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Towards an investigation of a MASS-assisted anti-grounding service through simulated nautical scenarios in a ship handling simulator

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Abstract. Vessel groundings pose a major risk for maritime safety, constituting 20 percent of all incidents in the last decade. Frequent dredging and bottom mapping are resource intensive solutions currently employed, but these services cannot be maintained with the necessary frequency in all critical areas. While ships are carrying echo sounders to acquire precise and current under keel clearance data, it does not allow the vessel to react to possible deviations from the map data. Within the RoboVaaS project, a service is designed, implemented and tested in simulation. This service consists of one or more small MASS travelling ahead of a merchant vessel, collecting bathymetric data with enough lead time for the merchant vessel to react to possible threats, e.g. by course correction. This service is tested in compliance with the IMO HCD guideline in a quick approach and safe environment using a ship handling simulator. The simulator is augmented by a display system based on an ECDIS map and displaying the bathymetric data in three different scenarios. These scenarios are tested with nautical officers to collect feedback for service design and implementation with trained personnel and show the effectiveness of the chosen human machine interface.

1. Introduction

One of the major risks for maritime safety is vessel groundings. Within the last decade, approximately 20 percent of all total losses were related to grounding incidents [1]. In European waters, over 2000 accidents that involved groundings have been registered between 2011 and 2018 [2]. Areas affected by shallow water effects and tidal bore are especially prone to grounding incidents. These circumstances can be found in port areas and approaches, where recurring sedimentation can restrict large ships. To combat these problems, the need for dredging and frequent bottom mapping arises, leading to resource-intensive missions with manned vessels and high-tech equipment. Moreover, waterborne is the largest international transport sector, carrying 90 percent of global trade, with ports and harbours serving as the maritime epicenter of the arterial inter-modal network. Port transit delays on intercontinental routes can quickly eliminate the single-digit profit margins of major carriers. In the European context, the majority of about 58 percent of shipping is internal short-sea, with a further 13 percent through inland waterways, rendering it particularly vulnerable to incidents of shallow water groundings [3]. Currently, anti-grounding measures in place are mainly bathymetric data in electronic navigational charts, marked fairways with ensured minimum depth as well as pilot services, which all rely on historical data (in case of chart data, they might even rely on measurements from up to several decades ago). Additionally, they might not be available especially in areas of lower traffic density due to high costs. While each merchant vessel is equipped with echo sounders, which provide online under keel clearance (UKC) data, those are only of limited applicability for anti-grounding decisions. In transit or approach in confined water, large vessels require maneuvering decisions up to 20 minutes ahead, thus the risk of shallow waters up to that point must be known. Even though forward-looking sonars, that can be mounted on a vessel, exist, none of them is currently capable to safely detect shallow waters in the required range due to the unfavorable horizontal measurement angle. A safer vertical measurement would however require a second sensor carrier unit in due distance ahead of the main vessel. This demand can be met by the recent technology developments in the area of Maritime Autonomous Surface Ships (MASS). Thus, real-time bathymetric data including the current tide offset shall be provided. In contrast to purely adding tide gauge measurements to an ENC, dynamic changes in the seabed are thus immediately detected and exact measurements between the depth contour lines are also possible by this concept providing a more accurate safety contour for merchant vessels in shallow waters

In this paper, a MASS-based anti grounding service concept along with a design and simulation implementation will be presented serving three purposes: 1) development and design of a service that provides bathymetric data on request as a foundation for anti-grounding decisions, 2) implementation of the service design into a ship handling simulator for evaluation purposes with certified nautical officers, and 3) building a deploy-able on-demand service without significant data transmission delays for real applications.

2. Service Concept

The RoboVaaS (Robotic Vessels as a Service) project investigates different use cases, how small MASS can support maritime transport and port operations. Despite the the small size the term MASS is chosen instead of the also frequently used term Autonomous Surface Vehicle ASV, as ASV is not defined in the context of the IMO and this vessel category will most likely be one derivative from MASS, as e.g. in [4], which also defines vessels below 7m length as *ultra-light MASS*. One of the envisioned use cases is the anti-grounding service. In the scheme of this service, a fleet of small MASS, is envisioned to be deploy-able on short notice. Those MASS sail ahead of a merchant vessel to collect bathymetric data of the seafloor with more favorable vertical measurement. Based on the spatial data of the MASS and the information of the ship requesting the service, the UKC is determined and displayed in an Electronic Chart Display and Information System (ECDIS). On the vessel's bridge, the information is color-encoded and displayed in an overlay of the ECDIS to visualize shallow waters quickly and precisely. The service concept is illustrated in Figure 1.

A MASS is equipped with a standard AIS transponder, a side-beam sonar, and computational resources for collecting and preprocessing the bathymetric data from the sonar while surveying during the mission. The preprocessed data of the MASS is shown to the officer of watch on the merchant ship indicating shallow areas in three different representations: 1) visualization of AIS safety-related messages in the event the MASS recognizes a shallow area violating the ship's under keel clearance (UKC), 2) addressed AIS messages sent periodically yielding a route for safe passage, and 3) heat maps of the bathymetric data showing the actual state of the seafloor, which is illustrated in Figure 1.

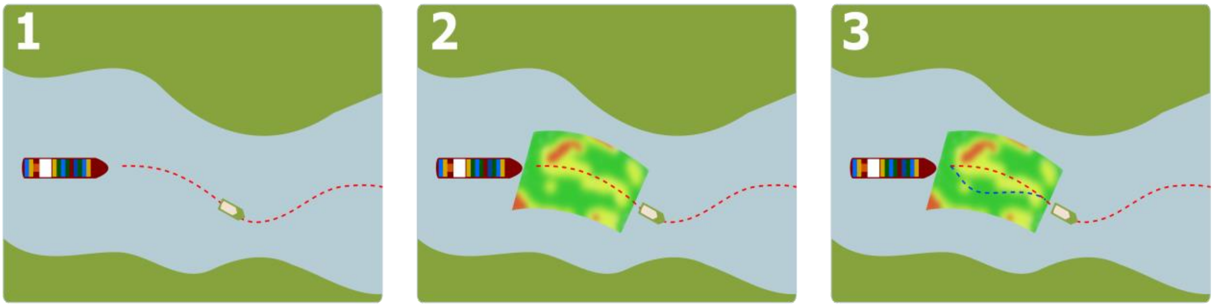

Figure 1. The application of the anti-grounding service is composed of three subsequent steps: 1) an ASV is sailing ahead and well in advance of a merchant vessel in demand of the anti-grounding service, 2) the ASV collects bathymetric data while sailing on a route requested by the merchant vessel, 3) the merchant vessel can react accordingly to the actual bathymetric data collected by the ASV. The bathymetric raw data is pre-processed on the ASV and either transmitted to the merchant vessel via VDES or coastal 5G networks for display of high density heat maps or via addressed AIS messages for indicating spots violating the UKC requested in an ECDIS.

3. Service Backend

Mission planning is a crucial part of the anti-grounding service and the deployment of MASS, thus the basic parameters of mission planning are briefly described. The aforementioned MASS platform is following a preplanned route. The route is initially based upon the route of the approaching vessel, which transfers its monitored route including its schedule, the merchant's vessel velocity (MVV), and allowed cross-track errors by the RTZ-format to the MASS mission planning. This gives the lower boundary for the MASS' velocity. The upper-velocity limit is given by maximum survey velocity (MSV) of the sonar. If the MVV exceeds the MSV, a lead time of the MASS for each way point has to be computed, so that safety restrictions (e.g. stopping distance of the merchant vessel) are not exceeded. In the long run, a system is aspired, where MSV is greater than the expected MVV. For the high-level control loop of the MASS, the Guidance Navigation and Control (GNC) paradigm is used, where the guidance component data is used as a reference, such as a set point, path, or trajectory [5]. Furthermore, environmental effects such as tide and sea state are considered [6], which can affect the effective velocity of the MASS. With the effective velocity of the MASS and the specific restrictions of the merchant vessel the bathymetric data can be collected to be effective for the anti-grounding service. These constraints are considered for the simulations as well to create a realistic scenario.

4. Experimental Setup

To avoid financial and logistical endeavors for the investigation of such a service in the real world, suitable bathymetric data is generated for several scenarios by simulation and deployed to a virtual full-scale simulation (VFSS). From port studies, it is known that real-time ship handling simulation (SHS) "is the only way to ensure that technical ship handling and the important human factors, are sufficiently incorporated", which is why this set-up is also used as methodology for assessing and reviewing the service in an early development phase [7]. However, this requires a realistic implementation within the VFSS' SHS set-up. This set-up is illustrated in Figure 2. The simulation environment is bound to the port of Hamburg as shown in Figure 3. It consists of a supervised merchant ship and a guiding MASS sailing in advance on the merchant ship's route. However, transmitting heat maps to the merchant ship raises technical requirements on the telemetry communication and data link since, dependent on the size and speed of the guided merchant ship, the distance between ship and MASS units has to be at least a few nautical miles to permit maneuvers to avoid a potential grounding given reaction delays, ships inertia, and constraints in maneuverability.

Thus, for the heat map representation as shown in Figure 3, any MASS is assumed to have advanced telemetry capabilities besides a standard AIS transponder. Assuming such advanced communication technology will be available off-the-shelf in the future (e.g. by VDES or coastal 5G networks), the heat map representation is integrated as an overlay to the ECDIS for the service implementation.

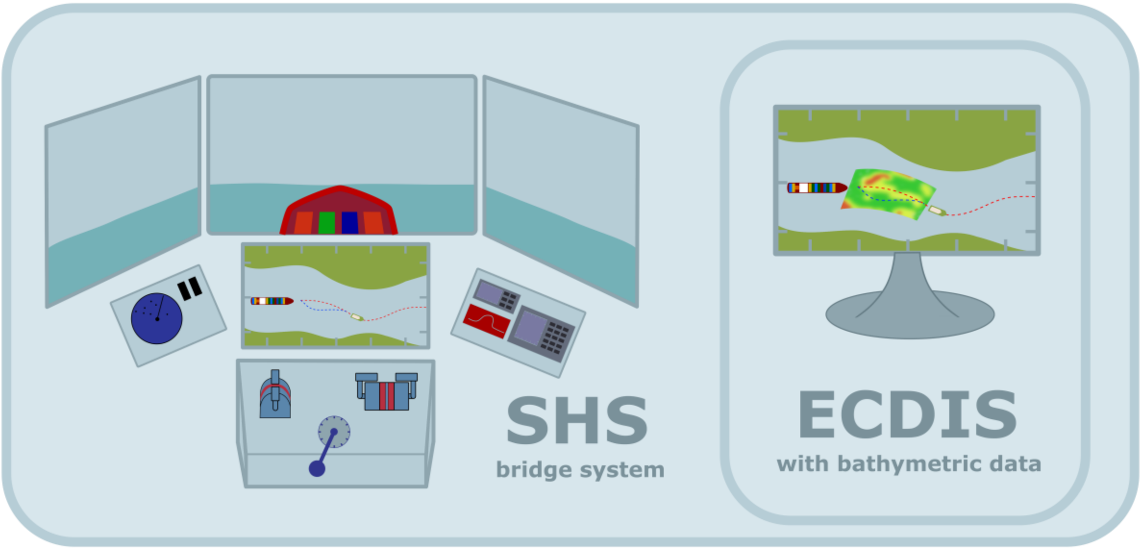

Figure 2. The bathymetric data captured and transmitted from the MASS fleet is shown at the Ship Handling Simulator (SHS) - or on the merchant vessel's bridge - to the officer of watch in an overlay in the Electronic Chart Display and Information System (ECDIS). The merchant vessel is responsible for requesting the MAAS service well in advance for a passage of an area or channel at an estimated time period as well as providing appropriate safety settings, i.e. draught and UKC, for surveying, and additional information, e.g. estimated maximum speed and ships dimensions for mission planning.

5. Service Evaluation

The MASS-assisted anti-grounding service introduces a new concept and its own ways of data representation into the bridge environment, which has to be tested carefully and thoroughly. With choosing a SHS as evaluation environment, the IMO HCD guideline to ensure quick testing in a safe environment can be fulfilled while having the flexibility to introduce the new system [8]. The experimental setup for the evaluation in the ship handling simulator is separated into three independent scenarios for anti-grounding given a merchant ship approaching to Hamburg port within a predefined and fixed nautical environment regarding weather, tide, seafloor, route, and own-ship dynamics. The three scenarios are: 1) approach without the aid of the MASS service just using the ship's own echo sounder, 2) approach with safety-related AIS messages given from one or more MASS to the merchant ship when detecting shallow waters or areas of caution, 3) approach with color-encoded ECDIS overlays indicating a channel of safe passage. The three scenarios will be executed several times with changing depth profiles to simulate runs with and without deviations from the existing ECDIS and record the nautical officers' reactions in form of control inputs such as speed and rudder. This will give insight into how quickly decisions are taken based on the additional information. Furthermore, feedback of the nautical officers will be collected on how the information is displayed. The focus lies on differences in perceived benefit between the three scenarios and the overall evaluation of the service. The evaluation of those approaches and actions taken while perceiving the augmented data in the ECDIS is investigated from a human-computer interface (HCI) point of view. By using the service an increase in the situational awareness for the nautical officers is expected to allow them to react faster and more effectively to situations that could risk the safety of the ship and crew with regards to groundings. One of the main goals of the evaluation is to determine if the designed service will be received positively in its current form and to incorporate the vital feedback of experiences officers.

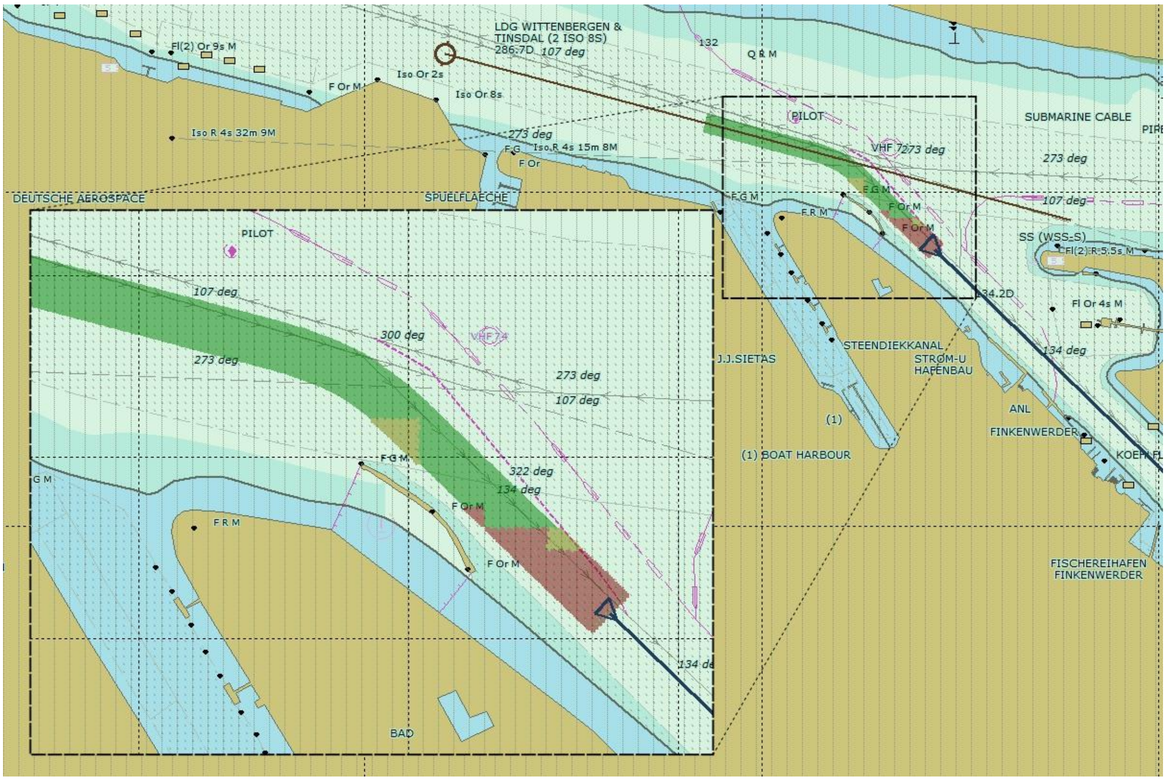

Figure 3. Screen capture of the ECDIS overlay showing a heat map (based on generated bathymetric data) covering the path of a surveying MASS with a beam width of 50 meters: 1) green shades indicate a channel of safe passage given the draught and requested UKC (received via AIS or set during the mission planning) of the supervised merchant ship, 2) yellow shades are areas of caution, which highlight bathymetric measurements where the depth is smaller than the sum of draught and requested UKC plus 1 meter, 3) red shades are shallow waters where the actual depth is smaller than the requested depth of the supervised merchant ship

6. Results and Future Work

The envisioned anti-grounding service has been successfully designed. Its findings have been used to implement three data visualisation scenarios with the SHS to create the test bed capable of evaluating the service design with certified nautical officers. Unfortunately, the envisioned testing with certified nautical officers could not be performed due to the regulations for personal contact active at the time of writing. Therefore the evaluation was limited to functional testing in-house at CML. The situation is monitored closely and invitations will be send to nautical officers as soon as the situation allows to continue the testing.

Acknowledgments

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