

Leveraging Maritime Automation for Efficient and Sustainable Port Maintenance

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Abstract. Maritime traffic is undergoing a transformation from on-board navigation towards highly automated, remotely controlled operations. Given the constrained and well-defined area of operation, port maintenance is a predestined use case for a highly automated vessel. In combination with alternative driving systems, maritime automation technologies hold a great potential of increasing efficiency and sustainability in port maintenance. To achieve this goal, this paper describes the concept of a highly automated hopper-dredger for port maintenance, proposing assistance systems for navigation in different automation stages according to the definition of the International Maritime Organization (IMO). Commercial off-the-shelf technologies are employed to realize assistance systems, transferring also solutions to the maritime environment that are already established in other industrial domains. A method for Verification and Validation of the proposed concept is presented and applied in sea trials with a research vessel. Regulatory aspects are considered as well. The study concludes that a remotely operated dredger can be realized based on State-of-the-Art sensor systems, enabling sustainable, efficient and cost-saving port maintenance. Based on the presented results, clear recommendations are derived for automation concepts and suitable technologies at different IMO automation level. The need for a legal framework to utilize the potential of the proposed concept in regular operations is pointed out.

1. Introduction

In recent years, considerable progress has been made in enhancing automated vessel navigation. Remotely controlled inland ships operated by the Belgian Company Seafar on the Rhine, the autonomous passenger ferries milliAmpere2 in Trondheim and MF Estelle in Stockholm as well as the autonomous cargo ship Yara Birkeland are prominent examples. Automated navigation addresses the challenge of skilled labour shortage in shipping. When operating or supervising a ship from a remote operation center (ROC), nautical staff is able to organize work schedules more flexible and obey regular working hours. Thus, jobs in the nautical sector become more attractive for junior staff. Additionally, automated ships can be operated 24/7 without staff being stuck on board. They can easily change shifts and leave after their work is done.

Despite these various benefits and a growing number of pilot projects, the development of Verification and Validation methods to ensure system safety remains a major challenge in unlocking the full potential of Maritime Autonomous Surface Ships (MASS) for regular operations. A certification process and the test methods required for it need to be introduced. As a first step towards this goal, the International Maritime Organization (IMO) has published a regulatory scoping exercise for MASS in 2021 [1]. Therein, four degrees of automation are defined: Degree I describes a ship that is operated by on-board crew, with assistance systems for decision support and potentially some automated processes. Degree II describes a remotely controlled ship with seafarers on board ready to take control and operate on-board systems. In Degree III, the ship is completely remotely controlled without crew aboard, but requires supervision and intervention by a remote control operator. Degree IV describes fully autonomous operations, i.e. the ship is able to determine and execute actions without human intervention.

The conditions under which a MASS is supposed to operate safely have a considerable impact on the design and validation processes [2]. Thus, a clearly constrained operating area is beneficial for conducting a case study designing a MASS and proposing test methods for verification and validation. The Use Case of an automated dredger for port maintenance provides such a constrained operating area. Additionally, automated navigation is highly beneficial in this context, given that dredging operations are time-consuming and have to be conducted regularly to ensure a safe navigation of cargo vessels. In combination with alternatives to conventional dredging, a higher economic and ecologic efficiency in port maintenance can be achieved. Conventional dredging has a negative impact on the environment and is cost-intensive [3]. To address these shortcomings, in the port of Emden, a special recirculation process is applied that exposes silt to oxygen to reduce its density and prevent it from settling on the ground [4]. The water depth is measured regularly by a service vessel with a sonar. Based on these data, a plan for recirculation is derived that determines which areas of the harbour the hopper dredger has to maintain in the respective shift. The dredger picks up the silt through a pipe. Inside its hull, it carries a plant that exposes the silt to oxygen before it is released again to the harbour basin. This procedure influences the density of the silt such that it is floating in the water instead of settling as a dense layer on the ground. Cargo ships can then cross the low-density silt without getting stuck. Thus, there is no need to remove the silt and dump it somewhere else. This sustainable maintenance process serves as a Use Case for the presented study. An integral system engineering approach is applied in the development of a highly automated dredger in this context. Integrating repeated Verification and Validation in the systems engineering process leads to a continuous system improvement and ensures that the system finally meets the requirements and fulfils its intended purpose. Automation concepts for IMO Degrees I, II and III as well as Verification and Validation methods are proposed and applied in sea trials.

The rest of the paper is organized as follows: Section 2 is dedicated to the regulatory aspects of automated shipping. Related studies on vessel automation and State of the Art technologies are presented in Section 3. The technological automation concept for the dredger is proposed in Section 4, followed by the verification and validation methods in Section 5. Section 6 describes the sea trials and finally, a summary and conclusion are presented in Section 7.

2. Regulatory Aspects

The regulatory framework for operating highly automated and autonomous vessels is currently under development. A major challenge in this regard are liability issues in the case of an

accident [43]. Also, IMO's International Convention for the Safety of Life at Sea (SOLAS) [44] make a minimum number of crew members mandatory for safe vessel operations. This minimum number is not defined in SOLAS, but determined for each ship individually. It has to be assessed whether for remotely controlled or monitored ships this can be reduced to no on-board crew.

IMO has published a regulatory scoping exercise for MASS in 2021. Based on that, a voluntary MASS Code is being developed and expected to be available this year. A mandatory MASS Code is expected to be established in 2032 [45]. For the time being, each flag state can decide on their own on regulations for highly automated ship operations. Norway is making considerable progress in this regard. The Norwegian Maritime Authority has published a guidance document for the installation of automation systems on ships that are intended for full or partial remote operations [46]. Additionally, the classification society Det Norske Veritas (DNV) has launched a class for Autonomous and Remotely Operated Ships (AROS) in January 2025, pathing the way for the registration of such vessels. With the automated cargo vessel Yara Birkeland and the two passenger ferries milliAmpere2 [47] and MF Estelle [48], three pilot projects in automated shipping are established or were initiated in Norway. In Germany, the Belgian company Seafar got an exemption for performing vessel remote operations on the Rhine [49]. This is the first step towards regular operations of automated vessels. The upcoming initiative of the Regulatory Sandboxes Law [50] that was announced to be introduced this year can be seen as a major step forward in reducing the effort for testing and certifying innovations. Thus, it is also expected to boost the development and market launch of maritime automation systems.

3. State of the Art in automated shipping

The following sections will give an overview on the State of the Art in automated shipping. Section 3.1 summarizes related projects driving the development of MASS for various use cases. In Section 3.2, common technologies used to realize assistance systems for MASS are discussed.

3.1 Related Projects

The related projects discussed in this section serve as a benchmark regarding suitable technologies and steps towards regular operations of MASS. This is important background information for the conception of the automated dredger.

The Norwegian University of Science and Technology (NTNU) drives the development of MASS with various research activities from which also the start-up Zeabuz originated. They are involved in operating the two autonomous ferries MF Estelle [5] in Stockholm and milliAmpere2 [6] in Trondheim. The Belgian Company Seafar has tested Remote Control operations of cargo ships on the Rhine [7]. Recently, an approval by the Federal Republic of Germany was granted for Remote Operations on the inland waterway between Salzgitter and Scharnebeck, again realized with Seafar technology in collaboration with HGK Shipping [8]. The European research project Autoship [9] also aims at advancing MASS development with a focus on inland shipping. IBM has developed an autonomous ship in the Mayflower Autonomous Ship Project [10] in cooperation with the research organization ProMare. The ship has completed a transatlantic voyage without a human captain on board [11]. In MUNIN (Maritime Unmanned Navigation through Intelligence in Networks), an unmanned bulk carrier for operations in intercontinental trade was conceptualized [12]. The project AVATAR focused on developing zero-emission automated vessels for urban waterways to distribute goods and return waste. After this general project overview, the following section is dedicated to a more detailed discussion of technologies used to enable automated vessel navigation.

3.2 State of the Art technologies

As discussed in the introduction and confirmed by the various related projects in the previous section, considerable progress is being made towards automated vessel navigation. Nevertheless, in regular operations, a vast majority of vessels today is still completely navigated by an on-board crew. Shifting the workplaces to a remote operation center poses several challenges. An important point is that a remote control operator has to gain situational awareness at a level that is comparable to that of a captain on board. To achieve this, additional sensor systems for environmental perception are necessary. This section intends to give an overview on the State of the Art technologies used for this purpose which serve as a basis for the automation concepts proposed in Section 4.

Since camera streams hardly enable precise distance estimations [13], Radio Detection and Ranging (Radar) and Light Detection and Ranging (LiDAR) sensors can provide valuable additional information. These two technologies are also applied in other industrial domains, for instance in the aviation [14] and automotive [15], [16], [17]. In the maritime domain, nautical Radars are commonly employed for ship to ship collision avoidance [18]. For object detection at short distances, they are rather unsuited due to insufficient resolution and a blind area in the near distance range [19]. To overcome this drawback, 1D frequency-modulated continuous wave (FMCW) Radars have been employed by [20] for distance estimations to port infrastructure. Another possibility are collision avoidance systems based on LiDAR data, which commonly have a higher resolution than radars [21], [22]. The authors of [23] propose a LiDAR based approach for object detection in the harbour environment. A LiDAR based collision avoidance system for an unmanned surface vessel (USV) is presented by [24]. The sensor setup of the milliAmpere2 also includes two LiDARs [6]. In [25], the performance of a 3D LiDAR and 1D Radar for object detection in the harbour environment is compared. The authors of [26], [27] and [28] use LiDAR and Radar sensors to support automated vessel navigation in locks and inland waterways. The presented studies suggest that camera streams for a general overview, complemented by Radar and LiDAR sensors for precise distance estimations, are a solid foundation for remotely controlled or supervised vessel operations. Radar sensors are more robust against environmental influences than LiDARs [13]. On the other hand, LiDARs commonly have a higher resolution and operating range [29], [21]. Combining both technologies is a good way to achieve high precision and environmental robustness of automated vessel systems.

For automated docking, ultrasound sensors are used [6], similar to parking assistance systems in the automotive domain.

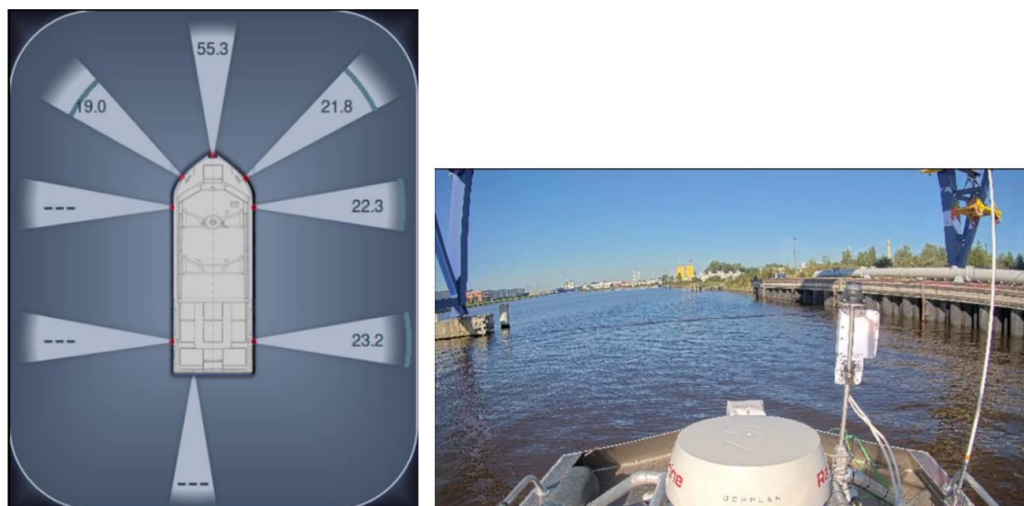
4. Technological Concepts for an Automated Dredger

In the following, technological automation concepts for operating a hopper dredger in the harbour environment in IMO Degrees I to III are proposed. An overview is provided in Table 1.

Table 1. Overview of Operational Mode and proposed Assistance Systems for an automated dredger in IMO Degrees I to II.

IMO Degree of Automation	I	II	III
Proposed Assistance Systems	1D FMCW Radar and LiDAR based decision support, Track Control without automated collision avoidance	1D FMCW Radar and LiDAR based decision support, Cameras, Track Control without automated collision avoidance	1D FMCW Radar and LiDAR based decision support, Cameras, Track Control with automated ship-ship collision avoidance
Operational Mode	On-board	Remote	Remote

At Degree I, the dredger is operated by on-board crew, i.e. no ROC is present. An assistance system for distance estimation to surrounding objects is already proposed at this stage. This recommendation is based on the fact that port maintenance requires manoeuvring close to port infrastructure like quays. Following the related studies presented in Section 2, 1D FMCW Radar sensors and a 3D LiDAR have been employed for decision support. These sensors are beyond State-of-the-Art equipment of current hopper dredgers. Accordingly, also a Graphical User Interface (GUI) has to be integrated on the bridge to display measured distances to the skipper. The GUI that was developed and used in the presented study is shown in the left panel of Figure 1. The right panel shows the camera footage of the same situation to illustrate the limitations of camera footage in distance estimations. Besides the assistance system for distance determination, also a basic track control system is proposed to assist the skipper in precisely following a pre-defined route for maintenance purposes.

**Figure 1.** Left: GUI for displaying distances to nearby objects measured by Radar or LiDAR sensors. Right: Camera Footage of the same situation.

In Degree II, interfaces for remote control have to be added to the bridge of the dredger. A ROC becomes part of the setup. The ROC that was built in the course of the study and used in the sea trials is shown in Figure 2. Control commands issued in the ROC have to be received and

processed on the bridge in order to be executed by the dredger. Additionally, the Remote Operator has to have a 360° overview of the vessel's surroundings. Therefore, cameras have to be added to the sensor setup and streamed to the ROC. Due to depth ambiguity of the camera streams, the Radar and LiDAR based distance determination that was already proposed for Degree I plays a key role in decision support for remote control of the dredger. Besides additional systems that are necessary on the ship side, there are also requirements to the ROC for safe remote operations. All information that is available to a skipper on board has to be provided also to the remote operator and has to be visualized adequately. Additional information can be obtained from shore-based sensor systems if available. For instance, [30] propose a berthing assistance system employing shore-based LiDARs. This could also support dredging manoeuvres close to the quay.

For data transfer between the dredger and the ROC, mobile networks or satellite communication can be employed. Since a reliable connection is crucial for remote control operations, redundant channels of communication should be established to account for potential disruptions. Also, the communication has to be protected against unauthorized access. To achieve this, encoding data transfer, using Virtual private Networks (VPNs) and establishing an authorization process for the remote operator once they take over control are recommended measures.

In Degree III, automated ship-to-ship collision avoidance is added to the functionalities of the track control system. Evasive manoeuvres are determined and executed by the system based on AIS data without the requirement of human intervention. Thus, the vessel can operate partly autonomous. However, the remote operator has the possibility to take control at any time if they identify a potentially critical situation.



Figure 2. The Remote Operation Center setup that was built as a part of the study and used in the sea trials.

According to [31], the functionalities of automation systems can be divided in perception, planning and acting capabilities. This sense-plan-act pattern is the formal framework for the proposed concepts and is also used by [32] to design an autonomous vessel. Figure 3 shows the

components and functionalities of the automated dredger and the ROC. The diagram for IMO Degree III is shown here since it comprises also most of the functionalities proposed for Degree I and II. The diagram is divided into components that on the one hand the automated dredger and on the other hand the ROC needs so that sense, plan and act tasks for navigation at Automation Degree III can be fulfilled. For sensing, sensor information of the dredger is pre-processed on board and then transmitted to the ROC where it is combined with shore-based sensor information. This combined information is the basis for the ROC operator's situational awareness and therefore also for the collision avoidance systems and manual decision making that is performed in the plan section. For Degree I, the diagram in Figure 3 would contain only the dredger side since it is completely operated by an on-board crew. In this case, some of the components, e.g. the distance GUI for decision making, are shifted from the ROC to the dredger. For Degree II, those components are needed on both the dredger and the ROC since an on-board crew is still present and needs the same information as the Remote Operator. In Degree III, as displayed in Figure 3, the dredger still provides sensor information, but components for decision support and situational awareness are fully shifted to the ROC since there is no longer an on-board crew.

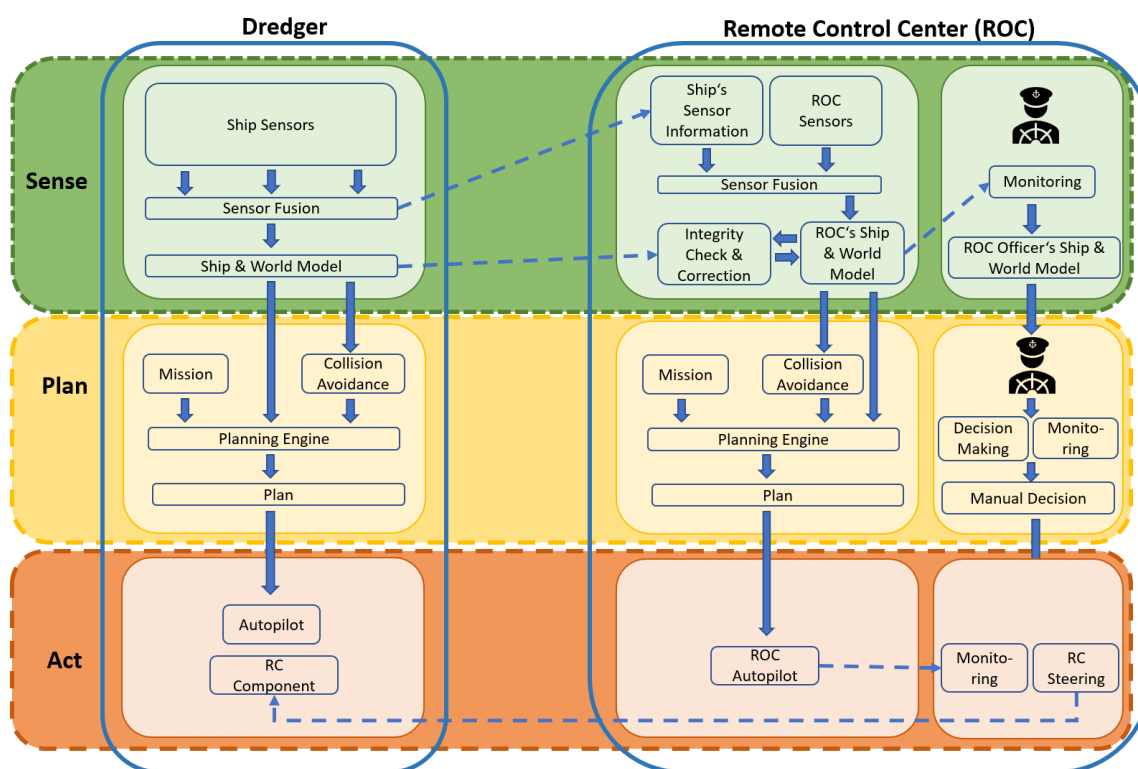


Figure 3. Sense-Plan-Act diagram of the automated hopper dredger in IMO Degree III.

5. Verification and Validation Methods

To evaluate the automation concepts proposed in Section 4, methods for the verification and validation of maritime automation systems are introduced in the following section. The proposed verification and validation methods are then applied to the collision avoidance systems of the automated dredger.

Given that highly automated maritime systems are complex systems operating in the even more complex open domain of maritime traffic, verification and validation are challenging but crucial to ensure safety. Traditional, purely distance-based methods quickly reach their limits here. Scenario-based testing is a promising alternative. Following the approach of [33], the idea is to systematically examine system behaviour across a carefully selected, representative range of operating conditions. This includes both normal scenarios (e.g., routine voyages in good weather) and critical scenarios (e.g., emergency manoeuvres in poor visibility and heavy seas, with involvement of unforeseen external objects).

One possibility to derive critical scenarios is performing an automation risk analysis. In the context of this study, a method that has been successfully applied in the automotive domain [34], [35] was applied to the highly automated dredger. [36] already applied the method to a maritime assistance system for collision avoidance. The process starts with the identification of hazardous system behaviour and then focuses on functional insufficiencies and component failures. In a next step, causal connections between hazardous system behaviour, functional insufficiencies, component failures and environmental conditions are analysed. As a result, risk triggering scenario properties are identified. For the automated dredger, manoeuvres approaching port infrastructure like the quay were identified as critical in case sensor systems for collision avoidance fail. Based on this analysis, a scenario where the automated vessel approaches the quay head-on and then performs a 90° starboard (or port) turn to continue along the quay was selected to test automated navigation in sea trials. To formalize the test scenario, Traffic Sequence Charts (TSCs) were used. TSCs are a visual specification language that is mainly used to model scenarios in the automotive domain [37] but has been adapted to and applied for the maritime domain [38]. A maritime TSC for the automated dredger approaching the quay is shown in Figure 4. It formalizes the test scenario that is used for verification and validation of the automated dredger in sea trials, see Section 6. A similar scenario has been modelled with a TSC by [39] as a basis for their proposed concept for scenario monitoring in testing. They propose and evaluate a concept for monitoring during testing whether tests are executed as specified by a given TSC. This is important information as only results from tests conducted according to specification should be used to draw conclusions in verification and validation.

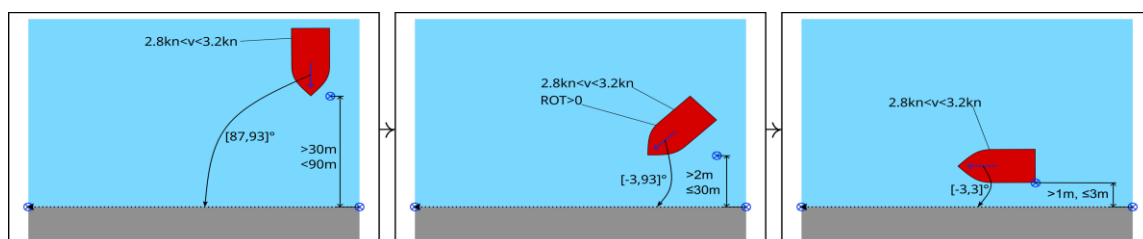


Figure 4. Maritime Traffic Sequence Chart formalizing the test scenario used for verification and validation in sea trials.

Besides methods for identifying and formalizing risk triggering scenarios for scenario-based testing, a method of hybrid testing was used as a tool for ship-to-ship collision avoidance tests. It enables the injection of simulated AIS targets into the network of the physical test carrier using sensor injection techniques as mentioned by [40]. In essence, the architecture of the test carrier is designed such that it supports maritime communication standards and is extensible in software and hardware to integrate a System under Test (SuT). Data streams read and written by the SuT can then be manipulated independently of the remaining architecture, enabling e.g. the simulation of AIS targets to test collision avoidance. In this way, any risk posed to the test carrier or the target ship when testing collision avoidance scenarios in physical trials is avoided. The hybrid testing was used for verification and validation of the automated ship-to-ship collision avoidance system integrated in the track control system of the dredger at Degree III.

6. Sea Trials

The proposed automation concepts for IMO Degrees I to III have been tested in several trial campaigns in Emden Harbor between 2022 and 2024. The purpose of the trials was to evaluate the performance of the proposed assistance systems in enabling safe remotely controlled and supervised vessel navigation. Therefore, the verification and validation tools introduced in the previous section have been utilized to thoroughly examine the preciseness of ship-based sensor distance measurements as well as the collision avoidance system of the autopilot.

For conducting physical sea trials, the eMaritime Integrated Reference Platform (eMIR) was used. eMIR is a generic open communication and service platform, providing infrastructure for testing maritime automation systems [40], [41]. It comprises two research vessels, the *Josephine* and the *Sally*, which are shown in Figure 5. Both vessels are equipped with the open testbed architecture described by [40].



Figure 5. The two research vessels *Josephine* (left) and *Sally* (right) that are part of the eMIR testbed.

For the decision support in IMO Degrees I to III, the *Sally* was equipped with eight Sick RMS1000 1D FMCW Radar sensors measuring distances all around the vessel. Additionally, a Velodyne Ultra Puck VLP 32C 3D LiDAR was mounted at the bow. The platform for mounting three Radar sensors and the LiDAR at the bow of the test vessel is shown in Figure 6.



Figure 6. The platform to mount three 1D FMCW Radar sensors and a 3D LiDAR at the bow of the test vessel *Sally*.

To evaluate the performance of Radar and LiDAR sensors for the use case of an automated dredger, several scientific studies were conducted. In [20], a data processing approach for utilizing the 1D FMCW Radar data in the maritime environment is presented. The data is filtered using criteria for signal amplitude, radial velocity and density. In the second step, a density-based clustering algorithm is applied. The processing aims at filtering out reflections from rain or the water surface. A comparison with DGPS-based distances of the test vessel to the quay wall shows that the approach overall enables a reliable distance estimation. An example for the comparison is shown in Figure 7. The manoeuvre used for the evaluation in [20] is a straight approach to the quay wall, followed by a 90° turn and a passage where the vessel drives parallel to the quay. This manoeuvre was derived from the automation risk analysis described in Section 5. Summing up, in [20] the cost-efficient 1D FMCW Radar sensors that are already applied in other industrial domains [17] were shown to be a suitable technology for decision support in automated dredger operations.

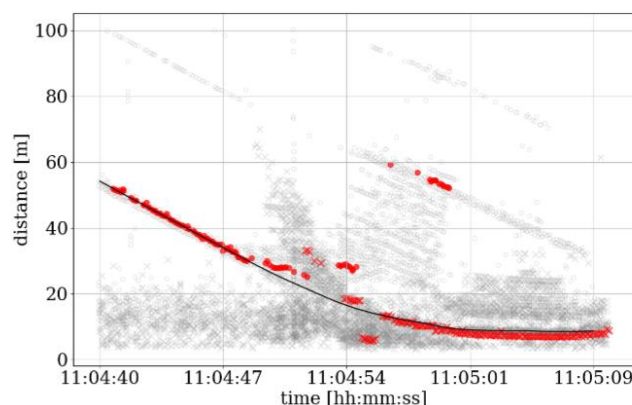


Figure 7. Comparison of distance values calculated from 1D FMCW radar data (red markers) to the DGPS based distance of the test vessel to the quay. The plot is extracted from [20]. Grey markers show the raw sensor data.

However, the operating range of the 1D FMCW Radar sensors is limited to 100 m according to the product data sheet. The filtering and clustering for the processing further reduces the detection

range to about 80 m. Also, the limited field of view and spatial resolution of the sensors makes it difficult to detect small objects or objects with a low radar cross-section. Therefore, also a 3D LiDAR was tested for distance estimations to objects in the harbour environment. The LiDAR data processing is described in [25]. The authors conduct a systematic comparison of distance estimations with 1D FMCW Radar and 3D LiDAR measurements. The manoeuvre used for the evaluation is the same as in [20], thus it also results from the V&V processes described in Section 5. However, the trials in [25] were conducted at a quay wall with a smaller wooden plank in front. The authors find that the LiDAR performs better in detecting this plank since it has a rather low radar cross-section. Therefore, for detecting such structures, it is recommended to equip the automated dredger also with a LiDAR sensor. In this case, also a fusion algorithm can be applied to Radar and LiDAR data to obtain more robust distance values and exploit the advantages of both technologies. In [27], this is done for the use case of an automated lock entry of the dredger. It is shown that the fusion yields more precise distance estimates than using only Radar or LiDAR data.

The collision avoidance of the track control system for Degree III was tested by injecting AIS targets into the network of the test carrier, as described at the end of Section 5. An example scenario is shown in Figure 8.

The tests revealed situations where COLREG compliance was not granted in the evasive manoeuvres. For instance, manoeuvres were not executed in a clear manner as demanded by COLREG. Rather, the system was changing the course several times back towards the target ship during the evasive manoeuvre. An additional drawback was the lack of considering no-go areas and port infrastructure in the manoeuvre execution. This led to dangerous situations several times during the trials which required intervention by on-board safety personnel. Admittedly, considering no-go areas was not claimed to be an intended functionality of the system in use, which is a drawback of the system in general.

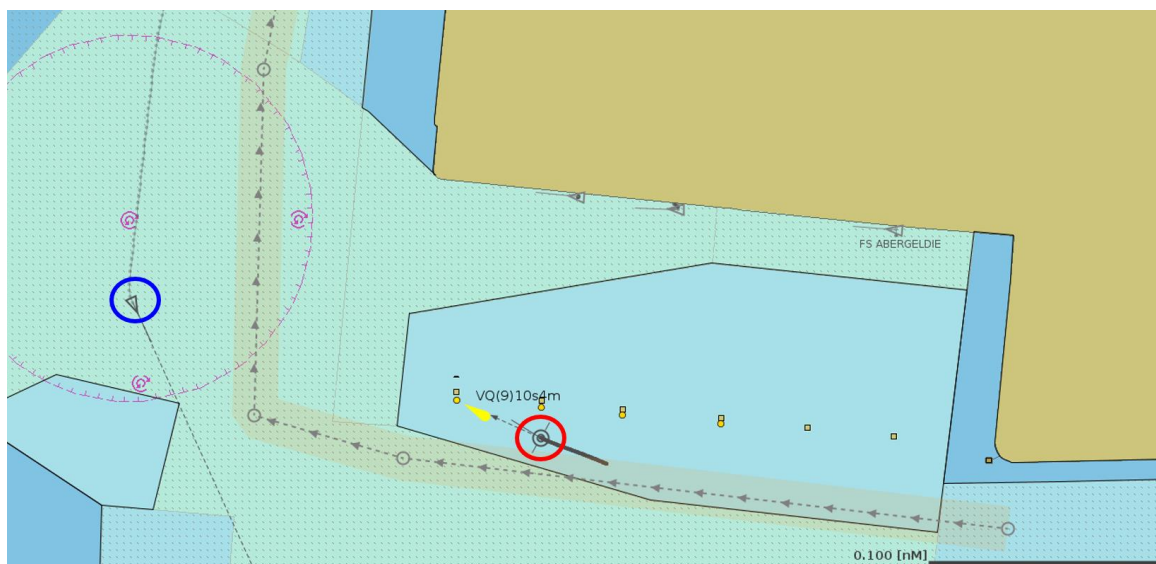


Figure 8. Testing collision avoidance with a simulated AIS target, highlighted by the blue circle on the left. The own ship is highlighted by the red circle on the right. It is intended to follow the grey track and started to perform an evasive manoeuvre. Map from [42].

7. Summary and Conclusions

This paper proposes automation concepts for operating a hopper-dredger in IMO Levels I to III. Given the well-defined and constrained area of operation, port maintenance is well suited for automation. Assistance systems for on-board operations based on LiDAR and Radar sensors enable precise distance estimates to port infrastructure. The same systems also ensure safe navigation in remote control in Levels II and III. Additionally, cameras give a qualitative 360° overview of objects in the dredger's surroundings. However, due to depth ambiguity, they are not suited for collision risk assessment when manoeuvring close to obstacles, which is a key requirement in port maintenance. Verification and Validation methods have been presented to test the automation systems, including a risk analysis and the formalisation of test scenarios in a Traffic Sequence Chart. LiDAR and Radar based distance measurements have been evaluated by comparisons with a DGPS-based Ground Truth. Collision Avoidance of the track control system in Level III was tested using hybrid simulation methods, injecting artificial AIS targets into the network of the test carrier. These tests revealed that some special requirements for ship-to-ship and ship-to-object collision avoidance arise in the harbour environment that are not completely covered by State-of-the-Art solutions. Ship-object collision avoidance and no-go areas have to be considered when performing evasive manoeuvres. Another challenge for automated collision avoidance is that the behaviour of target ships can differ from that in the open sea, e.g. a stand-on vessel is forced to change course to avoid collision with port infrastructure. Further, special rules apply to a dredger in operation as it is limited in changing course and speed. Therefore, it is a so-called right-of-way vessel and other ships have to take action to avoid collision in encounter situations. However, the automated dredger can also transfer to a different location in the harbour without being in operation, and in this case it is considered a motor vessel without right of way. Therefore, assistance systems have to be able to realize both navigational states and act accordingly. Even as a right-of-way vessel, actions to avoid collision have to be taken in case the give-way vessel does not fulfil its duty.

Despite some shortcomings discovered in the commercial State of the Art ship-to-ship collision avoidance system, the overall results of the study showed that State-of-the-Art sensor technologies are a sufficient basis to realize remotely controlled vessel operations in the harbour environment. Combining these technologies with alternative driving systems enables a sustainable and efficient port maintenance with more flexible working conditions for nautical staff. In this way, 24/2 operations of a dredger can be realized, which are beneficial for processes that avoid dumping silt in the sea, like the recirculation process applied at Emden harbour. An additional advantage of remote operations is that in the long term, multiple vessels can be supervised by one operator to save personnel costs. In the case of port maintenance, for instance several smaller dredgers could be operated instead of a single larger one. Then, maintenance can be conducted simultaneously at multiple locations. Additionally, the measuring of the water depth that serves as a basis for the recirculation plan, as described in Section 1, can be done by remotely controlled or supervised MASS. However, to unlock the potential of the proposed automation concept in regular operations for port maintenance, a legal framework for operating automated vessels needs to be established. Progress has been made in this regard in the recent years with the IMO regulatory scoping exercise and the AROS Class established by DNV. However, binding regulations for the registration and operations of automated vessels are still to be introduced. These are needed as a guidance and concession to developers of maritime automation systems as well as vessel operators to pave the way for a smooth market launch of these systems. The

regulatory sandboxes law that is expected to come into force in Germany is a promising step towards achieving this goal.

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