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Developments for remote controlled ship assistance operations of harbour tugs

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SYNOPSIS
In the three-year research project FernSAMS concepts for a remote-controlled tugboat have been developed. With the focus on unmanned ship assistance operations situational awareness, manoeuvrability, responsiveness and automatic towline connections are fundamental requirements that have been addressed. The interdisciplinary group of seven partners including players from industry, research institutes and university revised aspects in hydrodynamics, manoeuvring simulation, communication technology, digitalisation, human-machine interfaces and training concepts to find solutions for a remote-controlled tugboat that can contribute to technical, economic and ecological problems of handling ever growing vessels in crowded harbours.

1 Introduction

Tugboat business currently faces several challenges. Firstly, there is an increasing difficulty to handle ever growing cargo vessels within the limited space of harbour basins. Secondly, operators face high pressure to increase cost efficiency in a highly competitive market, without jeopardising safety of crew and operation. Thirdly, as maritime industry in general, tugboat business is facing a transformation task towards green technology.

As in other industries, a higher degree of automation enables optimisations that help to meet these challenges. In the case of harbour tugs, the discrepancy between high demands, which require a crew of well-trained specialists, and long waiting and stand-by times, which mean that these specialists can only contribute their skills during a small proportion of their working hours, is particularly striking. The complexity of some manoeuvers in close proximity of other ships and the need to collaborate with ship's crew, pilots and other tugs make remote control of tugs more feasible than fully autonomous ship assistance. However, remote control and temporary autonomous operation during simple manoeuvres like transiting makes it possible to relieve the crew of less demanding tasks and let them spend more time on qualified work [4].

In contrast to different projects on remote control of tugboats an unmanned operation is targeted, because only unmanned operation meets the goal to not exposing crew to dangerous operations and allows to balance costs of remote-control infrastructure aboard and onshore with savings on ship building by removing requirements for working areas.

But tugs' defined area of operation is perfectly suited to establish required infrastructure (antennas, maintenance stations, etc) for remote control. For an unmanned, remotely controlled tug, therefore, some challenges need to be solved, while keeping in mind that a new tug concept needs to align with current and future trends of internet of things and decarbonisation:

- Automatic or remote-controlled towline handling
- Ability to remote control highly dynamic manoeuvers next to and (hydrodynamically) influenced by other vessels.

This in term includes

- Secure, reliable and fast radio communication
- Sufficient situational awareness at remote control stand
- Superior manoeuvrability and quickest response of propulsion and steering gear

In the research and development project FernSAMS (German acronym for Einsatz ferngesteuerter Schlepper bei An- und Ablegemanövern großer Schiffe / remote controlled tug operations during berthing and unberthing maneuvers of large vessels) from 2017 until 2021 funded by the German Federal Ministry for Economic Affairs and Energy, the participating partners Voith, Fraunhofer CML, MacGregor, MediaMobil, Marine Training Center Hamburg, Technical University Hamburg-Harburg (TUHH) and the German Federal Waterways Engineering and Research Institute (BAW) developed essential concepts for remote-controlled tug operations.

While pushing has some role in assistance manoeuvres, the most important way to exert forces on the assisted vessel at various speed and different sea states is a towing rope. Without automatic or remote-controlled ability to connect and disconnect tow ropes, unmanned tugs are not feasible. Furthermore, any such device has to integrate within the existing process of heaving line, messenger rope and tow rope that is compatible with all cargo vessels and their crews.

Different concepts to transfer the rope have been discussed and evaluated in a technology screening process before MacGregor developed their new line catching pool system [7]. Guided by visual signals the vessel's crew throws a heaving line into a catching pool that makes up for the biggest part of the fore or aft deck of the tug. The heaving line is detected and automatically connected to the messenger line. This system has been realised in a scale model and was successfully tested.

Development of a remote-control station is all about providing an environment that enables a remotely operating tug master to gain sufficient situational awareness. This involves the identification of relevant data that needs to be gathered via sensors and the development of signal processing and presentation in a suitable human machine interface (HMI). Such an environment (figure 1) has been designed and implemented by Fraunhofer Center for Maritime Logistics and Services using virtual reality (VR) and augmented reality (AR) technology to compensate for the loss of kinetic and tactile perception [5] with a head mounted display showing 360° camera view enhanced with visual information of sensor data, e.g. tow rope status or distance to other vessels.

Remote control technologies can only be designed and developed in close coordination with a communication and data transfer system. Analysis of tug operations showed that highly dynamic manoeuvres of tugboats in short distance to other vessels require good visual perception based on cameras.

Therefore, transmission bandwidth needs to be high and latency should be short. To comply with the operational requirements and provide reliable data transmission the concept developed by MediaMobil (figure 2) includes

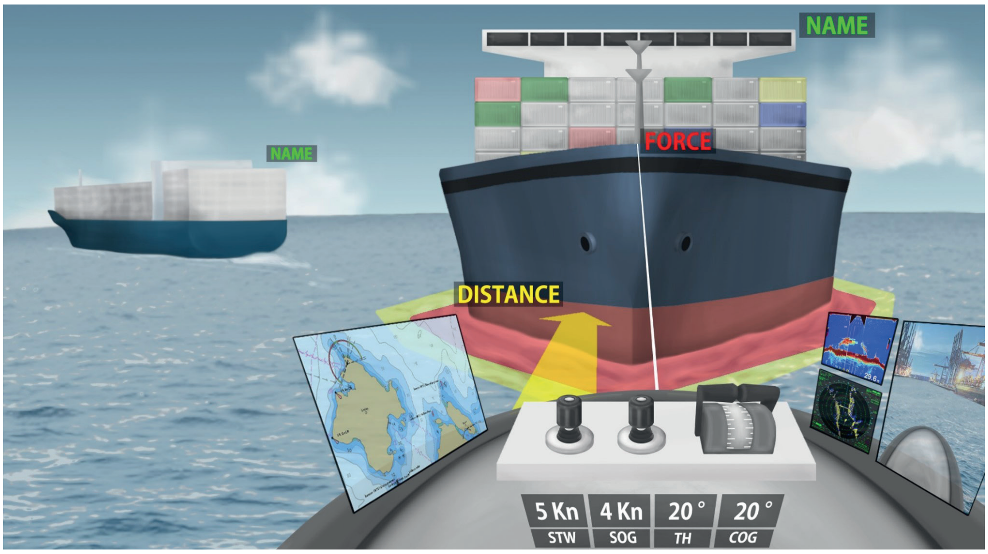

Figure 1: AR based HMI interface by Fraunhofer CML

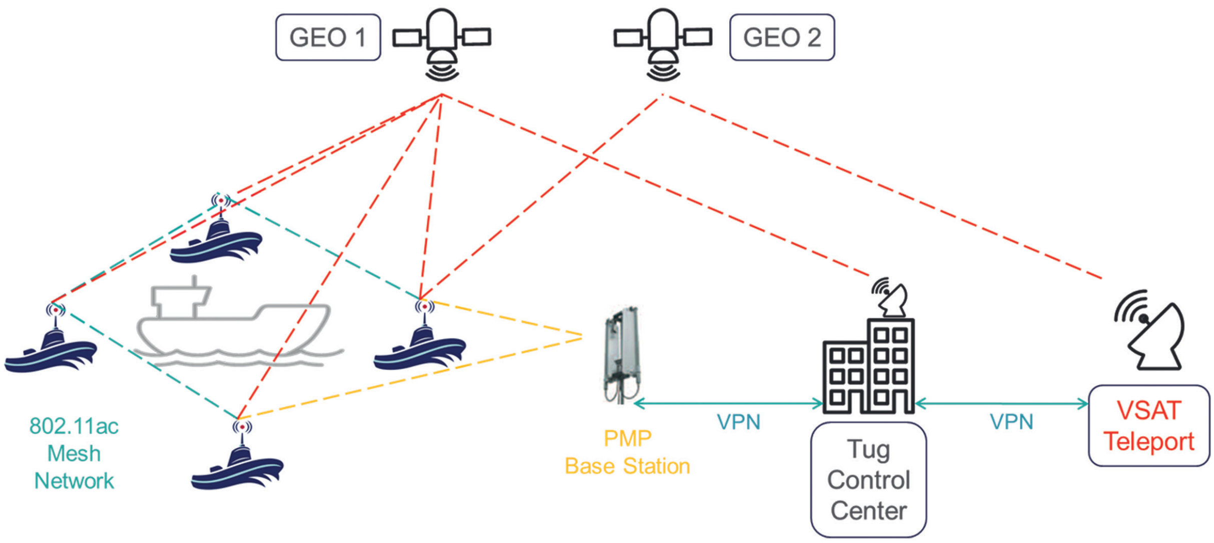

Figure 2: Data transmission concept designed by MediaMobil (source MediaMobil)

redundancy provided by terrestrial point to multipoint radio communication to several shore-based antenna stations that cover the harbour area and satellite communications as a back-up system. Furthermore, mesh technology can be applied for additional links if several harbour-based ships are equipped with the technology. The communications system provides seamless switch-over to best available links at all times, a quality of service approach to prioritise different data streams like control parameters, sensor data, camera stream etc. and security concepts according to BSI (German federal office for information security) standards.

Development and testing of remote-controlled tug concepts is heavily based on a digital twin implemented in manoeuvring simulations. To reach a sufficient level of accuracy ship handling simulation has been extended to include various hydrodynamic interaction effects of tugboats, propulsion, assisted vessel and harbour environment in a joint effort of the FernSAMS parties TUHH, BAW and Voith [9], [10]. Ship handling simulation also serves as an important part for a newly developed training program at Marine Training Center (MTC) Hamburg providing a complementary introduction of the remote controlled tug concept.

2 Optimised Tug Design for Remote Control

Adding remote control to widely used tug designs might not be sufficient to meet the requirements for more efficient and effective tug operations with ever growing vessels and less ecological impact. Furthermore, high manoeuvrability and responsiveness is of great importance to compensate some latency and challenges that are inevitable with remote control.

The holistic consideration of hydrodynamics, propulsion and automated line operations in the design of the tugboat enables an optimised design, which is prepared for further automation and relieves the crew operating remotely. The consecutive development of RAVE tugs [1], CRT tugs [2] and RAmora [3] by Robert Allan Ltd., Novatug and Voith serves as a sound basis for the remote-controlled tugboat developed within the FernSAMS project.

For a long time, the answer to the need of increasing towline forces has been to add more propulsion power in compact tugs. But this concept led to a decreasing use of hydrodynamic hull forces of tugboats, so called indirect towing, and therefore to a decreasing efficiency of towing operations. As an example, figure 3 shows possible towing forces of a tractor tug using half or full power at 6 knots. If more power is available direct towing becomes more attractive in a wider range of towing directions. Tugs with less power used to generate steering forces in indirect mode.

This theoretical calculation leaves out practical issues, as a tug master cannot always foresee which towing directions and amount of forces he will be asked to provide in the course of the manoeuvre. Switching from direct to indirect towing or vice versa takes time and leaves the vessel without towing force. And finally in direct mode towing directions of more than 60° at speed takes time to reach.

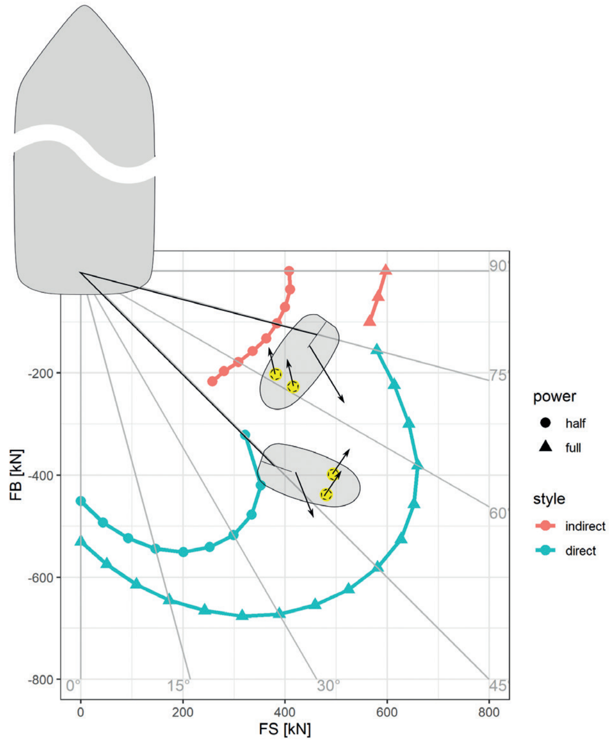

Figure 3: Influence of available power on direct and indirect towing at 6 kn

The RAVE tug concept enhanced with a carrousel type winch allows for a different way of manoeuvring and is a big support for remote control. The main differences are:

- Main sailing direction is bow ahead, independent of working as bow or stern tug.
- VSPs fore and aft with towline connection in between allows for heading, i.e. drift angle, changes even with high tow line forces.
- Indirect towing at any speed and position using the full underwater lateral area of the tug's hull.
- Combination of indirect hull forces with direct propeller thrust, because thrust is set in direction of towline.
- Fast and smooth change of towing direction at any time, because tug's drift angle is controlled independently of towing direction.
- Indirect towing as a bow tug in spring line position.
- Quick and precise adjustment of tow line force by variation of drift angle and additional propeller thrust, due to fast VSP thrust control.

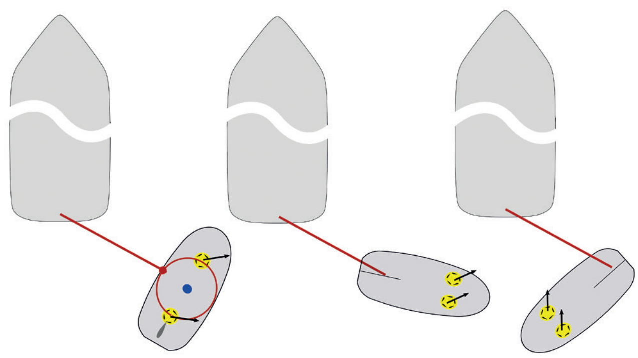

Figure 4: CRT combination of direct and indirect towing

The ability to control the tug's heading independently of towing force at any time and the quick thrust control of Voith Schneider Propellers showed to be most advantageous to deal with short but inevitable lag of data transmission.

The combination of direct thrust force with indirect hull forces increases towing efficiency of harbour manoeuvres at mostly used low and medium speed. Figure 5 shows resulting available towing forces using half power. In terms of overall efficiency part load operation is to be considered, because tugboat spend most of their operational time in extreme part load conditions. Current and future development show trends towards electric or hybrid powertrain that have a good part load performance. The proposed remote-controlled tugboat is perfectly prepared for this scenario using new type of electric driven Voith Schneider Propeller (eVSP).

For the eVSP, the highly efficient technology of the permanent magnet synchronous motor (PMSM), also known as torque motor, is the ideal solution. This modern electric motor technology is characterised by a very high efficiency in the entire motor map. For this purpose, the PMSM was integrated directly into the housing of the Voith Schneider Propeller, and a special PMSM was developed for this purpose. The result of the development is shown in Figure 6.

The PMSM was realised with the innovative, space-saving toothed coil technology and the buried magnet method. The buried magnets guarantee a very high functional reliability. A comparison of both concepts - eVSP vs. classical VSP - can be seen in figure 7. The PMSM torque motor of the eVSP substitutes the following elements

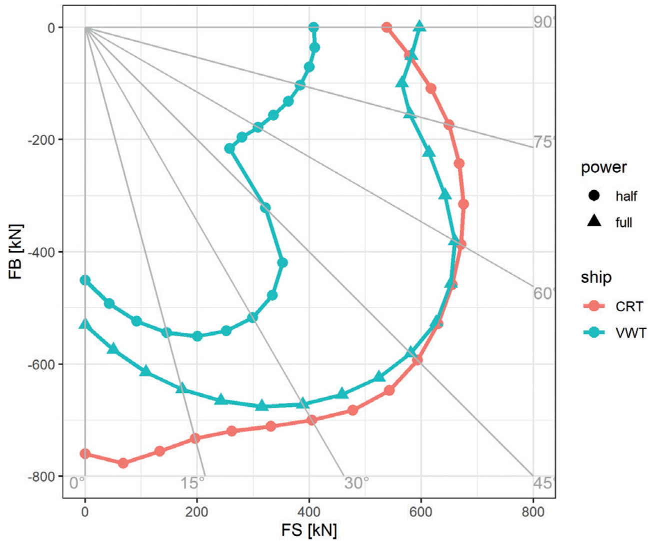

Figure 5: Combined direct and indirect towing mode of remote CRT at 6 kn

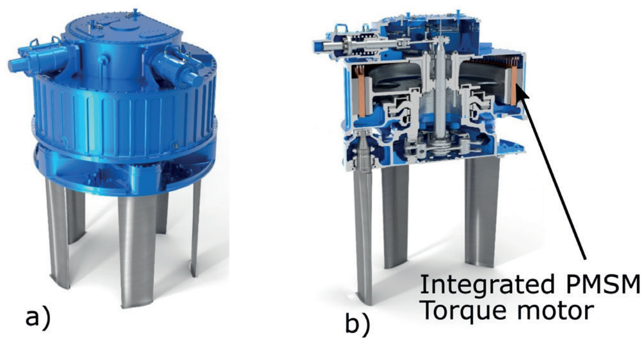

Figure 6: Electric Voith Schneider Propeller, CAD model a) in full view and b) in sectional view.

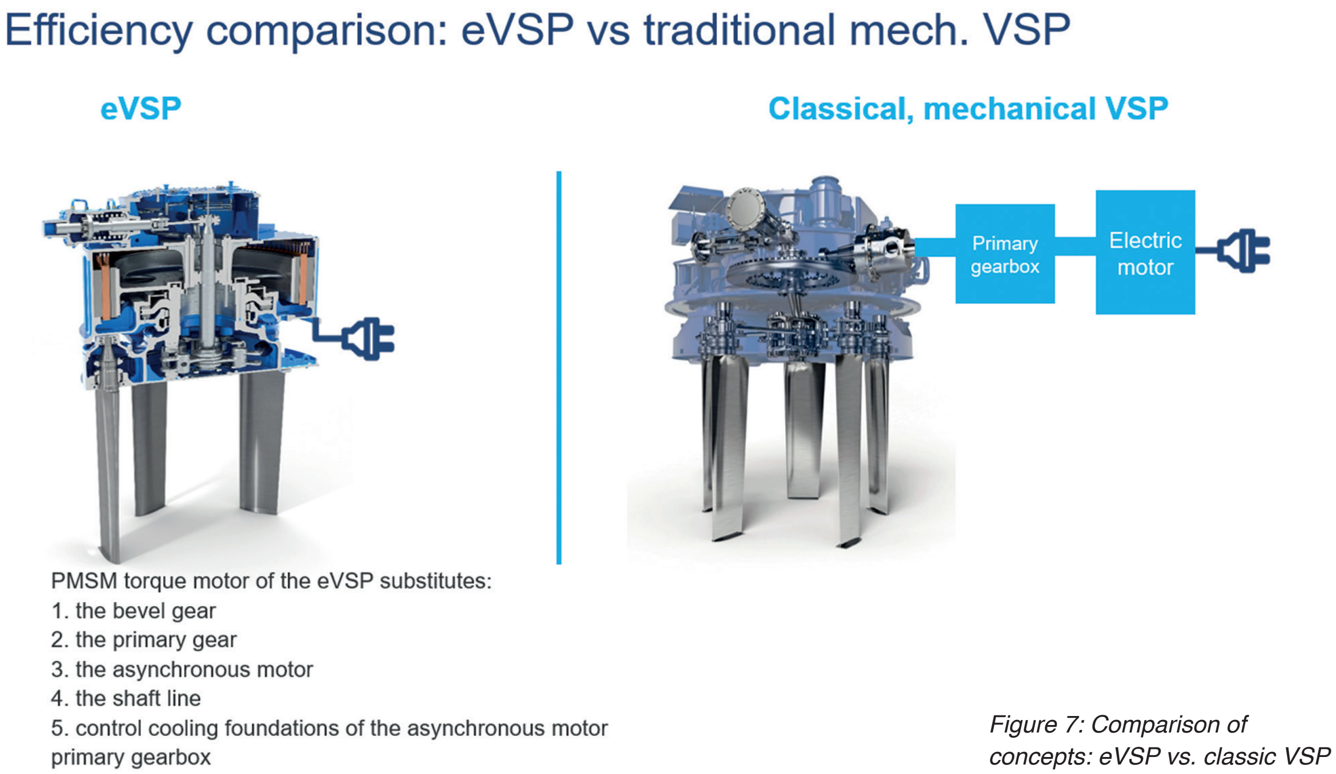

Figure 7: Comparison of concepts: eVSP vs. classic VSP

of the classical VSP:
- Bevel gearbox,
- Upstream gearbox,
- Asynchronous machine,
- Waveguides,
- Cooling/controls of the primary gear unit and the asynchronous machine and
- Foundations in the ship for the primary gearbox and the asynchronous machine.

In addition, the PMSM torque motor uses the same bearing as the hydromechanical part of the VSP. The high efficiency of the PMSM torque motor and the elimination of gearbox and shaft line losses are the basis for the efficiency increase in the range of 4% to 12%. With the agile PMSM torque motor, variable-speed new dynamic positioning controls can be realised for offshore vessels and remote-controlled tugs.

Remote controlled tugboats will not only affect the tug manoeuvres themselves, but in best case can also help to optimize the whole assistance manoeuvres including vessels and tugs [11]. Digitalisation and availability of data, which is gathered for and from remote control, like towing direction, towing force, position and distances of vessels, remaining power reserve, etc. can then be integrated in assistance systems of pilots and all stakeholders for assessment and improvement of processes.

The Voith condition monitoring system (CMS) as shown in figure 8 has been introduced in 2013 and since then has been installed on various VSP propelled offshore support vessels, tugs and ferries. A detailed description of its design and functionality is given in [8]. Besides other tasks, it proved to be useful for analysis and optimisation of thrust control and steering. Within the development of a remote-controlled tugboat it is easily connected to the Maritime Data Engine by MacGregor that serves as onboard data collection and server system.

3 Simulation and model scale tests

Development, testing and improvement of concepts is heavily based on ship manoeuvring simulations and model-scale tests. Multi-bridge simulations for tug assistance manoeuvres are well established and tug masters are often aware of their benefits and limitations. Direct comparison of simulations using dedicated simulator tug bridges and remote-control stations connected to the simulator at MTC, as shown in figure 9 was therefore used to test and design a VR based human-machine interface (HMI) [5]. For example, the importance of haptic feedback of thrust control handles became evident.

Figure 9: Tests of VR based remote control station connected to ship simulation

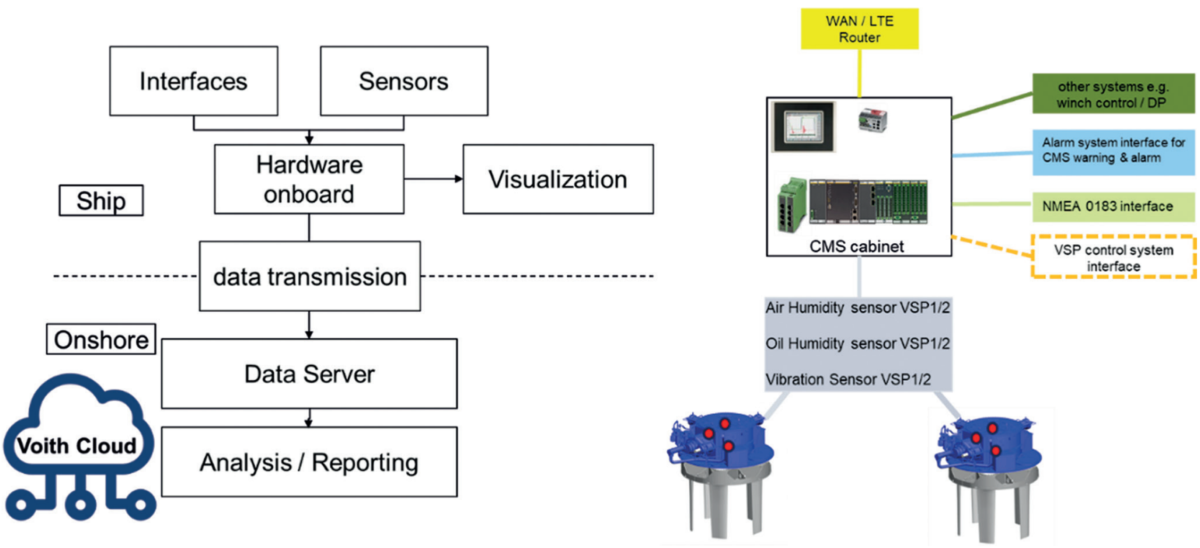

Figure 8: Voith Condition Monitoring System (CMS)

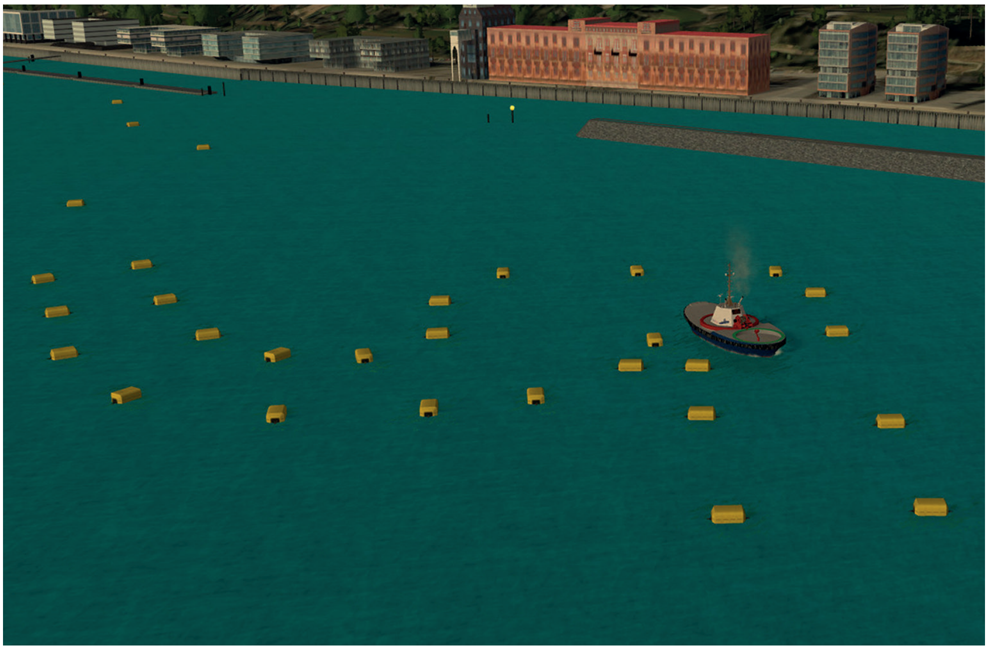

Figure 10: Simulation training parkour at MTC

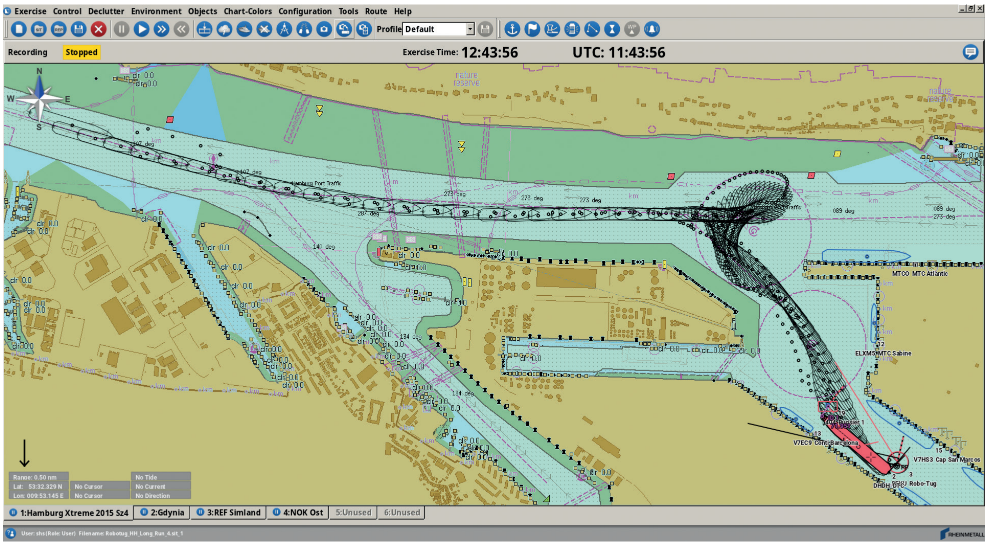

Figure 11: Simulation of tug assistance at MTC

Figure 12: Remote controlled scale model in Rostock harbour

Furthermore, the influence of lag caused by system processing time and data transmission can be quantified for different manoeuvring situations. For example, sailing a training parkour (figure 10) or doing a full tug assistance manoeuvre (figure 11).

Integration of sensors and camera and their specific features and weaknesses in manoeuvring simulation is only of limited use. To test a more complete setup of the whole system in a second step model-scale tests have been done (figure 12).

Figure 13 shows the tug model equipped with remote control components and figure 14 a view from the remote control during tests on a lake. Different quality levels for data transmission that reflect available bandwidth and latency according to different communications paths shown in figure 2 have been simulated to rate situational awareness, if some systems like camera view are not available [6].

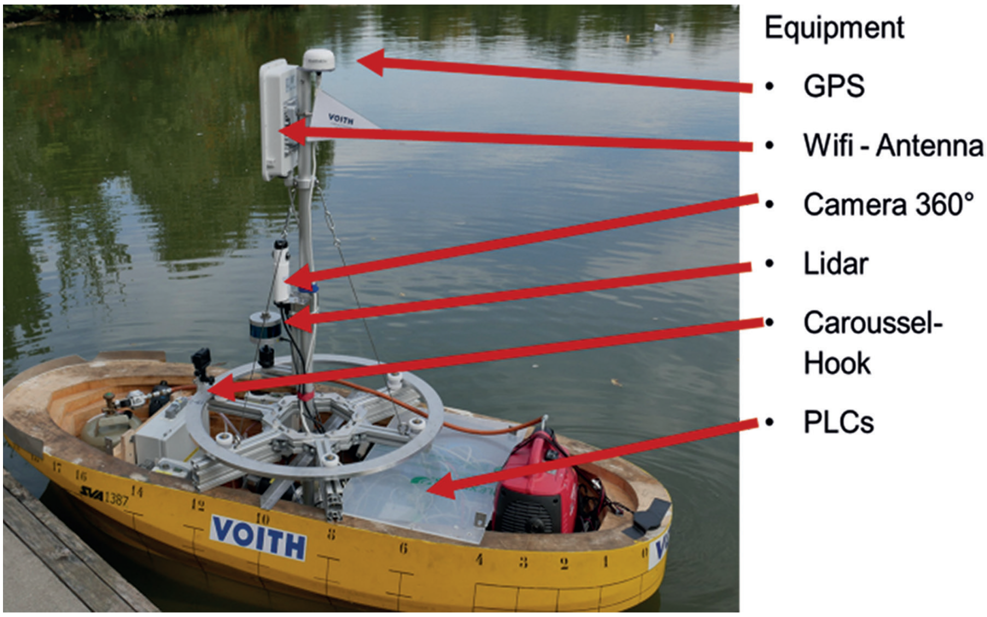

Figure 13: Model-scale remote controlled tug

As a next step full scale tests have been prepared but had to be postponed several times due to the Covid pandemic. These will now take place just before the TUGTECHNOLOGY 2021 conference, such that brand-new results will be included in the presentation.

4 Conclusion

Remote controlled tug assistance manoeuvres can contribute to the optimisation of harbour assistance and increase efficiency of tugboat operations. To achieve this, the proposed tugboat concept has been developed with the clear focus on enabling remote control during ship assistance through increased manoeuvrability and responsiveness. Main elements of this concept are electric Voith Schneider Propellers in line at bow and stern and a carousel winch. The combination of direct and indirect towing method and the ability of smooth and quick change of towing position significantly improves towing efficiency at all power levels and supports remote control with simplified steering and control of towline forces.

Within the FernSAMS project towline handling for unmanned tugs, communication systems for remote control of tugs and a human machine interface for remote controlled ship assistance manoeuvres have been developed. Manoeuvring simulations and model scale tests have proven the success and benefit of the overall concept combining all parts of the project.

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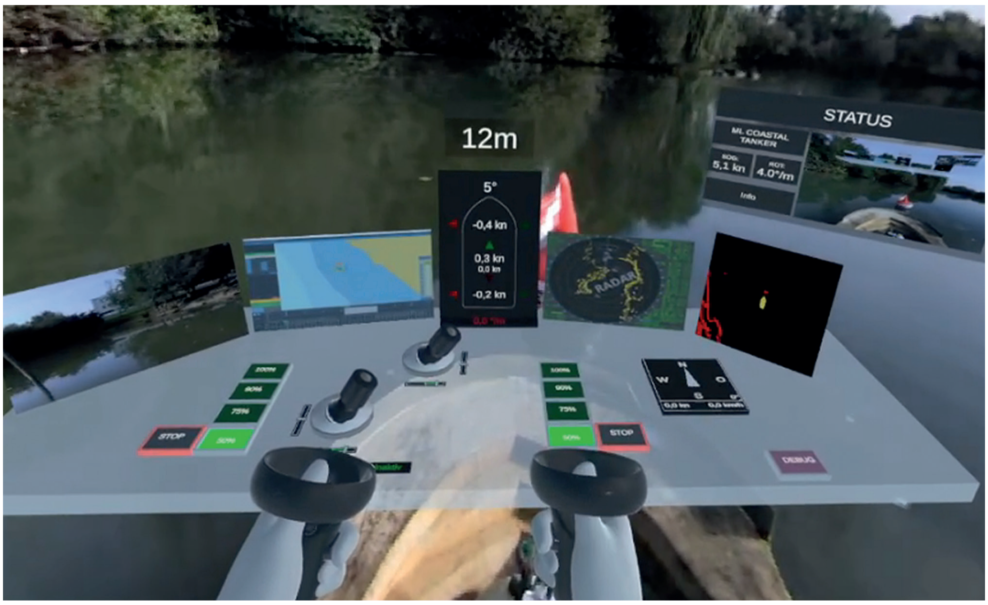

Figure 14: Remote control of model scale tug in AR view developed by Fraunhofer CML

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