016). There have recently been advertised numerous examples of sensors for constantly monitoring almost every part of a ship's hull and parts of its machinery because it is essential for a smart ship to discover any irregularity before a failure occurs. This has been shown in an illustrative way in Figure 2 (The Naval Architect, 2017c).

First of all autonomous or remote controlled ships need to assemble, process, and transmit enormous amount of data collected from thousands of sensors. This is defined as "Big Data". Thousands of sensors may generate up to $36 \cdot 10^7$ and even more separate data points.

"*Big Data* is the term that describes large volumes of high velocity complex and variable data that require advanced techniques and technologies to enable the capture, storage distribution, management and analysis of the information" (This very relevant definition was proposed by Tech America Foundation's Federal Big Data Commission, 2012).

Figure 2. Pictorial presentation of the distribution of sensors on board a smart ship (The Naval Architect, 2017c)

The capacity of data transfer from ships has increased rapidly during the last few years, reaching about 12 Gbps in 2016, depending on the band used, according to recent information (DNVGL, 2016). The newly developed Big Data platform has been designed to cleanse and manage the data collected from a number of sensors constantly monitoring the ship. In spite of the fact that processing the data on board can considerably reduce the amount of data that needs to be transmitted to the shore station, this amount still remains large. However it was actually shown that processing and transmitting this amount of data could be done as cheaply as 1$ per day (Germanischer Lloyd, 2013), therefore there are no practical difficulties to do so. The largest classification society, DNVGL, admitted that actually they were taken by surprise by this.

Figure 3. Infographic of data transfer from onboard to the shore office (The Naval Architect, 2017d)

The important development that characterized the Fourth Industrial Revolution is the now widely discussed Internet of Things (IoT). The IoT is difficult to define, but it seems so important with the development being applicable to the shipping industry that a special supplement was issued in the Naval Architect this year where many of the most important people representing the shipping industry tried to define the IoT and discussed its impact on the marine industry (The Naval Architect, 2017a). Simply the IoT is a renewed approach to the ultimate data application and its exploitation.

The IoT technology offers a means of combining the data from the already existing systems and sensors on board, plus additional intelligent sensors if necessary, in an intelligent system and then send it via satellite to the cloud and to the shore office (Figure 3) . This could be applicable to conventional ships, but will be essential for smart ships in the future (The Naval Architect, 2017d).

The above considerations show that the technology to build smart ships is actually already available or at least is under development, therefore there are no technical factors that would prevent the introduction of smart ships.

Collision avoidance systems and bridge layout

The creation of collision and grounding avoidance systems is a nautical task of predominant importance. An autonomous ship collision avoidance system may use the same information sources as in existing ships, e.g. radar transponders and electronic charts, but there will be no vision or hearing input from the crew members on the bridge. In this area, however, there is a rapidly developing technology that compensates for vision and hearing

The newly developed Intelligent Awareness System made by Rolls Royce that has already been installed in the 65 meter ferry boat Stella owned by Finferries, is for vessels of any type and is an example of new technology that actually makes it possible to run smart ships (The Naval Architect, 2017b). As the company stated: "The system functions as an advisory tool that empowers decision makers with a greater understanding of a ship's surrounding environment. Its application is particularly aimed at the safe navigation of busy ports, for example a large cruise ship navigating the port of Shanghai, or operating in challenging environments, such as dense fog experienced in Houston shipping channels".

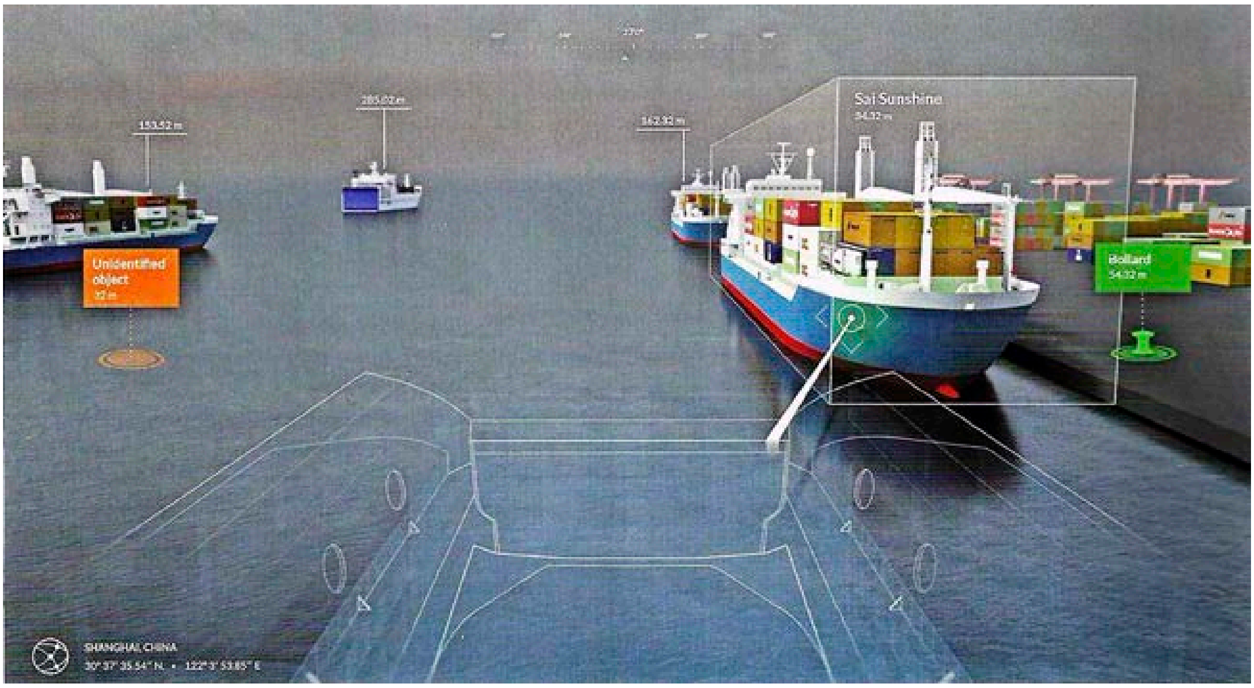

Figure 4. Rolls Royce's intelligent awareness bridge system (The Naval Architect, 2017b)

The system offers a unique birds-eye view of the environment including the bottom profile, as shown in Figure 4. Technologies such as machine vision, automatic ship identification, high definition cameras, laser-based systems (LIDAR), RADAR and AIS data, and enhanced ECDIS automatic avoidance path planning are already available or under development. All the facilities will be incorporated into one system on the bridge. Furthermore it is envisaged that augmented reality will also be used.

In the smart ship all the parameters that are currently recorded or observed on the bridge must be processed and sent to the shore station. It is essential that they must be transmitted continuously without any break or interruption and because of safety reasons they should be duplicated. The ship's Voyage Data Record (VDR) is where data from all the sensors are stored on board. This has been compulsory for all ships since the SOLAS 2002 amendment. But in smart ships the VDR will collect Big Data from several thousands of sensors. However, information provided by the sensors cannot be managed properly; therefore special dedicated systems for storing and processing the data must be developed. The data will then be stored in the cloud for further access by the shore office. This amount of data cannot be effectively observed at the shore station directly. There are already systems such as Kyma Web Solutions (DNVGL, 2016) for example, that enables ship owners in the shore office to manage and analyse this data, ultimately displaying them every fifteen seconds (the present standard). Similar systems will be used in smart ships, however the amount of data will be considerably larger. In fully autonomous or remote controlled ships the complete situational awareness and all pieces of the arrangement of the bridge must be recreated at an artificial bridge in the shore station. As pointed out by Levander (Levander, 2016) this would not replicate the real ship's bridge, but create a virtual environment creating an even better 360° view, and will also show close proximity situations, such as a pilot coming onboard and similar operations.

Maritime law and human factors

Smart ships may create a great challenge to current maritime law. This subject was discussed thoroughly in the paper by Balls (Balls, 2016). It appears that commercial operation of unmanned or remotely controlled ships may require the amendment of almost all international conventions related to marine transport. In his paper Balls thoroughly discussed which of these regulations and conventions may need to be amended.

Initially smart ships may operate with an exemption certificate as novel ships and the proper Administration may also require their temporary requirements to be satisfied. Equivalency rules in existing conventions may also be applicable in some cases. But the definition of novel ship may only be applied during the first period when few smart ships will operate. When they will constitute a large proportion of the fleet this solution will be not possible.

In all legal instruments a “ship” is defined as a manned object. Manned ships with some autonomous systems will fall under this definition. However it is clear that unmanned ships do not. This old principle, with regard to shipping, was based on the assumption that full responsibility for the ship at sea lies with the master who is onboard and is “the first after God”. This view has already been partially challenged with the development of on line communication with the ship owner’s office on shore that may recommend the master to take certain actions, although those actions at present mainly concern commercial affairs not affecting the technical operation of the ship which still remains the sole responsibility of the master. But still full responsibility for the operation of the ship at sea is in hands of the master.

Operation of autonomous ships controlled from the shore station put full responsibility for the ship at sea in the hands of this station. It is, however, questionable as to whether the man in control at the shore office could be assessed as “the captain”. This would be the most important issue; acceptance of this change by the conservative shipping world would need to overcome legal and emotional barriers.

Emotional barriers against the introduction of autonomous ships should not to be dismissed lightly. As said before, the shipping world is rather conservative and the seafaring profession has high self-esteem. Abandoning the position of ship master and replacing it with an anonymous controller in the shore control station may be considered as devaluing the profession. This may induce negative feelings against the introduction of unmanned ships. Replacing active ship crews in ships with a minimal crew for inspections and emergency, working boring shifts, will also devalue the attractiveness of the profession.

An important issue is also the present regulation in respect to the manning of ships in the international STCW Convention (Standards of Training, Certification and Watchkeeping) will need to be entirely changed, which may create significant protests from the trade unions.

Another problem that will not be easily solved is how to implement the current regulations on search and rescue operations at sea for smart ships. According to current regulations all ships are obliged to participate in search operations at sea and rescue people in distress. This certainly could not be entirely applicable to autonomous ships.

Safety and security

Safety and security are other matters that may affect the possibility of the introduction of smart ships into practical operation. The most important safety problems are safety against adverse effects of the sea (intact stability), safety against collisions and groundings that may cause damage to the hull, and safety against fire (fire protection).

The safety measures against the capsizing of intact ships for smart ships are not different from the measures applicable to conventional vessels. The intact stability of a ship may be impaired in adverse weather conditions. Generally ships should avoid dangerous situations at sea where there is a possibility of resonance or parametric resonance with oncoming waves that may result in extreme roll angles. There are also some other situations in rough seas to be avoided, for example broaching and surf riding. However ships are already usually provided with instructions to the master to avoid those situations that could be achieved by changing speed or heading or both. On board smart ships this could be done automatically without problems as the environment will be constantly observed and recorded.

However situations may arise at sea that are almost impossible to forecast. One of these situations is a tsunami. Tsunamis are rare events and usually are not dangerous for ships on the open sea, because the wave created by an earthquake in the open sea is extremely long and only becomes dangerous when approaching the shoreline. However another rare event that may happen in the open sea is a freak wave. Freak waves, although extremely rare, may reach a height of up to forty metres or even more in certain conditions and may cause a ship to founder. Freak waves are unpredictable, they appear at random and it would be rather impossible to develop an automatic avoidance system or mitigate the consequences of this phenomenon. The positive fact is that the probability of meeting a freak wave is extremely small.

The same applies to fire protection. Fire protection currently is assured with restrictions in the use of flammable materials as well as ships being equipped with automatic fire fighting appliances such as automatic sprinkler systems etc. The same will be applicable to smart ships. Also with the use of fire fighting ships there would be no difference whether the ship is conventional or unmanned. A problem may be present in passenger ships where evacuation situations may occur and evacuation operations require human command. But actually there have been no proposals to introduce unmanned passenger ships, apart from river crossing ferries.

The most serious problem with smart ships may be security against pirate attack. It could be physical attack such as happens now in some parts of the world, but, more importantly electronic attack, where pirate-hackers may take control of a ship that is unmanned or manned only with a small crew. It seems that a physical attack on an unmanned ship is not very realistic, because an unmanned ship could be constructed without any easily accessible openings and in such ships pirates actually have very limited ways to enter. Even if they enter, the automatic system may shut down all facilities and it is very improbable that the pirates will have tugs to tow a disabled ship to their safe harbour.

Another case would be when pirates take over control of the ship electronically. In such cases the ship could be directed to certain harbours, opened, unloaded, and expensive goods removed. Ransom in such cases may be not the prime purpose of the attack.

Economic considerations

There is the question as to whether smart ships will be economically profitable. Obviously the cost of the crew in fully autonomous ships would be much lower, as well as a semi-autonomous ship where only a skeleton crew consisting of three- four persons would be onboard. Also the removal of crew accommodations and the connected facilities will reduce the building cost and this space could be used to carry more cargo. The entire large superstructure and deckhouse will be not necessary and the reduced air resistance could result in fuel consumption savings. Levander (Levander, 2016) predicted that this could result in about 12 to 15 per cent fuel saving for a 40,000 dwt bulk carrier. Also the consequence of lower daily operating costs will result in a lower average speed which will bring further savings in fuel consumption.

Certainly the required installation of an additional number of expensive appliances as well as redundant machinery will drive up the building cost, but automatization, communication, and an increased number of sensors will be used in all ships in the future. Levander thought that the difference in the cost between manned and unmanned ships will be not large. At present, however, it is very difficult to predict whether autonomous or remote controlled ships will be economically viable because there are no ships of this kind in operation, and in the future many factors, such as insurance cost, salaries, etc, may contribute to the total cost of transport in a different way to how it is today.

Prospects for the future

It is important to have some vision about what types of ships may operate as smart in the future. There are already some types of autonomous vehicles in operation, such as underwater or surface robots used for different purposes, but they are not defined as ships.

Apart from special purpose ships and warships, all other ships are either cargo ships or passenger ships. It is quite obvious, that passenger ships cannot be fully autonomous or remote controlled. Such ships sometimes carry thousands of passengers, and the corresponding number of hotel staff and crew members. Passengers must be supervised all the time, their needs should be taken into account and their behaviour, that sometimes is unpredictable, controlled. Although autopilots and similar arrangements may be installed on board, the captain should exercise flexibility in piloting his ship taking into account the current situation on board, in particular having regard to human relations. Apart from being the captain and piloting his ship in high seas he is also the general manager of a very large hotel, having under his command his crew members and also a number of hotel staff. A "computer captain" cannot do this.

However, according to the definition included in the SOLAS convention, a passenger ship is any ship carrying more than 12 passengers. The SOLAS convention only applies, however, to international voyages. Therefore small ferries taking passengers across narrow waters could be handled without crew, controlled only by a shore station. Such ships are the first candidates for conversion to smart ships and certain attempts to operate such ferries in national waters are already being undertaken.

The area where smart ships may be possibly used is the transport of goods, presumably in bulk or in containers. Therefore it may be assumed that in the future container ships, tankers, and bulk carriers may be the best candidates to be constructed as "smart" ships.

It also seems that future smart ships will most likely be operated with a small skeleton crew on board. This certainly will reduce risk in case a failure happens on board during the voyage. If something happens to a fully autonomous unmanned ship, the ship certainly could be stopped, but then a repair crew will need to be brought by helicopter or rescue ship and that may be a costly enterprise if the failure happens in a remote area. Moreover a freely drifting ship may be a dangerous object without control.

There is also the question of when we may expect to meet smart ships in sea lanes. All predictions estimate that it may happen in the third or fourth decade of this century. Although the first experimental smart ship, as promised by joint DNVGL and Rolls Royce project, may hit the water by the end of this decade the regular operation of such ships may take a longer time.

Smart shipping would be a major technological revolution in shipping on the scale of the introduction of the steam engine in the ninetieth century, and containerisation in the twentieth century. In both cases the complete reorganisation of the shipping industry was necessary and it took almost fifty years to do so. Stopford (Stopford, 2015) said that revolution needs decades of painful development and risk-taking evolution. It is also necessary to take into account that shipping is rather conservative world. Ships are supposed to serve a long time and the replacement of the whole fleet will take decades.

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