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Application of e-Navigation to Support Ship Operation in Emergency and Routine Situations

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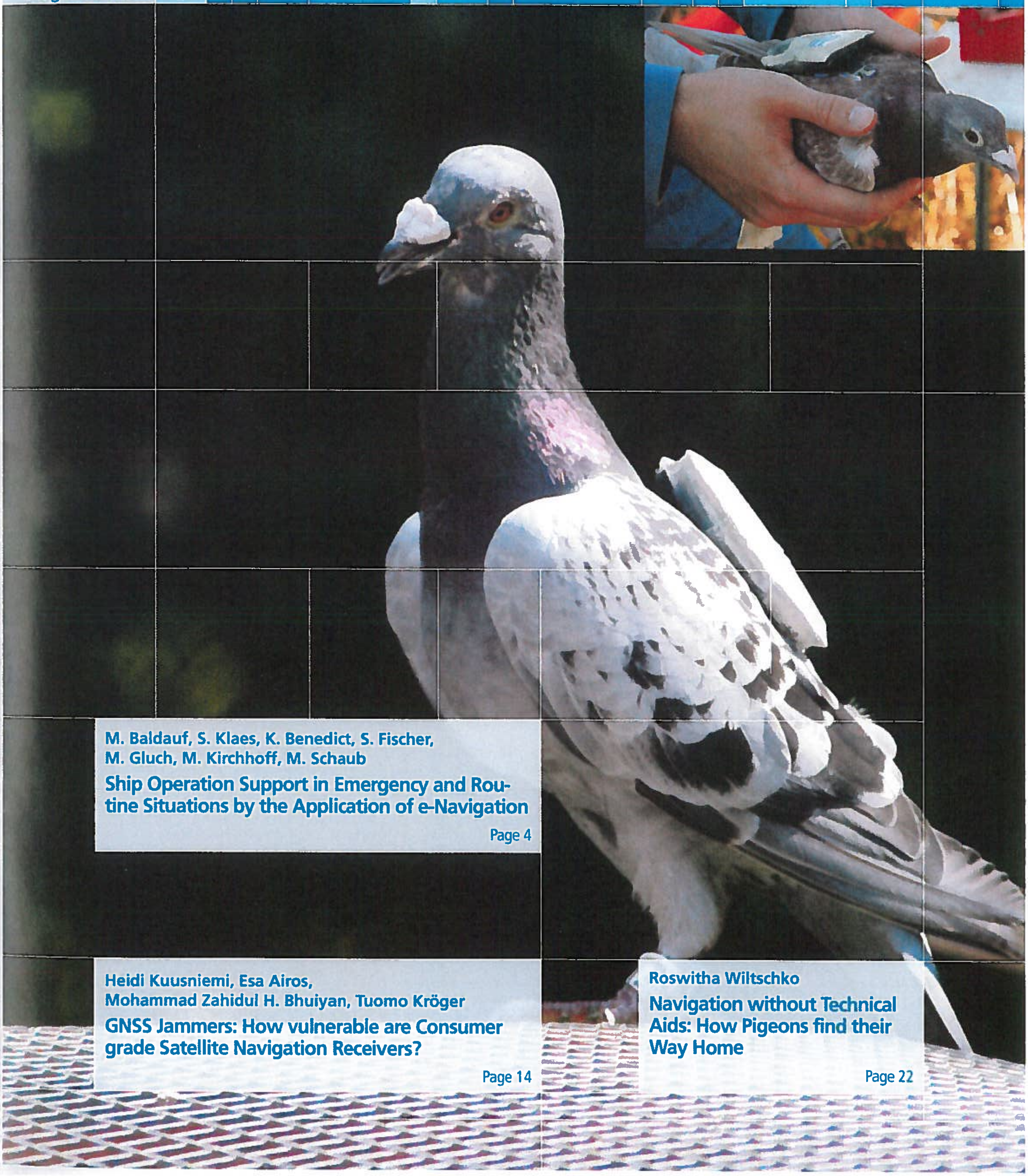

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Application of e-Navigation to Support Ship Operation in Emergency and Routine Situations

ABSTRACT: Safe and efficient ship handling in every situation and under all prevailing circumstances and conditions of the ship's status and the environment is one of the most important elements that are contributing to the safety of maritime transport. Specifically focussing on cases of emergencies, there is a need for quick and reliable information to safely manoeuvre a ship e.g. to quickly return to the position of a Person-overboard (PoB) accident. Within this paper investigations into onboard manoeuvring support for Person-overboard accidents will be presented. Based on a state of the art review, some selected shortcomings are identified and discussed. A potential approach for advanced manoeuvring support in the context of e-Navigation based requirements will be introduced and discussed.

A shorter version of this paper was presented at the International Symposium "Information on Ships" in Hamburg in September 2011 and is extended and substantially reviewed.

1 Introduction

Safe and environmentally-friendly shipping in clean oceans is the overall intention of all parties involved in maritime transportation. Both the subjects are therefore also two main opics on the working agenda of the International Maritime Organisation (IMO). In terms of engineering sciences safety is recognised as a condition where the risk is at or below an accepted level. Risk is often expressed as a combination of the probability and the consequences of a hazardous event. A usual method to quantify risks is based on accident figures. Currently an increasing number of statistics provide detailed information about the situation in the sector of maritime transport. Collected and statistically analysed data about vessel traffic and related accident figures (usually grouped into the categories of fire/explosions, collisions, groundings etc.). Just recently the European maritime safety agency (EMSA) has provided her 2010 annual report about maritime safety in European waters. Although, in comparison to the accident figures of 2007/08, a drop in the absolute numbers of accidents has been registered, it was also clearly stated, that the number of accidents is still higher compared to 2006.

Safe ship-handling and manoeuvring is one of the most crucial factors to ensure and contribute to the safety of the maritime transportation system. Safe and reliable handling of a ship has to be realised in every situation and under all potential prevailing circumstances of the ship status (i.a. characterised by ship type and shape, draught etc.) and the environment (as, e.g., water depth, wind, current etc.). In the case of certain dangers or concrete emergencies quick and reliable information in order to safely manoeuvre the ship e.g. to quickly return to the position of a Person-overboard (PoB) accident is of utmost importance and need. Especially in emergency situations, manoeuvring information provided according to the IMO recommendations and presented in standard wheelhouse posters or the required standard manoeuvring booklet [1] on the ship's navigational bridge are inconvenient and insufficient for quick application and use by the responsible officer of the watch (OOW).

According to the definitions given by IMO/IALA, e-Navigation is the harmonised collection, integration, exchange, presentation and analysis of maritime information onboard and ashore by electronic means to enhance berth-to-berth navigation and related services, for safety and security at sea and protection of the marine environment. Within this concept new approaches to provide advanced manoeuvring support in case of emergencies can also be developed.

There are ongoing investigations into potential enhancements for onboard manoeuvring support and assistance for the specific case of Person-overboard accidents. Among others motivated by the introduction of new information and communication technologies and their potentials for more sophisticated solutions, research and development activities taking also into account the latest e-Navigation initiative of IMO and IALA have been started. Based on analysis of selected accident case studies and existing solutions, representing the technical state-of-the-art, lacks and shortcomings will be identified and discussed in the next chapter followed by development of a concept for advanced situation-dependent manoeuvring support. Relations to and requirement derived from IMO's and IALA's e-Navigation initiative will be introduced and discussed.

2 Present situation and state of the art

As described in several case studies (see e.g. [2]), even today a person overboard accident in most cases unfortunately ends with the death of the concerned person. Although PoB accidents are not explicitly mentioned in the EMSA and also other accident statistics, it has to be taken into account, that there is a big risk connected with this type of accident. Available statistics from national Marine Accident Investigation Branches all over the world show that in up to 75% (see e.g. Annual Marine Incident Report 2003, Queensland) of such cases a mariner or passenger overboard finally died. Several publications refer to an average number of up to 1,000 dead worldwide per year due to person overboard accidents. According to the latest information about cruise and ferry passengers and crew overboard accidents only of North American passenger shipping companies, compiled by KLEIN for the period from 2000 to 2010, there were over 150 PoB accidents in total.

Compared to groundings and collisions, person overboard accidents are obviously rarer events. However, in terms of risk assessment have much greater consequences. A person overboard accident requires immediate decision making and prompt action (see e.g. [3] - [5]). Every second is important and influences the success of the actions to rescue the person overboard.

General IMO guidance [6] for emergency measures as well as standard plans are available which can be visualised, e.g., as flow chart diagram as exemplarily shown in the figure below.

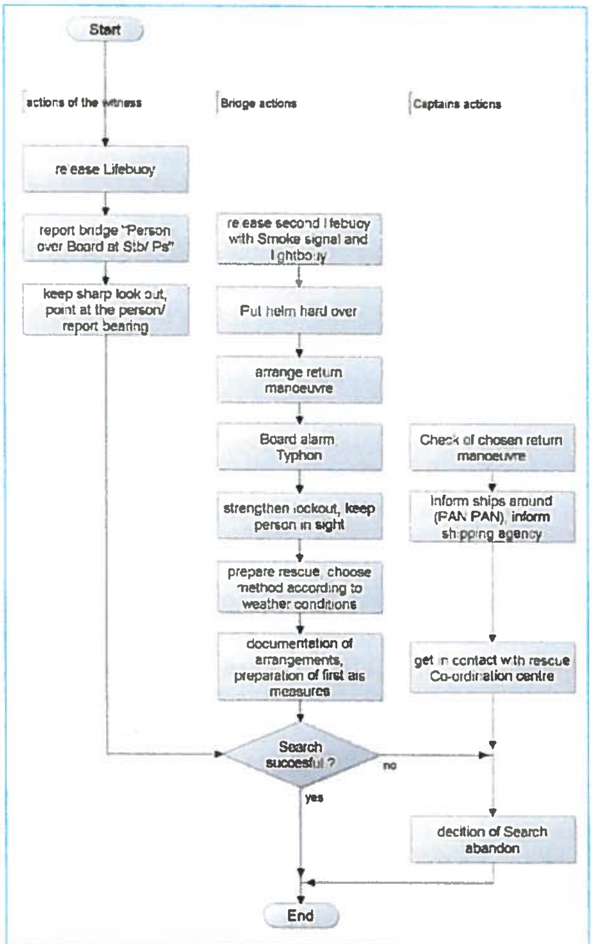

Figure 1: Sample of a Person-overboard action plan addressing actions of witness, captain and members of the bridge team (according to [7])

But the poor success rate of rescue actions begins already with the difficulties of recognising the event immediately. Within the frame of the German-Swedish project for research and technological development, there are ongoing experimental studies to automatically detect the accident. The approach consists of a series of experiments using different sensor systems to in-time detect a fallen person and send a signal to the bridge and initiate an alarm [2].

The first task of the bridge team then is to mark the position, release a life ring with safety buoy (smoke and light signal), keep sharp look out and turn the ship back to the position of the accident to pick up the person overboard.

The crucial action is to bring the ship back to the position of the accident. In guidelines, rules and further literature, several manoeuvres for person-overboard accidents are described. However, there is no single standard procedure recommended, as the effectiveness of a manoeuvre depends on the type and status of the ship, and especially on the prevailing circumstances of the particular situation. The guidance given therefore basically takes into account only the amount of time passed after the accident. According to the IAMSAR (International Aeronautical and Maritime Search and Rescue) / MERSAR (Merchant Ship Search and Rescue) Manual, firstly published by IMO in 1970, threefold action cases for manoeuvring are described:

- "Immediate action" situation,
- "Delayed action" situation and
- "Person missing" situation.

Referring to the experiences and proven effectiveness in many person-overboard casualties the SINGLE-TURN, the WILLIAMSON-Turn as well as the so called SCHARNOW-Turn are mentioned in the MERSAR manual and were subject to earlier research (among others [8] and [9]). However, there are further turns which are rarely used in commercial shipping as knowledge and/or experience is limited. In case of real accidents, almost no experience is available to most of the ship officers; they have never or seldom experienced such an accident personally.

In addition, if a vessel is equipped with a fast rescue boat (FRB) the option of immediate help and rescue has to be taken into consideration too for decision making on manoeuvring.

The mandatory training procedures, including the conduct of return manoeuvres, are normally executed under good conditions in order to keep a safe environment for persons involved in the training routine. Contrary to this, in accidents the conditions, especially the wind and waves, are worse. Action plans according to the International Safety Management (ISM) Code are available, but in the case of real situations the use of these plans is often limited because plans are made to give more general guidance. No technical means, or only unsuitable ones, are available e.g. for the immediate selection and planning of the manoeuvre in the respective situation.

Today ECDIS and GPS or other systems are available to allow for marking the position of an accident electronically. However, it has to be done manually. As accident investigations have shown in such stressful situation the crew member may fail to do so.

From a detailed review of products available on the market, it is known that most Radar/ECDIS equipment (i.a. Transas NaviSailor or Furuno ECDIS EC 1000) contain a function to display a marked position and moreover may also provide information about distance and Time To Go (TTG) to the marked position on basis of calculation using actual course/speed information.

Some more enhanced systems (e.g. latest Visionmaster FT systems of Sperry Marine) even allow for the display of search patterns – but this is needed later, if the immediate measures for finding the person right after the accident have failed.

The consideration of external factors, such as wind influence on the ship's track, is possible only on the basis of the mental model of the ship officer on watch; no computer-based support is available when it is most urgently needed.

Like all other maritime accidents, person-overboard and search and rescue cases are rare events. Immediate actions are necessary and have to take into account the prevailing circumstances of the environment and the manoeuvring characteristics of the ship. The general guidelines and information for manoeuvring have to be adapted to the actual situation. However, the manoeuvring data displayed on paper on the bridge to assist the captain and navigating officers are of a general character only and of limited use in the case of real accidents. Manoeuvring assistance regarding optimised conduction adapted to the specific hydrodynamic and the actual environmental conditions are urgently needed.

Although new and highly sophisticated equipment and integrated navigation and bridge systems (INS / IBS) have great potential to provide enhanced assistance, situation-dependent manoeuvring information and recommendation are not available yet. The same is true for SAR actions. Optimisation and coordination of all involved parties is needed, taking into account e-Navigation related concepts.

Finally, the related training courses need to be enhanced, especially by means of the use of full-mission ship-handling simulation facilities.

3 Intergrated maritime technologies for advanced manoeuvring assistance

3.1 Selected Aspects of Manoeuvring

Ship manoeuvres can be divided into routine manoeuvring and manoeuvring in safety-critical and emergency situations. This division can be developed further by considering different sea areas where manoeuvres have to be performed: e.g. in open seas, in coastal waters and fairways as well as in harbour approaches and basins. Routine manoeuvring in open seas covers ship-handling under normal conditions, e.g. in order to follow a planned route from the port of departure to the port of destination; this includes simple course change manoeuvres, speed adaptations etc. according to the voyage plan.

Manoeuvring in coastal areas, at entrances to ports and in harbour basins include manoeuvres, e.g. to embark and disembark a pilot, to pass fairways and channels and even berthing manoeuvres with or without tug assistance.

Manoeuvring in safety-critical and emergency situations deals with operational risk management and includes manoeuvres to avoid a collision or a grounding, to avoid dangerous rolling in heavy seas, or to manoeuvre in the case of an real accident e.g. return manoeuvres in case of a person overboard accident or when involved in Search-and-Rescue operations.

Taking the case studies described in the second section it can be concluded that there is a strong need to improve and support the ship command with more sophisticated situation-dependent manoeuvring information, especially in an emergency. It is worthwhile to use the potential of e-Navigation and the related new technology in order to generate such assistance to the human operator when a person has fallen overboard.

3.2 Situation dependent manoeuvring assistance by dynamic wheelhouse poster and electronic manoeuvring booklet

Earlier investigations, e.g., into the field of collision and grounding avoidance have shown, exchange and integration of information even available on a ship's navigational bridge from different sensors and sources is unsatisfactory (for more detailed explanations see reference [10]).

Until today the change of manoeuvring characteristics, e.g. with respect to their dependencies on speed and

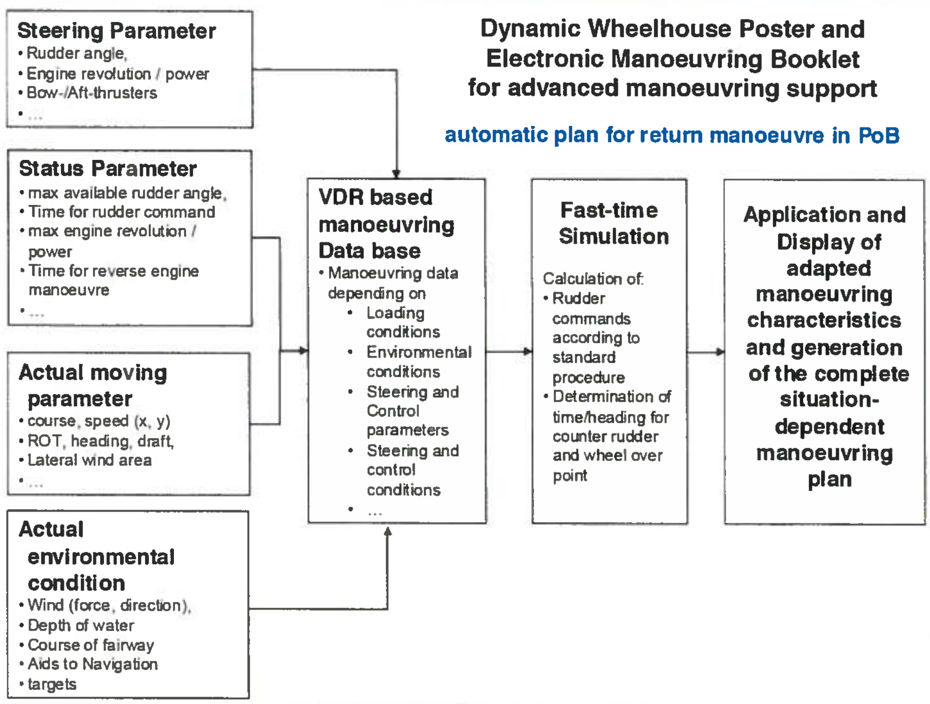

Figure 2: Principal structure and data-flow for generating a dynamic wheelhouse poster and manoeuvring booklet to provide situation dependent manoeuvring support for return manoeuvre

loading conditions, as well as on environmental conditions (e.g. water depth, wind and current) has not yet been sufficiently considered. High sophisticated Integrated navigation systems (INS – see also [11]) are installed on board but do not provide the bridge team with situation-dependent manoeuvring data e.g. turning circle diameter, stopping distances etc. for the actual situation. However, the ongoing developments under the IMO's and IALA's e-Navigation initiative with the application of new technologies and availability of enhanced information and data might allow exactly this in the future. In the context of the e-Navigation concept and its definition, the introduction of a dynamic wheelhouse poster and an electronic manoeuvring booklet are suggested. Up-to-date manoeuvring information adapted to specific purposes and situations can be provided by using enhanced integrated simulation technologies.

For that purpose a first generic concept has been drafted to combine own ship status and environmental information from different sensors and manoeuvring information that, e.g., could be gained via a mandatory Voyage Data Recorder or from ECDIS recordings [12].

For a person overboard accident the mandatory wheelhouse poster should contain information about return manoeuvres. Spotlight analyses have shown that in most cases this information is incomplete and only partly or not available in the documents, even for the basic cases of deep and shallow waters as well as for loaded and ballast conditions.

3.3 Application of fast-time simulation techniques for Manoeuvring Assistance

Fast-time simulation is a technique which allows for the calculation of future system's status and the real-time behaviour faster than in real time. One advantage of fast-time simulation is the prediction of future system conditions including the consideration of actual changes of steering parameters and effecting external impact parameters.

The following equation of motion is used as the model for the ships dynamic and implemented in software modules for fast time simulation (FTS – among others refer to e.g. [13] and [14]):

$$
\begin{aligned}
X &= m(\dot{u} - rv - x_G r^2) \\
Y &= m(\dot{v} + ru + x_G \dot{r}) \\
N &= I_z \dot{r} + m x_G (\dot{v} + ru) \qquad (1)
\end{aligned}
$$

On the right side are the effects of inertia where u and v represent the speed components in longitudinal and transverse direction x and y, and r is the rate of turn of the ship. The ship's mass is m, and xG is the distance of the centre of gravity from the origin of the coordinate system, Iz is the moment of inertia around the z-axis. The ship's hull forces X and Y as well as the yawing moment N around the z-axis are on the left side. Their dimensionless coefficients are normally represented by polynomials based on dimensionless parameters, for instance in the equation for transverse force Y and yaw moment N given as the sum of terms with linear components Nr, Nv, Yr and Yv and additional non-linear terms. Other forces, such as rudder forces and wind forces are expressed as look-up tables. There are additional equations for the engine model, and also look-up tables to represent automation systems characteristics. The solution of this set of differential equations is calculated every second; some internal calculations are even done at a higher frequency. Further detailed descriptions of FTS can be found in [15].

The inputs for the simulation module consist of controls, the states and the data for the environmental conditions. Additionally, there is an input of the ship's condition parameters. They are normally fixed but in case of malfunctions they might change, e.g. reducing the rudder turning rate or maximum angle. The results from the simulation module are transferred to be stored or directly displayed on demand in the dynamic wheelhouse poster or the electronic booklet.

The module is used to perform calculations to predict the path for specific actual or planned commands. In this way the module can be applied to plan and optimise the return manoeuvre and automatically produce the complete situation-dependent manoeuvring plan for a return manoeuvre.

4 Situation-dependent plan for return manoeuvers

4.1 Aim and Objective of the Planning Process

The objective of the simulation-based manoeuvre planning and optimisation process is to find a suitable procedure which can be used in a particular situation for the actual status of a real ship.

There are standard files for manoeuvre control settings for simulating specific manoeuvres. By means of the fast time simulations, various results of manoeuvres will be generated. The final goal is to achieve the sequence for an optimised manoeuvre control setting adapted to the actual situation parameter. Presently, the biggest problem is that there are many options possible and the effect of the changes of the parameters used in the models is not very clear; some changes may even have effects which counteract the results of the others. Therefore it is very important to know which parameters which have a clear impact on the manoeuvring characteristic.

An example is given below to indicate the need and the effect of manoeuvring optimisation by means of an Emergency Return Manoeuvre.

4.2 Planning of an Emergency Return Manoeuvre

The example discussed in the following extract is the emergency return manoeuvre using the well known "Scharnow-Turn".

As with all other emergency return manoeuvres, the fundamental aim is to return the vessel to the original track by the shortest route and with minimum loss of time. In practice the vessel initially follows the turning circle, and after shifting the rudder by a course change of about 240°, finally turns to counter rudder and amidships. The vessel then swings back to the opposite course at a certain measurable distance from the original track, at a certain distance from the reference manoeuvre.

The first problem is how to get the "Optimal reference manoeuvre" because the heading change of 240° is an average only and can differ among ships from 225° up to 260° or even more, as can the Williamson Turn

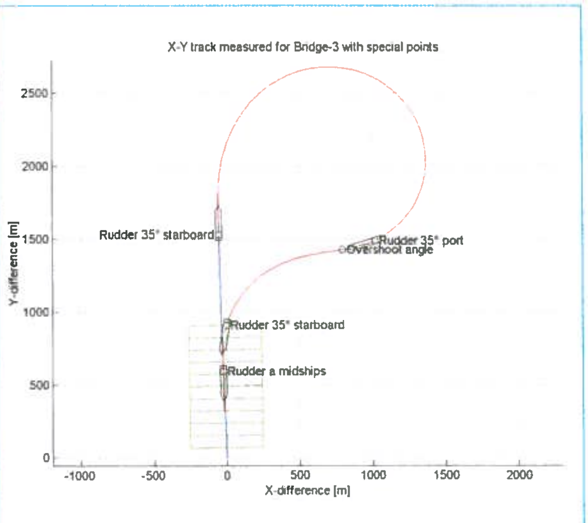

Figure 3: Reference outline for the Scharnow–Turn

which can vary from 25° to 80° instead of the standard average value of 60°.

The following figure demonstrates the wide variety of the outcome of the standard course of rudder commands compared for a container vessel, a cruise ship (blue), RoRo-passenger ferry (brown) and two container feeder vessels (green and red).

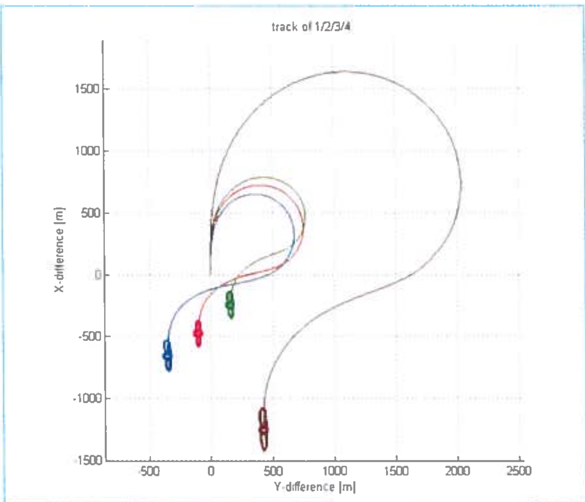

Figure 4: Comparison of the outline of standardised Scharnow–Turn for four different types of ships

Beside this basic variance according to the ship type, there are other more important dependencies that have a substantial impact on the outlined path of a return manoeuvre.

Furthermore there are dependencies of the final outcome of the return manoeuvre on the loading condition as well as on wind force and wind direction. Of course, the outline would change again if the ship is fully laden or if shallow water effects occur.

Finally, for reasons of completeness, it should be mentioned that there are dependencies on the initial ship speed and on the available water depth. It is clearly to be seen that adaptation of the manoeuvre plan has to be performed for each single varied situation parameter. On the other hand, the simulation software module is able to provide the corresponding data accordingly.

The next step after having simulated the standard manoeuvre procedure for the prevailing environmental circumstances is then to determine the best manoeuvre sequence.

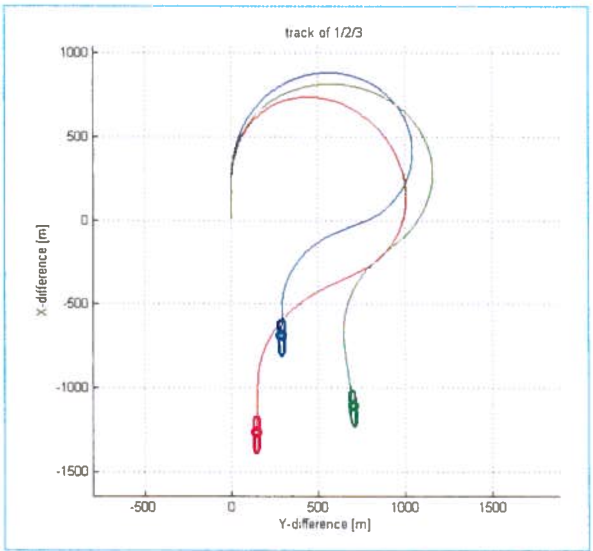

Figure 5: Comparison of the outline of standardised Scharnow–Turn for a 7.500 TEU container ship in ballast condition for three different wind conditions (no wind- blue and wind Bft 6 from north (red) and north-west (green) respectively)

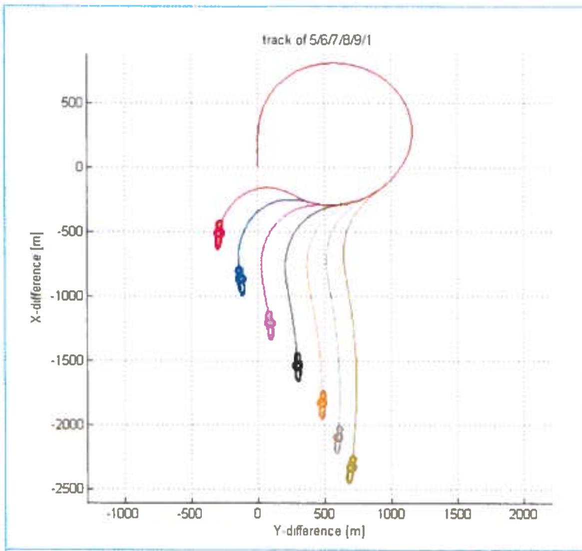

Figure 6: Optimisation of a emergency return manoeuvre by series with different heading changes from 240° up to 300° (with in-creasing steps of 10°) for counter rudder

Using the simulation software module there are two principal ways available in order to determine the optimal sequence for the situation dependent manoeuvre plan:

- The first option is to simulate series of manoeuvres using standard „SCHARNOW-Turn" (or WILLIAMSON-Turn) manoeuvring commands in automated simulation series. This method can be seen in Fig. 6 below, where several heading changes were used as parameters to vary the final result of the distance between the initial track and return track.

The results presented in Figure 6 are for the 4.600 TEU container ship in ballast conditions and taking into account northerly winds of Bft 6.

The second option is to start with a standard „SCHARNOW-Turn" manoeuvre command series for automated simulation, combined with an optimisation procedure.

An optimising algorithm is used to find the suitable heading change for counter rudder as parameter to achieve smallest distance (limit=10m) between initial track and return track on opposite heading (limit=2°). The optimal track is indicated by yellow colour in

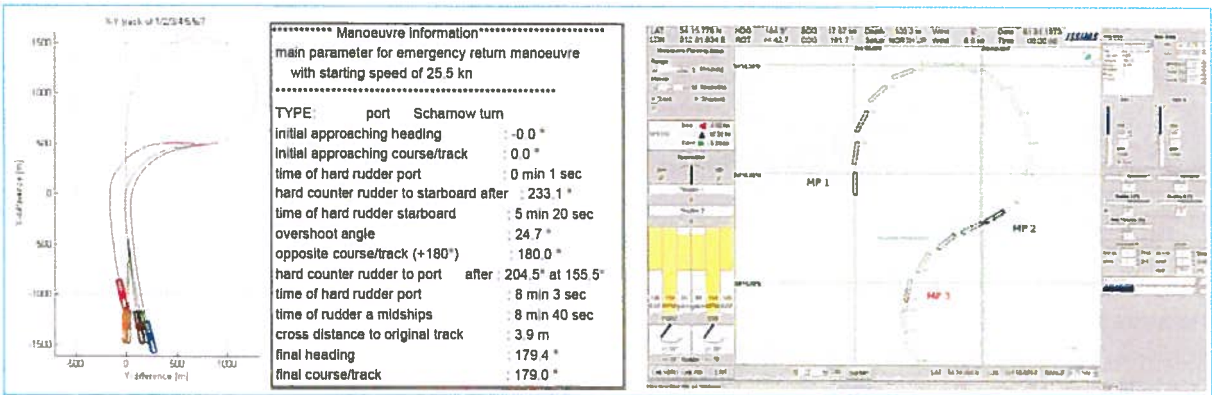

Figure 7: Emergency return manoeuvre optimisation procedure (left) with display of manoeuvring details for optimised manoeuvre and planning integrated in an ECDIS environment (right)

Fig. 7. The main parameters of the optimised manoeuvre procedure are given in the table format.

5 Further application of FTS for enhanced manoeuvring support

Beside its application for very specific emergency manoeuvres as mentioned above, fast time simulation techniques, moreover, allows for a wide spectrum of other use cases of ship operation. There are ongoing investigations to apply FTS for several purposes.

By means of FTS the planning of complex manoeuvres, as e.g., to enter or leave a port and to pass harbour basins from or to the dedicated berthing place can be supported very effectively. Implemented algorithms for manual planning of harbour manoeuvres allows the bridge team to test different strategies and to check a chosen steering sequence for the actual or even for expected conditions of the ship status and additionally under varying environmental conditions directly in an ECDIS-based human machine interface. A significant reduction of the number of elemental manoeuvres was one of the first preliminary results.

The following figure 8 shows exemplarily one scene from planning the complete manoeuvre to leave the port (left) and its use for online manoeuvring support by means of the prediction of the track to be expected according to actual manoeuvring handle settings. The simultaneous display of the planned track, own ship's position and heading together with the predicted track allows immediate decision on necessary action to keep the planned track and keep safety margins respectively.

Another very important application of this technology is its use for energy-efficient and environmentally-friendly ship operation. First case studies performed in [16] have proven the thesis that it is possible to not only smooth the steering sequences when manoeuvring in harbour basins but also to optimise the sequence in terms of energy efficiency. Time savings were positive side effects of making use of FTS based predictions for planning purposes or just only to support decision making by online displaying the predicted path for ordered manoeuvring handles.

Finally, as demonstrated and described in [17], FTS-based prediction tools have proven their invaluable potential for all kind of ship operation training purposes as well.

6 Summary, conclusions and outlook

Investigations into the overall situation regarding onboard manoeuvring assistance and into the integration of new maritime technologies onboard ships are

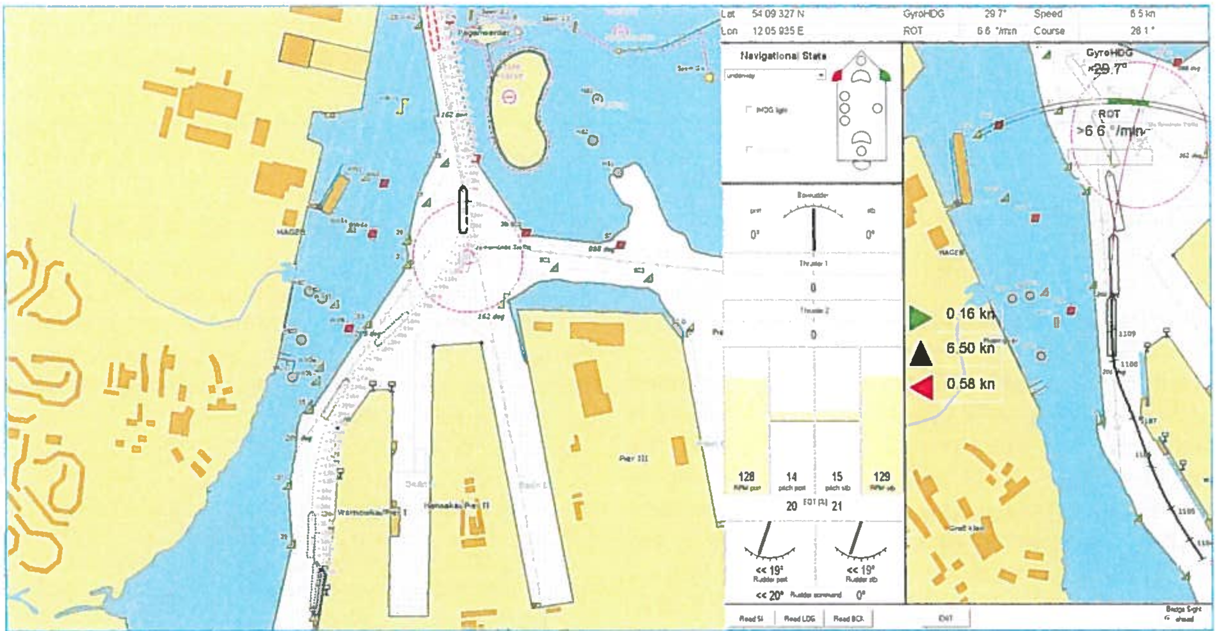

Figure 8: Sample of a manoeuvring plan for leaving the berth and entering the harbour basin (left) and using Prediction methods overlaid on the planned track for steering the ship (right)

performed. The ongoing investigations have shown that there is potential to increase operational safety in shipping.

Taking into account the availability of new technologies and new equipment, situation dependent manoeuvring information should be provided to the navigators on the bridge rather than continuing to provide them with static manoeuvring data which often are incomplete and inconvenient in use.

For these purposes, the introduction of a dynamic wheelhouse poster and an electronic manoeuvring booklet is suggested, to provide ship's command with up-to-date information about the manoeuvring characteristics of their ship, adapted to the prevailing environmental conditions.

A concept is developed and exemplarily applied in order to support the accomplishment of manoeuvring tasks in case of a person overboard accident. The fundamental element of this concept is based on innovative fast-time simulation technologies. It is applied for the purpose of providing situation-dependent manoeuvring data by taking into account actual environmental conditions and actual ship status information. The use is also demonstrated exemplarily for the generation of optimised situation dependent manoeuvring plan for an emergency return manoeuvre.

Future investigations, i.a., will deal with enhancement and validation of suitable visualization of the fast-time simulation results to support decision-making in an ECDIS environment. Therefore, human factor related investigations dealing with a user-centred design of the human-machine interface have to be performed. Additionally, investigations into the application of the concept on other situations will be carried out.

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