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Remote-Controlled Tug Operation via VR/AR: Results of an In-Situ Model Test

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ABSTRACT: The German-funded FernSAMS project aimed at the development of an unmanned, remote-controlled tug operation with AR/VR technology. After an extensive simulation test with ship-handling simulators, the developed FernSAMS AR/VR system has now been in-situ tested with a scale model of the tug. The model test results showed very robust stability in remote operations with improved situational awareness with the VR/AR system and sensors. After a short introduction of the FernSAMS concept as well as some first insights into FernSAMS Human-Machine-Interface tests within the simulator, this paper introduces the technical setup of the scale-model tests being conducted with the FernSAMS concept to test the operational and technical feasibility of AR/VR-based remote control. This includes an overview of the systems and sensors integration and an analysis of the effectiveness of AR/VR system combined with 360-degree video streaming.

1 INTRODUCTION

Unmanned harbour tugs are being commercialized to reduce risks of the human factor in towing operation and labour costs caused by long idling time. With the fast-growing state-of-the-art technologies such as 5G, Virtual Reality/Augmented Reality technologies, and advanced sensors, a high degree of stability of remote control and situation awareness is more feasible than before. Rolls-Royce and Svitzer [11], Kotug [8], Wärtsilä [16], NYK [10], and Samsung Heavy Industries [12] have successfully demonstrated remote tug operations with different kinds of remote control centre demonstrators.

However, there are still major challenges that compensate for sensory loss since important sensory channels like kinetic and tactile ones are eliminated during remote operations. Furthermore, for a remote operator, sufficient information must be transferred from the ship to the shore control centre in a timely manner to gain adequate situational awareness.

It is essential for tug operators to have sufficient situational awareness to analyse the situations, plan actions, and execute remote control. However, achieving a high-quality visual presentation with less sensor loss is very challenging with conventional 2-D camera-based approaches and additional information in the form of text or sensor data. Furthermore, substantial investment for the equipment in the shore control centre is not avoidable.

Hence, the goal of the FernSAMS Human-Machine interface is to improve the situation awareness with VR/AR technologies and reduce the cost for setting up the shore control center. This paper is organized as follows. In Chapter 2, we present the basic concept of FernSAMS and its shore-based remote control center. After the overall introduction of FernSAMS, in Chapter 3, we describe the Human-Machine-Interface within the FernSAMS project. After a short result analysis from simulation run in chapter 4, chapter 5 presents the In-Situ Model Test's technical setup. Finally, we summarize the results from In-Situ-test and discuss the future outlook in Chapter 6.

2 FERNSAMS CONCEPT

The typical harbour tug operation consists of several stages, from unberthing, transit, and towage operation to berthing. The FernSAMS project is aiming for an unmanned, remote-controlled tug based on Voith Schneider propulsion (VSP), Macgregor Maritime Data Engine (MDE), Media Mobile communication system, and FernSAMS assistance system (Fraunhofer CML) during this harbour operations.

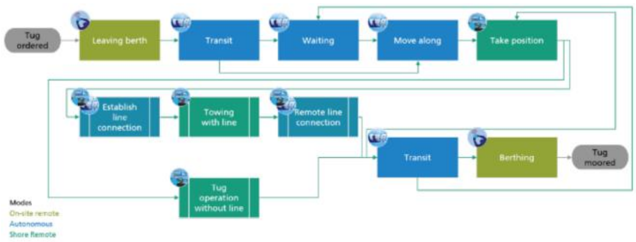

Figure 1. Flow chart for tug operation with remote FernSAMS assistance system [15]

The development of a remote-controlled harbour tug including all components required for its operation necessitates the previous analysis and specification of operations, which is presented in detail by [Figure 1]. The considered operations between the tug being ordered and moored again range from leaving berth, berthing through transiting, waiting, convoying and taking position to pulling or pushing operations with or without establishing a line connection respectively. This analysis not only provides the basis to determine the degree of automation or remote control, but also to specify features of the tug and its assistance system required for remote-controlled operation assisted by autonomous functionalities [15].

2.1 *Overview of the FernSAMS*

The main concept of the FernSAMS assistance system is to develop an enhanced HMI with the help of VR/AR technology and sensors, which enables remote operation during the assistant jobs and autonomous operations in manoeuvring mode from RCC (Shore Control Centre). FernSAMS assistance system is designed to fulfil the level 3 automation, according to the International Maritime Organization's (IMO) definition [7], which means "remotely controlled ship without seafarers on board."

2.2 *Remote control centre*

The main purpose of the RCC is to provide the ability to take control of autonomous vessels from a remote location, especially as means to avoid critical situations, collisions, and allisions that are outside the capability of the automatic navigation algorithms [4]. Typical RCC infrastructures consist of large screen displays and working stations to provide a clear overview of surroundings and navigational information such as Electronic Chart Display and Information Systems (ECDIS) and AIS/radar, which shows resemblance to modern ship's bridge. However, as the importance of RCC increases, innovative RCC technology and design is needed to enhance human-machine interactions and safety of operations.

The hardware requirements for the landing station were defined during the planning of the onboard tests [Figure 2]. The landing station will be set up in a room with a table and a seat. There must be at least 1x1m, and preferably 2x2m of space around the seat. To receive ship and sensor data, the PC is connected to the network via Ethernet LAN, and a 220V connection is required for power supply. Ideally, the shore station is located near the in-situ test environment.

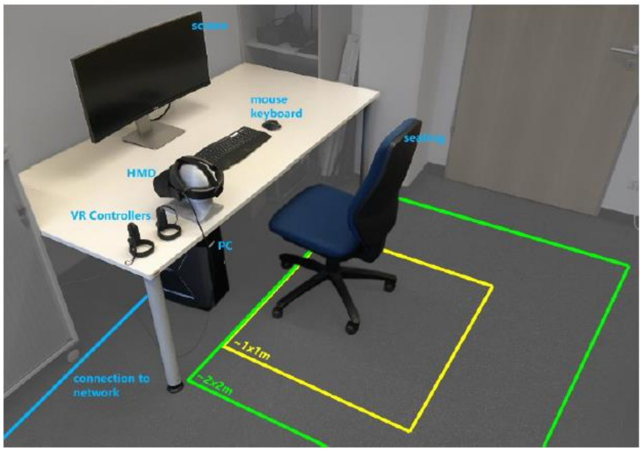

Figure 2. Shore Control Station Set Up

3 HUMAN-MACHINE-INTERFACE WITH VR/AR

Situational awareness (SA) describes the mental state of a person to be aware of the elements in his environment and their meaning [5]. Situational awareness plays a particularly important role during vehicle control, a situation in which the environment may be subject to high dynamics. The studies [6] found that 71% of all human errors are mainly caused by insufficient situational awareness. Therefore, during the development of the FernSAMS assistance system, ensuring the operator's high SA was one of the main criteria for evaluating the human-machine interface.

3.1 *Virtual and Augmented reality*

Virtual Reality allows the users to experience the real world [9], which is one of the key characteristics for compensating sensory losses like kinetic and tactile perception during remote control from RCC. VR/AR-based HMI design in FernSAMS [Figure 3]aimed to improve situation awareness by creating a virtual/augmented environment that resembles the actual bridge system with a human-centric design.

3.2 *Virtual bridge system*

The VR/AR system was implemented with the Unity 3D engine and used the ship's data to generate 3D visualization. The virtual bridge's current design were modified and improved based on the feedback and surveys during simulation runs [15]. The main information displays and virtual representations are as follow:

- Navigational data display
- ECDIS / radar
- Top-down display for LiDAR sensor
- Environmental data (wind) display
- Joysticks and touch buttons for VSP command
- 3D space with the virtual ocean, ships, and line

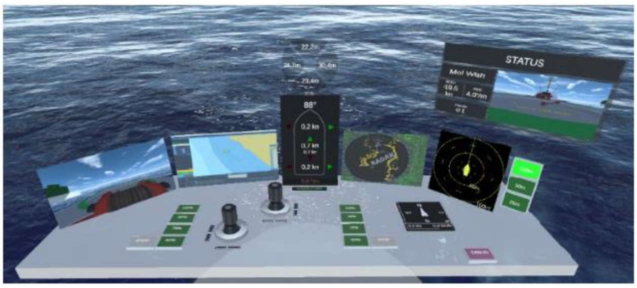

Figure 3. Virtual bridge in simulation

4 SIMULATION RUN

Within FernSAMS, extensive simulation runs and usability tests have been carried out with a state-of-the-art RME ANS 6000 simulator with two bridges from project partner MTC Hamburg GmbH. The knowledge gained in the simulation test regarding the usability test with different setups was transferred to In-Situ Model Test. In the simulations, three different setups were tested as below and compared to a zero alternative, where the simulated vessel was directly controlled. With regards to the test set-up and detailed results it is referred to [2].

4.1 *VR with Oculus Touch Controllers / Oculus Touch Hand rotation*

The new setup of an innovative approach not only for controlling a tug, but also for inputting and displaying information initially caused difficulties for the test person. The unfamiliar controls and the initially obstructive visual system (due to the image quality in the VR view) made the manoeuvres difficult.

Only after a certain training phase and certainly also with the support of the additional setup solution mentioned in section 3 was it possible for the test person to understand the visual system in a differentiated way. After a certain training phase, manoeuvres with this setup were possible without problems. However, it can be assumed that an adequate period of acclimatisation to the VR goggles is necessary to enable the helmsman to work under VR for a longer period of time.

4.2 *VR with Voith handles*

As mentioned earlier, this setup was included in the evaluation of the runs based on initial feedback from users and served to help the test subject become familiar with the VR system. After initial problems, this setup proved to be the best among the VR setups [Figure 4]. The desired functionalities visible through the goggles and the familiar control via the haptic feedback on the position of the levers made it easy for the test person to safely steer the ship as usual. The lack of freedom in VR due to the missing controls was not perceived as annoying. In general, the functionalities were based on templates and menus and arranged according to subject areas.

The results from this simulation run showed that the operator preferred to use the No.3 setup to feel direct haptic feedback of the commanded values to limit sensory loss [2]. And another important finding from the simulation test is that one operator can conduct harbour tug manoeuvring and towing runs with the developed AR/VR system.

Figure 4. Simulation run at MTC

5 TECHNICAL SET-UP FOR IN-SITU MODEL TEST

After the simulation runs with other industrial partners, the actual system integration and communication test have been carried out for the In-Situ Model test. FernSAMS's assistance system has been integrated with the Voith Schneider propulsion (VSP), Macgregor Maritime Data Engine (MDE), Media Mobile communication system.

5.1 *Overview of the system architecture*

Figure 5 shows the system architecture for the In-Situ Model test. The system integration's main focus was to minimize the latency in the communication and achieve steady reliability during remote operation. The distinctive difference with the simulation run setup is that 360 degree-camera and LiDAR sensors were integrated with the VR/AR system. The LiDAR sensor was chosen as 2nd visualization sensor to detect adjacent objects efficiently with low bandwidth.

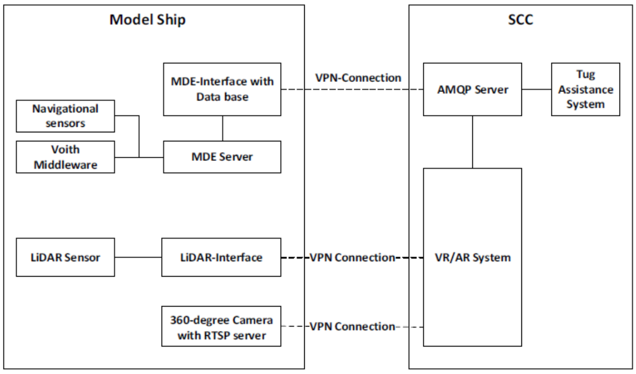

Figure 5. System architecture

5.2 *System integrations*

Macgregor's Maritime Data Engine is a data normalizer that collects and standardizes the data from the ship's system. MDE provides standardized Open Platform Communication United Architecture (OPC UA), a data exchange standard for industrial communication [14]. The MDE has been integrated with the voyage sensors and Voith Schneider propulsion system for the model ship's standardized data collection. The data collected from the MDE is converted into XML format and transferred to the AMQP server in the RCC with the fixed interval via Virtual Private Network (VPN).

The latency and limitations of the networks, such as the bandwidth, are the main challenges of remote rendering [13] from the 360-degree camera into the VR/AR system. The study [1] shows that low latency (below 1 second) is achievable with Realtime Streaming Protocol (RTSP) and VLC plugin integration within VR/AR system. In the FernSAMS project, the 360-degree camera was integrated into the ship's side local area network, and 360-degree image rendering can be done via VR/AR system over the VPN.

For the Point cloud data streaming from the LiDAR sensor, Robot Operating System (ROS) is integrated with the LiDAR sensor for the point cloud data pre-processing. A voxlgrid filter was used to down sample the point cloud data. The VR/AR system can subscribe the pre-processed data over ROS bridge server, which provides a WebSocket transport layer.

In the RCC, all the information is shared via the AMQP server, which is a message broker allowing two parties to communicate. The VR/AR system interacts with Tug Assistance System (TAS), a desktop application developed by the Qt C++ framework. TAS subscribes relevant XML data from the AQMP server and transfers created sea-chart back to the AMQP server. The MDE interface communicates with the AMQP server in the RCC bidirectionally.

5.3 *Communication*

Communication plays a crucial role in remote control [3]. The communication link should be robust and secure for the real-time data transmission between the ship and RCC. In the FernSAMS project, the communication link consists of three independent communication channels as below.

– Point-to-Multipoint (PMP)
– Mesh Networks
– Very Small Aperture Terminal (VSAT)

The maximum bandwidth, packet losses, and latency of each communication channel must be taken into account to cope with worst-case scenarios that limit the system's full functionality. Increased packet losses and latency in the network causes serious artifacts during the steaming from 360- degree camera in the VR/AR environment. In the VSAT communication channel, the video streaming from 360- degree camera is set to be disabled for secure data transmission in limited bandwidth and longer latency. Besides, the communication between the ship and RCC should be monitored. For this purpose, the information about the connection quality ("0" undefined, "1" very poor to "5" very good) for each connection type (PMP, Mesh, VSAT) is transferred to the MDE server. Therefore, the operator is able to confirm the network condition and diagnose the problems in the virtual bridge.

6 RESULTS FROM IN-SITU MODEL TEST

The findings gained in the simulation with regard to the usability of the various test setups were transferred to the model tests of the system. An important outcome of these tests was the need for direct haptic feedback of commanded values through joysticks as opposed to gesture-only control to limit sensory loss. Furthermore, the pass-through AR interface was highlighted as an intuitive technology to minimize sensory loss for vision.

Thus, two setups were tested in the simulations:

1. operation from the VR with Voith handles
2. operation from the VR with Oculus Touch hand rotation

Additionally, a direct remote control with direct visual contact from ashore was used as a back-up and zero alternative.

Figure 6. Model Ship

6.1 *Data tracking*

During the test runs [Figure 6] it was possible to record 23 parameters. The recording was carried out at 1Hz and stored in the database with a time stamp.

- Id: the sequence of the data
- InstanceID: Instance ID represents different sessions
- Timestamp
- Longitude (± 0 - 90 Degree)
- Latitude (± 0 - 180 Degree)
- Rate of turn (degree / minute)
- Heading (0-360 degree)
- COG (0-360 degree)
- SOG (kn)

Subdivided between the sent or commanded values and the received or controlled values.

1. Commanded values
   - EOT 1
   - EOT 2
   - VSP Steering 1
   - VSP Steering 2
   - VSP Driving 1
   - VSP Driving 2
2. controlled values (feedback)
   - EOT 1
   - EOT 2
   - VSP Steering 1
   - VSP Steering 2
   - VSP Driving 1
   - VSP Driving 2

The type and quality of communication was also investigated and recorded.

- Communication type (1-3): each number represents a different communication channel (1: Mesh 2: PMP 3: VSAT).
- Communication quality (1-5): index numbers on communication quality (5 is the best quality and 1 is the worst quality).

Figure 7. Plot from trial run

For the evaluation, different parameters were compared to show how the transmission of the data and the execution of the manoeuvres worked. For this purpose, in addition to comparing the data, the positions of the ship were plotted on a map at intervals of 10 seconds (Figure 7).

Both together give a good impression of the feasibility of a remote-controlled system. For explanation, here is one of these plots and the corresponding data comparison (Figure 8). For simplicity, the descriptions of the values have been abbreviated.

In the first graph, the heading and the COG (course over ground) were compared. In order to make statements about the quality (CommQuality) and the type of communication used (CommType), this was also implemented in the graph and multiplied by 100 for better representation.

The values from the commanded values and from the control were compared in separate graphs. The designations were changed slightly. Position 1 is always the eighth system and position 2 the front. This resulted in the following abbreviations:

- VSP Steering VSPS Aft
- VSP Steering VSPS Bow
- VSP Driving VSPD Aft
- VSP Driving VSPD Bow

The suffix com or ste stands for the commanded or steered values.

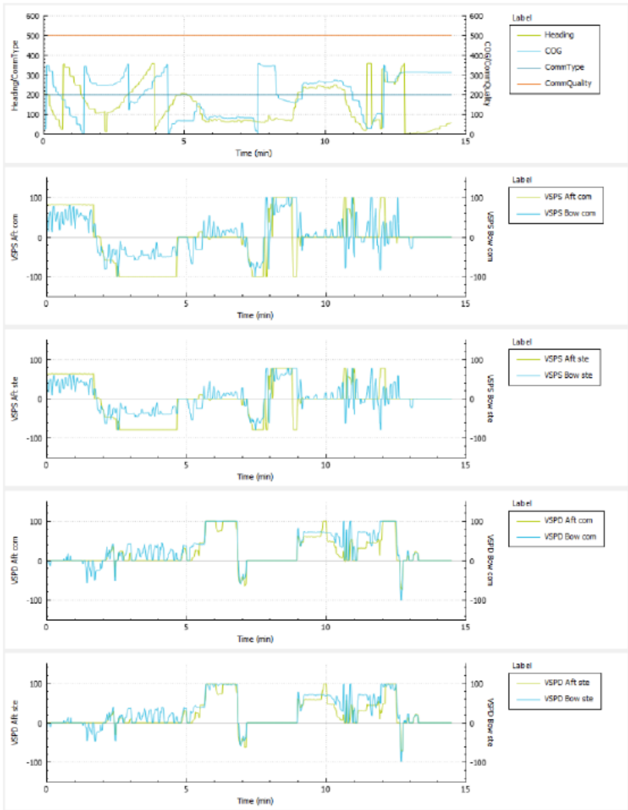

Figure 8 Graphical representation of the parameters of a trial run

6.2 *Lessons Learned from In-Situ-Test*

In the measurement runs, possibilities for the remote control of tugs were successfully demonstrated under the thematically similar running topics as in the simulation runs. As in the simulation runs, similar performance indicators were used for the measurement runs. These were defined in advance with the corresponding benchmarks in order to be able to carry out a good evaluation. The Key Performance Indicators used for the evaluation of the VR Remote Tug Assistance are basically:

- Stress on the subject,
- Comparison of receptivity between the different setups,
- Orientation in the different systems,
- Efficiency in manoeuvring the tug

Through the runs in the simulator and the previous assessment of possible control systems, an ideal set-up for the test person could be established for the in-situ test. Even with the new perspective through the VR glasses, which was still unfamiliar in the simulation, a familiarity with the system and the operation was now clearly recognisable. The operator experienced significantly less sensory loss during the 360-degree visualisation in the VR environment [Figure 9] than in the simulation. The interaction between the command interface in the VR/AR system and the model vessel was very responsive in terms of latency in communication, and the operator does not feel any significant delays.

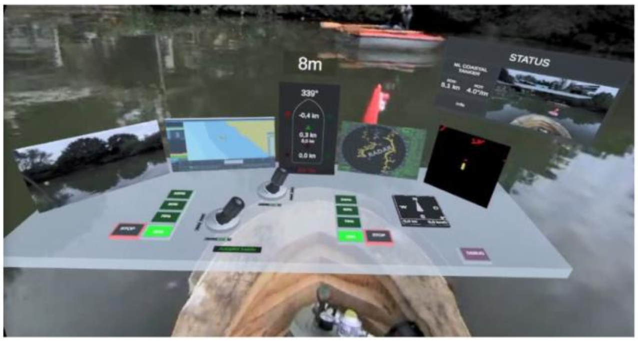

Figure 9. Virtual bridge with 360 degree-camera streaming

The graphical representation of the in-situ test runs provides us with insights into latency times in connection with different transmission qualities. The basic finding in addition to the graphical evaluation in connection with the visual representation of the run and the underlying objective shows that a tug can be controlled in a controlled manner with the aid of a remote control within the framework of the tested set-up.

A final determination as to whether and to what extent this concept can be used on tugs in the future can only be made with the help of a real test on a real tug.

7 CONCLUSIONS

Based on the executed technical demonstration tests, the principal technical feasibility of a remote controlled tug according the the FernSAMS-concept can not be denied. The legal feasibility has not been assessed by this project, however, the ongoing work on international and national levels with regards to MASS are expected to allow for a legal perspective on remote tug operation's feasibility as well. With regards to the further development, a more in-depth feasibility study with a full-scale demonstrator vessel is recommended. Further, additional technical stabilization measure as well as defined fail-to-safe-procedures are necessary for a commercial realization. With regards to the AR scope, the visualization of the HMI during pure satellite connectivity must also be further investigated.

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