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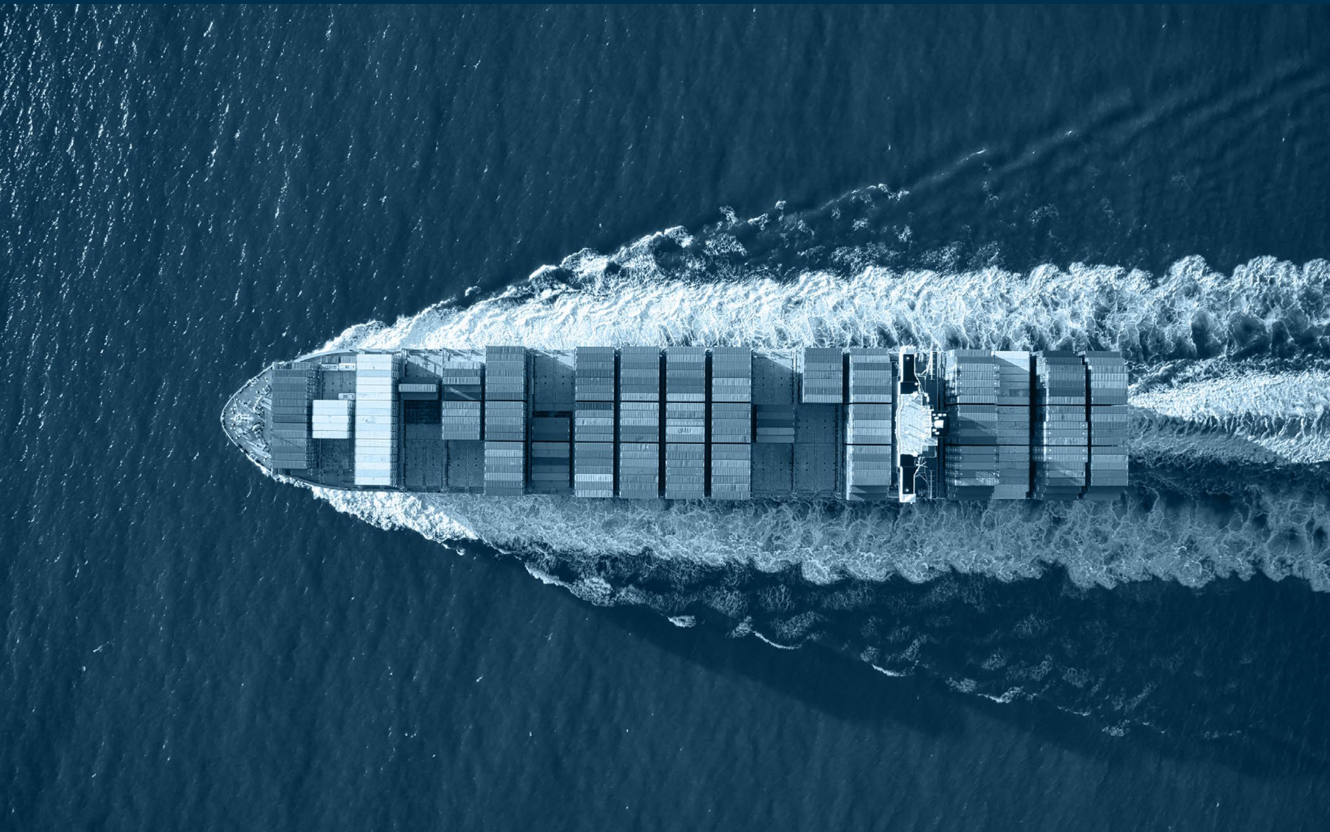
Reports

Jarkko Paavola & Suvi Kivelä (eds.)

Development of Applied Research Platforms for Autonomous and Remotely Operated Systems

Results from the ARPA project 2020–2023



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Development of Applied Research Platforms for Autonomous and Remotely Operated Systems

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MINISTRY OF
EDUCATION AND CULTURE
FINLAND

NOVIA
UNIVERSITY OF APPLIED SCIENCES

TURKU AMK
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Content

Maritime RDI Environments

The Data Platform

Industrial RDI Environments

Introduction

Dear reader,

Welcome to the final deliverable of the ARPA project, a collaborative effort between Turku University of Applied Sciences and Novia University of Applied Sciences from 2020 to 2023. ARPA acronym stands for Applied Research Platform for Autonomous Systems. Due to their importance for South-West Finland, we focused on the digitalization of marine industry and shipping.

Funded by the Ministry of Education and Culture with a two-million-euro grant for the period of 1.10.2020-31.12.2023, the ARPA project is part of the RDI profiling initiative. This initiative strategically positions both universities to focus on autonomous systems in the future.

The journey towards fully autonomous logistics involves significant steps such as remote operations and partly automated vessels. However, this journey is long and heavily dependent on the evolution of regulatory processes.

The ARPA project was structured around three focus areas: physical environments, virtual environments, and a Data Platform that bridges these domains. Our results, which are available in this publication and ARPA blog https://arpa-project.turkuamk.fi/blog/, demonstrate the synergy between these areas.

Physical research platforms are a test vessel, a Remote Operation Center (ROC), and industrial environment. Metaverse, digital twins and simulations create meaningful digital prototyping and testing environments complementing physical RDI environments. The data platform is the central hub for all the data collected in physical test environments and produced within digital twins and simulations. The platform will be utilized in distributing open data sets.

Main results presented in this publication are the following:

- Development maritime RDI environments
  - Test Vessel eM/S Salama is presented in (ref. Test Vessel eM/S Salama), its sensoring platform for navigational situational awareness in (ref: Sensor Platform Design), and wireless connectivity to provide data transfer to Remote Operation Center (ROC) in (ref: Wireless connectivity for situational awareness and remote operations)
  - Remote operation center for the eM/S Salama is presented in details in (ref. Remote Operations Center) and it is Metaverse applications in (ref: Next Generation ROC Solution - Visualizing Sensor Fusion to Enable Remote Control of an Electric Boat Inside the Metaverse)
  - Novel use case for remote operation center is Remote Pilotage concept in (ref: A Virtual-Reality Remote-Pilotage Concept). Majority of communications in maritime domain is still speech in VHF frequencies. The digitalization concept for providing this information to ROC is investigated in (ref: A Concept of Maritime Automatic Speech Recognition)
- The Data Platform and related data governance is presented in (ref: Data Platform Design). A way forward towards true maritime digital twin is presented in (ref: Towards a Roadmap of Maritime Digital Twins). Cybersecurity issues are considered in (ref: Cybersecurity threat information sharing for the maritime environment)
- In addition to maritime environment, ARPA project developed also robotics and automation test platforms for targeting Industry 4.0 applications in factory environment as presented in (ref. RDI environment for advanced robotics and autonomous work machines), and in (ref: Industrial Metaverse Approach – How to Remotely Control Robots in a Multiuser Environment) for Metaverse approach.

The ARPA project has significantly impacted both participating universities of applied sciences. We now look forward to continuing our work with external stakeholders, including companies, authorities, universities, and research organizations. Our goal is to enable the development of reliable, safe, secure, and trustworthy remotely operated, automated, and autonomous systems.

Thank you for your interest in our project.

Jarkko Paavola, Project Manager, Turku University of Applied Sciences
30th of November 2023, Turku

Maritime RDI Environments

Juha Kalliovaara, Mika Seppänen, Ari Putkonen,
Jani Auranen, Juhani Hallio & Juho Koskinen

Test Vessel eM/S Salama

In response to the growing need for advanced testing infrastructure in the maritime industry, a decision was taken to build a test platform dedicated to maritime environments within ARPA project. This innovative endeavour was made possible by applying for and receiving additional investment funding, notably the TEHOTEKO project (January 2022 to August 2023). The primary objective of the TEHOTEKO project is to provide support to small and medium-sized enterprises (SMEs) in tackling the challenges posed by the integration and application of artificial intelligence (AI) algorithms to their operations. TEHOTEKO is financed by the European Regional Development Fund (ERDF).

While TEHOTEKO encompasses a diverse range of AI and machine learning applications, Turku University of Applied Sciences (Turku UAS) has made a strategic decision to specialize in the field of maritime environments. As a result, the test platform of the project was chosen to be a test vessel with advanced sensing, ICT, and AI capabilities. The test vessel will be tightly integrated into the existing ARPA project test infrastructure.

Test vessel features

The vessel is equipped to function both manually and autonomously. It boasts a state-of-the-art commercial autopilot implementation, with navigational devices from the Furuno product line. A remote operation centre was also built to allow seamless control and monitoring of the vessel.

The autonomous operation is based on the Robotic Operating System 2 (ROS2) software architecture. The vessel's multi-satellite navigation system is compatible with GPS, GLONASS, BeiDou, Galileo, and QZSS satellites.

To enhance situational awareness and facilitate the vessel's ability to detect other boats and potential obstacles, it boasts an array of multi-modal sensor systems. These encompass a comprehensive suite of technologies, including Lidars, RGB and thermal cameras, AIS (Automatic Identification System), radars, and more.

In support of AI algorithm testing, an advanced ICT infrastructure has been integrated into the test vessel. This allows seamless integration and testing of artificial intelligence capabilities within the maritime domain. Moreover, the inclusion of the BHI SmartBox for wireless connectivity guarantees uninterrupted data transmission and communication by aggregating several links from different technologies, such as mobile networks and satellites.

The test vessel serves the Finnish industry in testing and developing their AI and Machine Learning (ML) –based solutions in many different application areas. The test vessel is pivotal in collecting data from the multi-modal sensor system for ML datasets and studying wireless connectivity in maritime environments. The test vessel is shown in Figure 1.

Figure 1.
The test vessel eM/S Salama.

Phases in the development of the test vessel

The development of the test vessel is not a trivial task, and it includes several challenging phases. The different phases are described briefly in the following.

1. Defining Requirements and Specifications: The initial phase involved a thorough examination of the vessel's requirements and specifications. This includes crucial parameters like size, weight, speed, power, and the essential regulatory and certification standards that must be adhered to.
2. Electrical System Design: A pivotal aspect of the project was designing the vessel's electrical system. This includes accommodating a variety of electronic devices, necessitating a provision for 12/24/48 V DC and 230 V AC electricity. Overcoming non-trivial challenges related to safety, interference, and grounding is crucial for ensuring the system's safe and efficient operation. The team also designed the charging system and acquired an aggregate for a reliable backup energy source.
3. CAN Bus Architecture Design: The development of the Controller Area Network (CAN) bus architecture is paramount for seamless communication among the vessel's various devices. The vessel's equipment relies on NMEA2000, J1939, and CANopen messages for effective interaction.
4. Simulations: The team conducted comprehensive simulations to assess both the overall vessel's NMEA2000 system and the vessel's resistance characteristics. This includes evaluating frictional resistance, wave-making resistance, and air/wind resistance.
5. Procurement of Key Components: Sourcing essential components like the hull, motors, and batteries is a critical step. The team acquired these components from established commercial suppliers while ensuring their compatibility with the overall system design.
6. Motor and Rudder Controller Design and Implementation: The design and integration of a motor controller are essential for enabling motor control via NMEA messages, facilitating remote and autonomous operations.
7. Sensor Selection and Integration: The team focused on identifying the most suitable sensors for capturing essential data for ML datasets and obtaining situational awareness.
8. ICT Subsystem Design and Implementation: The development of the Information and Communication Technology (ICT) subsystem is instrumental in facilitating data processing, storage, and seamless communication within the situational awareness system.

9. Electrical System Implementation: This phase involved the installation and integration of electrical system components, including batteries, power distribution panels, wiring, and safety devices, all executed in strict accordance with electrical and safety standards.
10. CAN Bus Integration: Connecting and configuring all pertinent electronic systems – encompassing propulsion, navigation, sensors, and control systems – through the CAN bus system.
11. Rigorous System Testing and Compliance: Thorough system testing is conducted to ensure the vessel complies with all pertinent safety regulations, certifications, and guidelines. This phase also entails the careful preparation of documentation for registration. Notably, this work marks a pioneering milestone, as it represents the first work boat in Finland to utilize electric propulsion.

Figure 2 shows the roadmap for the test vessel development. The vessel launch event was held in June 2023 in Ruissalo, Turku, Finland. The vessel was named eM/S Salama. Test drives were conducted during summer 2023 and data was collected from the sensors for ML purposes. This data will be annotated during winter 2023–2024. The development of the autonomous features is on-going, and the features will be field-tested during summer 2024. Extensive studies of mobile network coverage and suitability of mobile networks for remote operations will also be conducted during 2024.

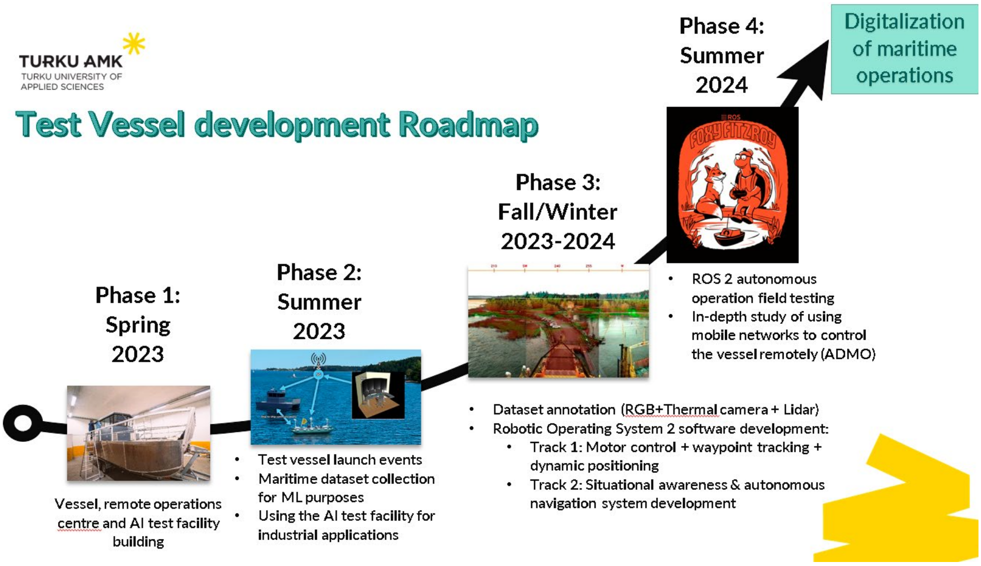

Figure 2.
Test vessel development roadmap.

Conclusions

The test vessel serves as a dynamic and versatile test platform. The ICT and sensor system can be upgraded and further developed in iterations to meet the evolving needs of the maritime industry.

Foremost, the test vessel plays a pivotal role in the collection of machine learning datasets, serving as an invaluable resource for sensor fusion, object detection, tracking, and scene understanding. The vessel's comprehensive suite of sensors and AI-driven capabilities facilitate the gathering of crucial data for the development and enhancement of machine learning models tailored to maritime applications.

Additionally, the vessel supports critical studies in wireless connectivity coverage within the maritime environment. By conducting coverage studies, it helps refine the effectiveness and reliability of wireless communication systems at sea.

The utilization of the Robotic Operating System 2 (ROS2) further enhances the vessel's capabilities, allowing for efficient sensor control, data acquisition, and motor control through its distributed systems and modular architecture. Vessel data management, featuring a well-structured data platform architecture and storage solutions, ensures the seamless handling and storage of the vast amounts of data generated during its missions.

Beyond this, the vessel serves as a hub for wireless communications and remote operation and monitoring, enabling real-time control and oversight.

In the future, we will be integrating drone fleets (both aerial and underwater) into the test vessel's overall system, enhancing situational awareness and extending the scope of data collection for advanced applications in maritime AI.

Furthermore, the vessel plays a pivotal role in field trials and pilots, validating the efficacy of machine learning algorithms, physical products, and wireless connectivity solutions. Its adaptability and versatility position it as a crucial asset in advancing technology and innovation within the maritime domain, making it an indispensable tool in the ongoing evolution of the maritime sector.

Juha Kalliovaara, Jani Auranen, Tommi Tuomola
& Amin Majd

Sensor Platform Design

To enable digitalization and efficient maritime operations, we need different types of sensors. Data from sensors can be used for decision-making support, smart diagnostics, monitoring, and remote operation.

This article focuses on sensors and wireless connectivity of autonomous systems. These are the backbones for creating situational awareness and enabling remote operations.

Autonomous vessels face the critical challenge of achieving precise situational awareness to inform their decision-making processes. This challenge arises from a lack of information regarding the vessel's immediate surroundings, necessitating the collection of comprehensive data from diverse types of sensors.

Object detection using computer vision in the maritime environment is a very challenging task due to varying light, view distances, weather conditions, and sea waves, to name a few. False detections might also occur due to light reflection, camera motion, and illumination changes. No single sensor can guarantee sufficient reliability or accuracy in all different situations. In multimodal sensor fusion, we combine information from several types of sensors to overcome weaknesses in different sensor types to ultimately obtain more robust situational awareness [1].

The ARPA project aims to produce open data sets for research in machine learning algorithms relating to improved situational awareness. This data will also be published openly and on the ARPA data platform described in article Data platform design.

Sensor platform for stereo vision data collection

In the realm of autonomous navigation and computer vision, precise distance estimation is paramount to ensure the accuracy and safety of applications such as self-driving vehicles, robotics, and augmented reality. An innovative approach to addressing this challenge involves the simultaneous use of dual RGB cameras and Lidar technology, with Lidar serving as the ground truth benchmark.

In this system, a pair of RGB cameras captures environmental data from slightly different perspectives, emulating the principles of stereoscopic vision. This stereoscopic setup enables the extraction of depth-related information. Each RGB camera records images from varying angles, and the disparities between corresponding points in these images are analysed to derive accurate distance measurements. This technique, commonly known as stereo vision, excels at delivering precise distance estimations.

To enhance the accuracy of distance estimations, Lidar technology is incorporated. Lidar, short for Light Detection and Ranging, utilizes laser beams to measure distances and angles to objects within the environment, resulting in a detailed 3D point cloud representation. Lidar produces precise spatial information that serves as a reference point for accuracy in the context of stereo vision camera data.

We constructed a portable system consisting of two RGB cameras and a Lidar mounted on a steel tripod with an aluminium crossbar. The cameras are affixed to the top surface of the bar with t-nuts and an aluminium plate to prevent rotation along the z-axis. The separation distance between the stereo cameras is approximately 157 centimetres, and their height from the pier deck is 128 centimetres. The pier's height from the water level is about 45 centimetres, and the estimated camera height from the water surface is 173 centimetres.

We employed Hikvision DS-2CD2T45G0P-I cameras with a wide-angle 1.68mm focal length, configured at 4 MP resolution in fish-eye mode. The cameras operated with minimal digital noise reduction and smoothing, a fixed aperture time of 1/50 seconds, and enabled features like high dynamic range and automatic gain adjustment.

The Lidar system we utilized was a Velodyne VLP-32C, capturing data at 10 Hz within a 140-degree front sector, matching the effective camera field of view. This setup was carefully designed to prevent any laser light interference with the camera lenses, reducing glare and reflections. For synchronization, a laptop served as an NTP server for the cameras, ensuring precise system clock alignment using a USB-connected GPS receiver.

The data was collected from a pier at Dalsbruk Marina in Finland during the busy summer period in July 2022. Other weather conditions have also been generated by using generative adversarial networks (GANs) with the data collected [2]. Figure 1 illustrates the equipment installation on the pier, which comprises a tripod with two RGB cameras in stereo mode and a Lidar. The tripod was set up on a floating concrete pier anchored to the shoreline and the sea bottom, with some slight swaying and heaving when waves from passing boats impacted the pier. The cameras were primarily oriented in a north-east direction.

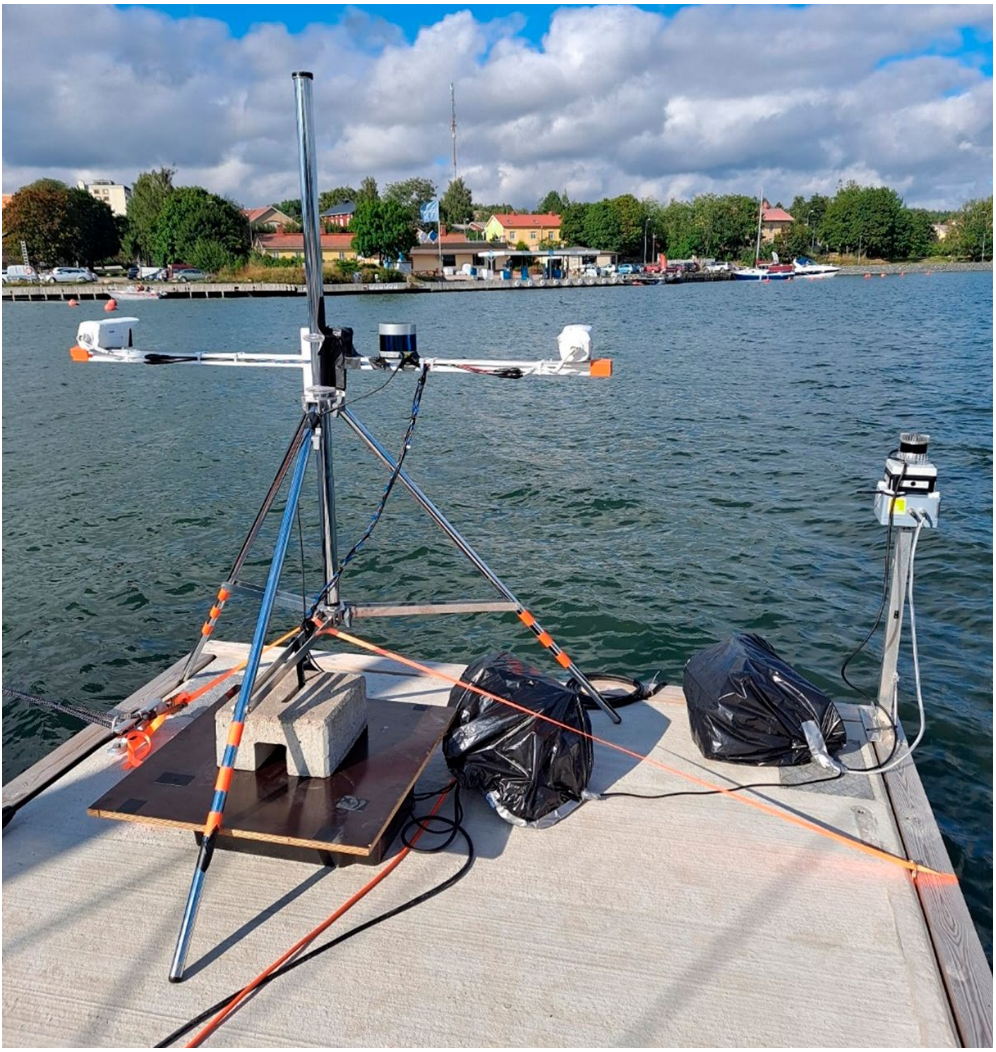

Figure 1.
Stereo vision camera setup installed in Dalsbruk Marina.

The data was annotated during winter 2022–2023, and the full dataset will be published in late 2023. Other publications are currently in preparation. Data was also collected with the same setup from a moving vessel, but it is still being annotated. An improved version of the stereo camera setup is being developed for a fixed installation on the eM/S Salama test vessel. It will include a higher-quality RGB camera pair.

Sensor platform of eM/S Salama for data collection and real-time situational awareness

We aim to advance maritime environmental sensing through multi-modal sensor fusion. Our autonomous test vessel, eM/S Salama, is equipped with an array of sensors, including RGB cameras, LiDAR, and thermal cameras. In the future, this innovative platform will expand to integrate data from a drone positioned atop the vessel, along with image data sourced from an underwater drone and supplemented by sonar data.

The primary objective is to synchronize data from these diverse sources to facilitate multi-modal sensor fusion. Our goal is to leverage the combined capabilities of these sensors to construct a comprehensive 3D model of the maritime environment. The technology involved encompasses advanced data integration techniques, multi-sensor calibration, and fusion algorithms. The resulting 3D model will provide valuable insights into our maritime surroundings, enabling enhanced environmental monitoring, smart navigation, and situational awareness in complex aquatic scenarios.

Our sensor array, shown in Figure 2, comprises three key components: RGB cameras, thermal cameras, and Velodyne LiDAR. Designed for autonomous maritime applications, this system ensures data collection for sensor fusion and real-time situational awareness.

The camera array consists of three weather-proofed RGB and thermal cameras, creating approximately a 140-degree panoramic view for daylight and thermal imaging. These images are crucial for maritime operations, particularly in situations that demand precision and reliability.

For high-resolution RGB imaging needs, we rely on the Allied Vision Prosilica GT 1930 camera. Its exceptional performance, high resolution, and versatile software support make it ideal for applications in quality control, industrial automation, and scientific research. Three GT 1930 RGB cameras are employed to capture panoramic daylight images.

For thermal imaging, the Teledyne Dalsa Calibir DXM640 camera offers exceptional sensitivity and resolution. Designed for surveillance, industrial monitoring, and scientific research, its compact yet robust design suits both portable and fixed installations in maritime environments. Three Teledyne thermal cameras are used to obtain panoramic thermal images.

Complementing our sensor array is the Velodyne LiDAR VLP-32C, renowned for its compact size, wide field of view, high data accuracy, and real-time 3D scanning capabilities. This LiDAR sensor is instrumental in ensuring safety and reliability in autonomous maritime operations, where precision environmental perception and 3D mapping are essential.

Figure 2.
The sensor setup.

The data collection system (Figure 3) consists of the RGB camera, thermal camera, and LiDAR data handler services that acquire the raw data from these sensor sources. The process orchestrator service is responsible for launching and synchronizing the data collection between the handler services. Synchronized sensor data can be used for multimodal sensor fusion. All the services are separated into their own Docker containers. The MQTT broker is used as a communication channel between the services. The raw data from RGB and thermal cameras is encoded with GStreamer and published as RTSP streams. In the current implementation, the LiDAR data is stored as PCAP files on disk.

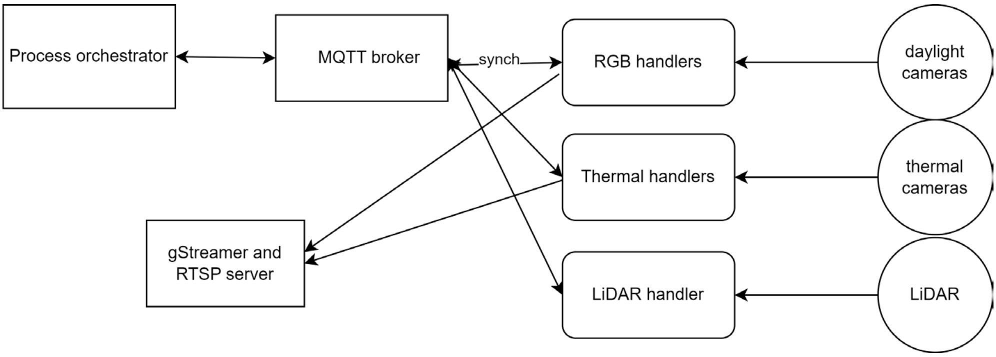

Figure 3.
Data collection system architecture.

Conclusions

One of the biggest obstacles in machine learning and sensor fusion research is the lack of domain-specific datasets. In the ARPA project, we will lend a hand to the research community by collecting sensor data from the marine environment and publishing it via our data platform and other publicly available platforms. The data will be published in open access so that all of the researchers in the field can exploit it in their research.

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Juha Kalliovaara, Tero Jokela & Pekka Talmola

Wireless connectivity for situational awareness and remote operations

Sensors and wireless connectivity of autonomous systems are the backbones for creating situational awareness and enabling remote operations.

To allow actual field trials of remote operations, we applied for extra funding that was used to build our test vessel eM/S Salama and the related remote operations centre. These are described in sections [Test Vessel eM/S Salama] and [Remote Operations Center].

For the in-depth study of wireless connectivity in a maritime environment, additional funding was applied for and received from Business Finland for the ADMO project [1], which started in March 2023 and will continue until 2025. The project will continue the activities started in ARPA and described in this article.

Maritime wireless connectivity

To enable digitalization and efficient maritime operations, we need wireless communication systems and different types of sensors. Data from sensors can be used for decision-making support, smart diagnostics, monitoring, and remote operation. Digitalization presents many opportunities and advantages for industry players, but it can only reach its full potential when data flows are seamless.

In the maritime environment, no single connectivity technology provides a connection stable enough to allow for seamless data flow in every location. Therefore, a combination of different technologies with different capabilities is required. For example, mobile networks provide high capacities close to the shoreline, while no connectivity may be available in the open sea. Therefore, connectivity over a satellite network is required in this situation.

The maritime domain, one of the 5G vertical domains in 3GPP, is moving forward with digitalization and mobilization of the commercial and safety fields. Legacy 3GPP-based technologies and solutions can be used for the digitalization and mobilization of the maritime domain, but the legacy 3GPP technologies and solutions may not be able to fully support the requirements of digitalized maritime services. The maritime radio environment was not originally considered by 3GPP when the technical specifications and solutions were standardized for LTE and 5G.

Satellite access is one of the 3GPP radio access networks supported over the 5G system, so it is possible to provide seamless maritime mobile services in the open sea by integrating multiple access technologies including satellite access, depending on the service scenarios. However, satellite access has very different latency and bandwidth characteristics compared to terrestrial 5G, and thus it needs to be carefully analysed how the satellite access can meet the demands of remote control and other relevant use cases.

Maritime mobile networks and connectivity measurement campaigns

4G (LTE) and, more recently, 5G have revolutionized mobile (and even fixed) data communication for land-based terrestrial use, providing in the best case hundreds of Mbit/s bit rates and almost universal coverage. This has increased the interest in using mobile networks also for maritime, especially due to the increased requirements for high-speed data in many new applications like remote operations.

LTE is uses OFDM for the downlink and SC-FDMA for the uplink with a maximum bandwidth of 20 MHz, giving theoretical bit rates of 300 Mbit/s for DL and 75 Mbit/s for uplink. However, in practice, the maximum bit rates are lower – in many cases, on the order of 100 Mbit/s and 20 Mbit/s for a 20 MHz bandwidth. In addition, these are the maximum bit rates of a cell and are shared with all the users in the cell area. In a congested cell, the bit rates may drop to a few Mbit/s or even lower. LTE can use FDMA or TDMA, depending on the frequency band used. LTE has been deployed on many different bands from 700/800 MHz (B20/B28), 1800 MHz (B3), 2100 MHz (B1), and 2300 MHz (B40) to 2600 MHz (B7). For maritime use (as for any rural area), probably the most important are the low frequencies (700/800 MHz), as the propagation is much better than at higher frequencies, which are mainly used to cover densely populated areas with smaller cell sizes. For large rural and archipelago areas, the lower frequencies provide possibilities for much larger cell sizes, thus resulting in more economical network deployment. The downside is that in a large cell, the number of users can also be high, and the bit rate per user drops. Especially if a large passenger ship with thousands of users comes to a coverage area of a single cell, the drop-in bit rates can be dramatic.

5G is in many ways very similar to 4G/LTE, but it has more flexibility, many improvements, and new features. Bandwidths up to 100 MHz and higher are used, increasing the theoretical bit rates up to 1 Gbit/s (3.5 GHz band), although in practice, the maximum bit rates are lower on the order of a few hundred Mbit/s. 5G was initially deployed in the 3.5 GHz band (n77, n78) and currently also goes to the 26 GHz band and, more importantly for maritime use, to the 700 MHz band (n28). However, the larger bandwidths on the order of 100 MHz are not available in the 700 MHz band, and 5G uses the same 10 MHz bandwidth as low-frequency LTE. Therefore, the advertised high bit rates are not available for 700 MHz rural deployments. Still, 5G offers an improvement over LTE.

Although radio propagation over water is typically better than over land, and in many cases, line of sight (LOS) conditions apply, the available range from the base station is limited to a few tens of kilometres, even when using the 700/800 MHz bands. The consequence of this is that mobile network service is limited to coastal waters, giving a smaller range than VHF communication, for example. The situation is somewhat different if there is an archipelago, where mobile networks can be built using the islands. In this case, the backhaul network may be more critical than finding places for the base stations.

The population in the islands also forms a basic customer base, so building the network is economically more viable. A good example of this is the archipelago between Turku and Åland, which makes it possible to have almost full coverage for the sea route between Turku and Stockholm with only a short gap between Åland and the Stockholm archipelago. In general, Finnish coastal waters are fairly well-covered due to the large number of islands. Table 1 gives some properties of the different mobile bands. For the range in the lower 700/800 MHz frequencies, a higher upper limit has been added to reflect the better propagation over water.

Band [MHz]	**Technology** [4G/5G]	**Range** [km]	**Bandwidth** [MHz]	**Mode** [FDD/TDD]	**DL bitrate** [Mbit/s]	**UL bitrate** [Mbit/s]
700	5G	loka.30	10	TDD	110	55
800	4G	loka.20	10	FDD	75	25
900	4G	10	10	FDD	75	25
1800	4G	5	20	FDD	150	50
2100	4G	4	20	FDD	150	50
2600	4G	2	20	TDD	150	50
3500	5G	2	130	TDD	1200	400
26000	5G	0.5	800	TDD	8800	3000

Table 1.
4G/5G properties at different bands [2].

Measurement results from the Parainen-Nauvo ferry

In ARPA and ADMO, extensive measurement campaigns are performed to measure the current mobile network coverage and quality of service at sea and the fairways – the coastal fairways of Finland, especially in the Turku archipelago. Measurements between Naantali and Kapellskär will be conducted in the ADMO project on the ferries operating between Finland and Sweden.

The measurement campaigns study the signal propagation properties on the open sea and archipelago. We study how the handovers work at sea and how the mobile network deployments differ from normal terrestrial deployments. The propagation environment at sea is very different from that on land, and thus there might be different types of internal network interference, and the network signals may propagate differently due to the completely different environment. We study whether the quality of the service at the same signal level is worse at sea than on land due to these differences in the networks and the environment.

In coastal waters, the availability of 4G and 5G mobile networks is already rather good and increasing all the time. These networks allow for higher capacity connectivity for the ships and thus will enable more extensive remote digital services for the vessels. As for autonomy, the high capacity offered by the mobile networks enables remote surveillance and operations of the vessels.

The availability and quality of 4G and 5G networks have been measured in the Turku Archipelago to assess their suitability for autonomous operations. Some of the initial results from the 5G measurement at the Parainen-Nauvo ferry are shown in Figure 1. The figures illustrate the observed 5G signal levels in the 3500 MHz (left) and 700 MHz (right) bands. At this exemplary measurement, the signal levels from all three operators at 700 MHz are very good, and there are no problems with connectivity. In the 3500 MHz band, the signal levels were lower, due to the worse propagation properties of the higher frequencies. Naturally, this is a route that has many passengers during the summer, and the operators have clearly invested in the network in the area. Also, the measurements conducted at the fairways in the inner archipelago show that we have very good coverage. Lower coverage and quality of service are expected in the measurements that will be conducted in 2024 at the connection ships between the islands in the outer archipelago.

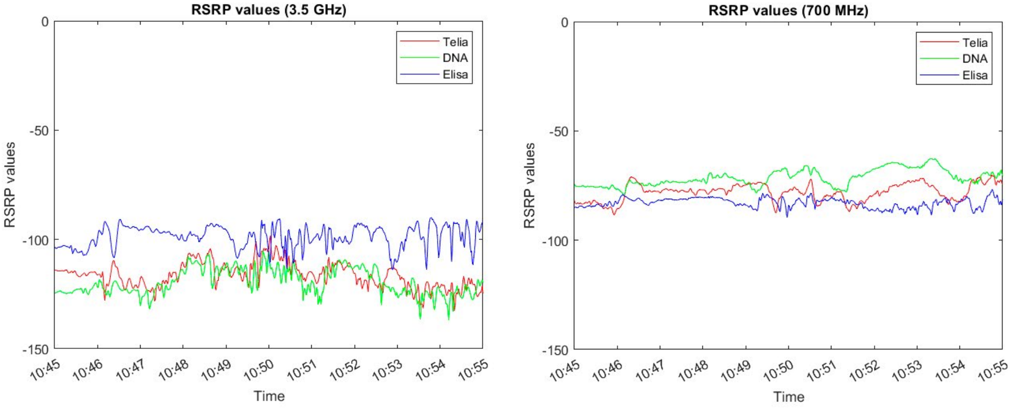

Figure 1.
Measured 5G signal levels from the Parainen-Nauvo ferry.

Further measurements and analyses on the measurements will be conducted and published in the ADMO project. The measurement results will be compared to the coverage maps that the mobile network operators have provided to Traficom. Also, we need to define whether the current key performance indicators and measurement methods are accurate enough or if we need to develop new ones. Existing measurement methods and available measured data on the performance of communication networks are thus analysed, and new measurement methods are potentially developed for future analyses.

In ADMO, we will also develop artificial intelligence (AI) mechanisms to study the operational reliability and radio environment of the 5GA wireless communication system to achieve optimal connectivity utilization. This information can be used together with the information on the expected wireless link coverage at the location of the vessel and the channel quality indicator data reported by the wireless systems to analyse and predict the state of wireless connectivity systems. We will investigate whether the vessel sensor data should be processed locally at the vessel or in the cloud depending, on the use case and state of the wireless links.

Remote Operations Centre trials

The sensors and actuators on the eM/S Salama test vessel will be connected to the Turku UAS remote operations centre, described in section [Remote Operations Center], using mobile networks to enable remote operations of the test vessel. If the existing network in the area is not sufficient for the requirements of remote operation, a base station of the Turku UAS 5G test network will be installed at the test area. We will integrate the AI algorithms developed in ADMO to evaluate the state of the wireless communications links to our research vessel and develop all the software components needed to pilot the remote operations.

The trials target the exploration and showcasing of the benefits and opportunities of 5G in a real operational environment. This allows for analysis of the additional value of 5G for maritime digitalization. The pilot will also study the use of other dedicated maritime connectivity technologies to allow for comparison to 5GA and investigating hybrid connectivity. Figure 2 illustrates how the test vessel is connected to the remote operations centre through a 5G network. It also shows other ADMO project use cases like ship-to-ship communications and ship internal communications.

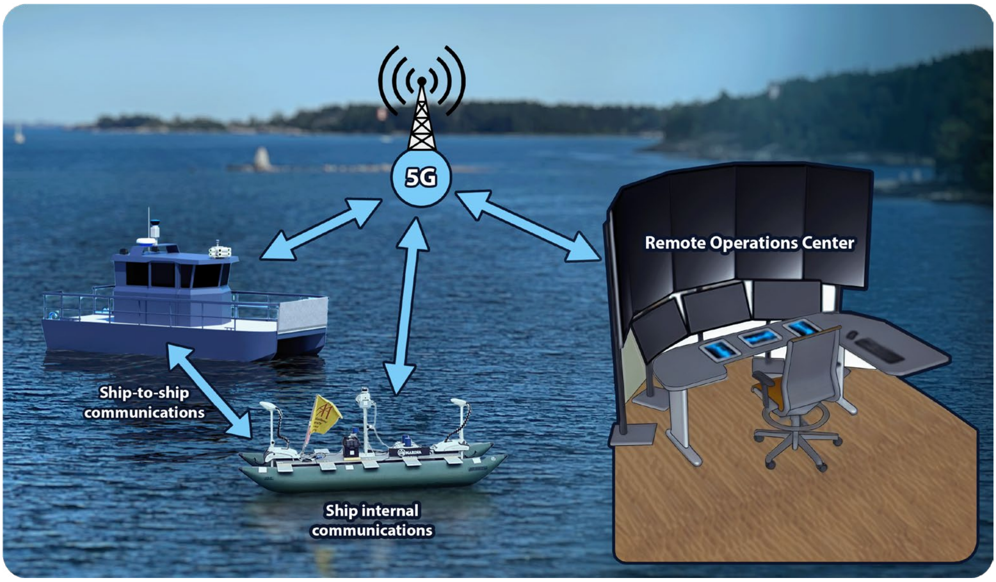

Figure 2.
The trial setup for remote operations.

Conclusions

Wireless connectivity is an integral component in the automatization of maritime transport. To enable autonomous and remote operations, wireless networks need to provide reliable connectivity in maritime environments. ARPA and related projects study the performance of current connectivity options from the point of view of maritime digitalization, and they trial selected use cases. This is important for the development of services based on autonomous operations. Also, the trials and studies increase knowledge on how wireless networks should be deployed to better serve maritime operations.

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Juha Kalliovaara, Juho Koskinen & Juhani Hallio

Remote Operations Center

In response to the growing need for advanced testing infrastructure in the maritime industry, a decision was taken to build a test platform dedicated to maritime environments. The chosen test platform is a test vessel with advanced sensoring, ICT, and AI capabilities.

To monitor the operation of AI and machine learning algorithms at the test vessel, a centre is needed from which the operation can be controlled and monitored without being physically on board. Remote monitoring and remote operation are particularly useful in applications where there is a limited number of experts with the required competence for the task and the distances to the physical operation sites are long.

For this purpose, additional investment funding was received from the European Regional Development Fund (ERDF) for the TEHOTEKO-ROC project, where a remote operations centre (ROC) was built. This deliverable briefly describes the design and features of the ROC.

Remote Operations Centre

The ROC represents a critical component in the test vessel's advanced operational infrastructure, designed to enable both remote monitoring and remote operation of the vessel. The ROC's software, procured from a reputable commercial supplier, has entered its final testing phase, with plans for a launch scheduled for late 2023.

One of the ROC's core functions is handling and visualizing telemetry data from the vessel. This data is transmitted efficiently through the utilization of NMEA2000 messages, ensuring a seamless flow of essential information. Moreover, video streams are transmitted via the Real Time Streaming Protocol (RTSP). Notably, the ROC is set to elevate its capabilities with the introduction of surround sound during the autumn of 2023.

Figure 1 shows a high-level illustration of the ROC implementation. The data from vessel interfaces is transmitted to a data processing and communication unit, which transmits the data wirelessly to the ROC-PC through a cloud service. The ROC itself boasts a display setup featuring five 55-inch screens and three 24-inch screens. This extensive array of screens serves various purposes, including providing a 180-degree view of the vessel's surroundings, displaying telemetry data, and showcasing map data. For operational control, tablets are employed, offering a user-friendly and versatile means of modifying and testing various control systems. This approach offers greater adaptability and efficiency than traditional physical controllers or exact replicas of the vessel's dashboard. Furthermore, the ROC is designed with scalability in mind, enabling the seamless addition of extra screens to display information from various sensors, such as side-view cameras, thermal imaging devices, and Lidar sensors. This adaptability further enriches the vessel's capabilities and operational flexibility. The ROC is located at the Turku UAS campus in Kupittaa, Turku.

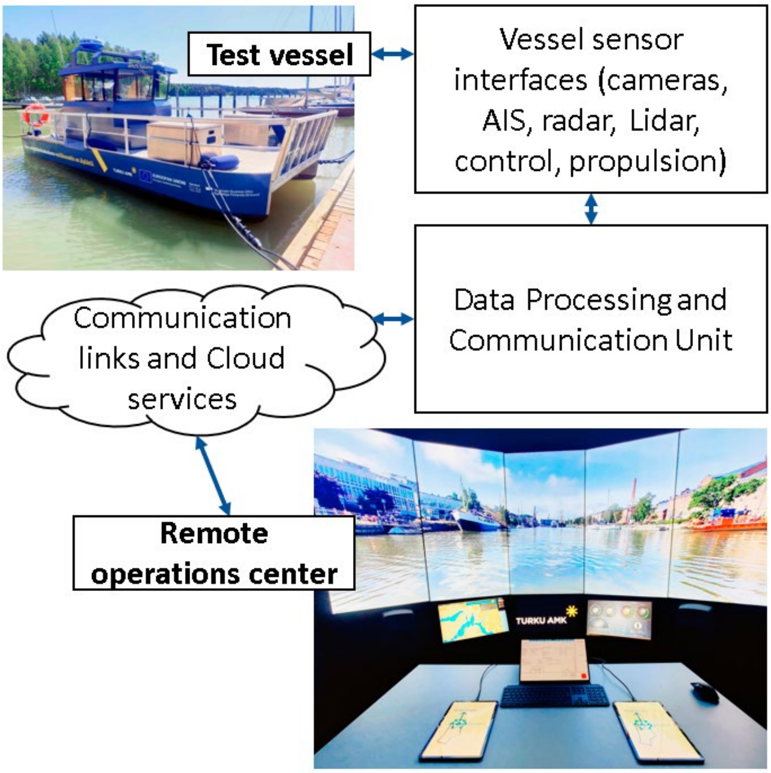

Figure 1.
High-level illustration of the ROC implementation.

The vessel’s motors and rudder are operated using an ESP32 microcontroller unit (MCU) –based dynamic control unit (DCU), which communicates with the vessel’s NMEA2000 bus. The motor and rudder controller architecture is shown in Figure 2.

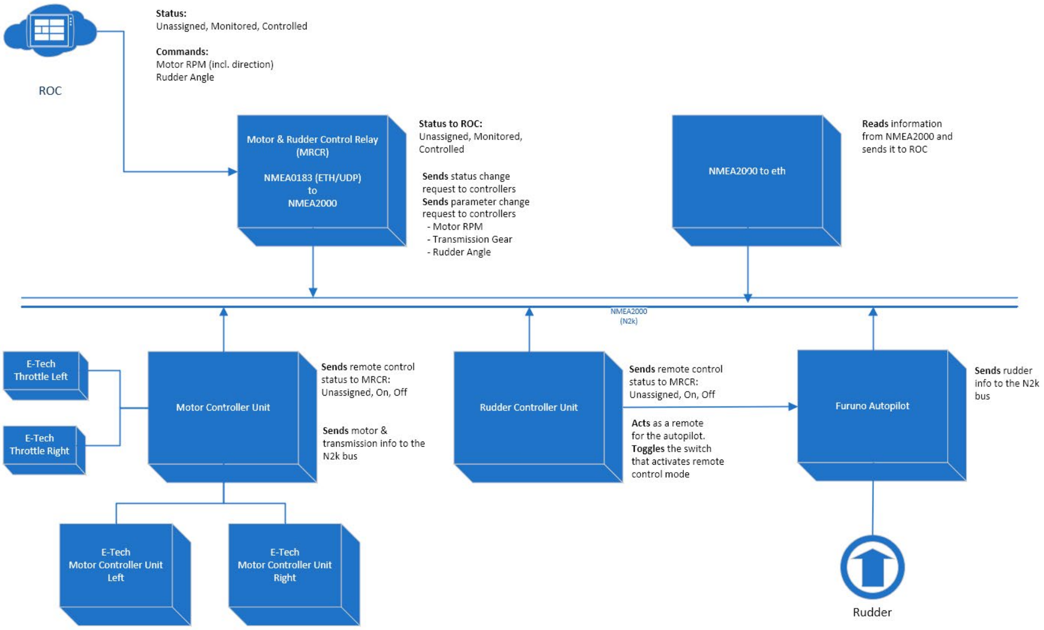

Figure 2.
Motor and rudder controller architecture.

The ROC can send commands to change the RPM of the motors and the rudder angle. The motor and the rudder control relay send status change requests to the motor and rudder controller units, which include the functions needed to change the RPM of the motors and the angle of the rudder. Status messages from the motors and rudder are sent to the onboard NMEA2000 bus.

The functionals of the DCU are divided into two devices with custom printed circuit boards (PCBs). One device controls motors mimicking throttle inputs, and the other controls the rudder as a remote for the Furuno autopilot. Both devices incorporate a CAN controller for NMEA2000 and a digital-to-analog converter (DAC) and relays. DACs provide throttle input and the rudder remote input. Relays are used for changing the throttle input provider and as a switch for the autopilot. The DCU includes several fail-safe functions. A heartbeat signal must be sent by the commanding unit at set intervals to maintain operational mode. The vessel's local operator can also revert to the manual operating mode by moving the engine control lever from idle or pressing an emergency button.

Conclusions

The ROC serves as an indispensable counterpart to the test vessel, seamlessly complementing its capabilities. By enabling remote monitoring and operation, the ROC augments the vessel's functionality, making it a dynamic and multifaceted platform.

For future development, the ROC could see improvements in several aspects. First, the introduction of advanced AI and machine learning algorithms could enhance the ROC's ability to process and interpret data, further optimizing decision-making and safety protocols. Additionally, integrating advanced cybersecurity measures would ensure the robust protection of sensitive vessel data.

Moreover, the incorporation of augmented reality (AR) and virtual reality (VR) technologies within the ROC could provide operators with immersive and interactive control interfaces, thereby revolutionizing vessel operation. Further improvements in real-time data analytics and predictive maintenance capabilities could enhance the vessel's efficiency and reduce downtime. A detailed description of the development of these next generation ROC features is given in an article [Next Generation ROC Solution - Visualizing Sensor Fusion to Enable Remote Control of an Electric Boat Inside the Metaverse].

In the future, the ROC may evolve to become an even more pivotal hub for real-time decision-making and enhanced situational awareness, harnessing the full potential of cutting-edge technology to push the boundaries of maritime operations.

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Next Generation ROC Solution

Visualizing Sensor Fusion to Enable Remote Control of an Electric Boat Inside the Metaverse

This paper presents a look into the integration of next-generation Remote Operation Center (ROC) solutions with the metaverse to enable remote control of vessels and vehicles such as our own electric test vessel eM/S Salama. It briefly summarizes how the Turku region is investing in ROC technology within the maritime sector, remote-controlled and autonomous vessels, our recent achievements in this field including the fusion of sensor data with ROC solutions, user interface design innovations, and the integration of all the above into the metaverse. As an example case, the paper explores the integration of an industrial metaverse into the ARPA physical test platforms and the development of a prototype with rich sensor visualization. The paper concludes with a discussion on the challenges encountered, future plans, and the potential combination of traditional ROC with Extended Reality (XR) and see-through implementations.

Background

The maritime sector has witnessed the evolution of Remote Operation Center (ROC) systems. For example, Turku UAS has acquired a solution with a fully customizable user interface supporting up to eight displays and with control options from touch controls to traditional ones. In addition, the ROC supports multiple displays for streaming high-definition video, data protocols to control equipment and advanced UI elements overlaying instruments and information. The ROC can be used in remote operations, remote monitoring, remote piloting, remote surveillance, and can also be connected to simulator environments in mariners' education and fleet management solutions [1].

In Turku, remote-controlled and autonomous systems to be used in maritime have already been studied for years, especially on the academic side. In 2018, one of the first commercial efforts was taken when Rolls Royce established a research centre to focus on unmanned and remote-controlled vessels. Their vision of the future can still be found on YouTube [2]. Nowadays, various companies in Turku have their business focus on this topic. Turku UAS in turn has made significant investments in remote-controlled and autonomous systems in the last couple of years. Kongsberg has placed at Turku UAS' disposal over a million euros worth of equipment [3]. Investments in new energy and digital technology have been finalized in 2021 [4]. Furthermore, in 2023, investments in the electric test vessel eM/S Salama and the ROC system have been finalized, and these are now in active use by researchers [5]. In this paper, researchers from the Futuristic Interactive Technologies at Turku UAS will report how the results achieved in the ARPA project can be used in the near future to focus on the visualization of sensor fusions inside the industrial metaverse.

Visualizing Sensor Fusion Inside the Metaverse

Concurrently, metaverse technologies have emerged as a transformative digital realm, intertwining virtual and real environments. XR and metaverse technologies have been used in these visualizations. The term metaverse refers to a virtual interconnected digital environment. It is a virtual space for different technologies to come together, thus creating a shared, interactive space. It allows users to interact and engage. The broad definition of a metaverse is not confined to a single application or platform; instead, it envisions a collective virtual universe where real and digital elements coexist. We have defined metaverse as a technology enabling social communication, hands-on training, and digital twins [6]. In the context of remote-controlled and autonomous systems, there is a need for fluent collaboration between stakeholders, for controlling or monitoring vessels with authentic controllers, and for digital twins to increase the level of situational awareness.

During and after the pandemic, the metaverse received a lot of attention. There is hype around the metaverse, but it seems obvious that the industrial metaverse will be the first big hit. For example, Nokia is highly interested in the industrial metaverse. They have conducted along with Ernest Young a large survey (860 business leaders in the US, Brazil, the UK, Germany, Japan, and South Korea) [7]. Based on this survey, there is a high demand in the technology industry for industrial metaverse solutions. Next is a short summary of research activities in the ARPA project related to the visualization of sensor fusion inside the industrial metaverse. For this purpose, our research group has developed an industrial metaverse environment. In the environment, various visualizations utilizing neural networks are available, including the identification of vessels from 360-degree video footage, as well as the same video footage augmented with LiDAR and AIS data (Figure 1). These are presented to users as video panels, which are intended to be later integrated into the remote user interface of the eM/S Salama vessel within the ROC environment.

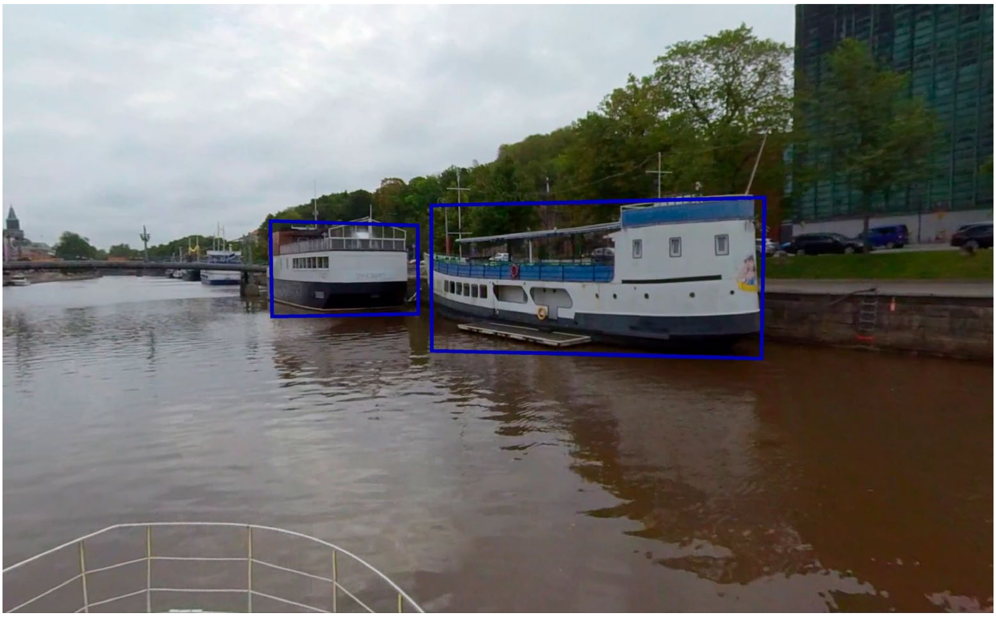

Figure 1.
LiDAR data visualization augmented on a 360-degree video as an example of object detection.

The environment also includes a model of a battleship, featuring a prototype view of the command centre (Figure 2) with multiple monitoring screens (currently displaying static content), and on the command bridge, the ability to view simulated AIS data on a map display. One important feature for real-time situational awareness is a 360-degree view of the operating environment (Figure 3). Nokia has been developing a technology called Real-time eXtended Reality Multimedia, or RXRM [8]. It could potentially cut off almost all latency from video streaming and also reduce the required bandwidth, making it more suitable in situations where enhanced situational awareness or remote governance is needed. In this environment, upon climbing onto the battleship's deck, there is an opportunity to explore a 360-degree video view of Nauvo Harbor, demonstrating the possibility of replacing this view with Nokia's RXRM technology to provide a real-time view from the eM/S Salama vessel to the ROC environment.

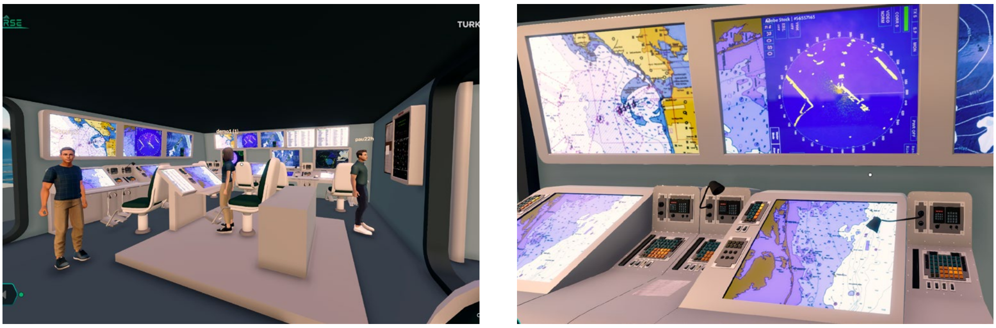

Figure 2.
Illustration of a multiuser battleship environment with rich situation-aware visualizations.

Figure 3.
360-degree video integrated into the metaverse.

We have also focused on UI design by identifying and solving UI challenges that probably would be applicable in a remote-controlled context. A key consideration is that the virtual environment does not have the physical world's restrictions when it comes to the controls and UI. For example, we have found that it is preferable to implement some of the controls typically used on the command bridges differently in VR, where the importance of control accuracy and latency can be tackled, creating new UI elements. For instance, a small delicate control knob that is adjusted with the fingertips in the physical world can be implemented in a much more user-friendly manner in a virtual environment (e.g. a floating ball to grab and steer). Based on our experience, it is not a good idea to let precise hand location correspond directly to a vessel's movement in a sensitive way. The normal human tendency to use the hands was found to be easily misinterpreted by a machine. Conclusively, while designing UIs for remote-controlled systems, it is highly recommended to implement safe and reliable alternatives, such as applying an activation stage before giving the system the final input.

Conclusion

From autumn 2023 onwards, we have started applying these visualization solutions to enable collaborative remote control of the eM/S Salama. The reported solutions can partly be used as an extension forour own ROC overlaying some sensor data on the top of ROC displays or, if needed, in a similar type of ROC environment in the metaverse to bring additional stakeholders who are not physically present in the same place. Especially in some specific use cases, such as disaster management, it is obvious that a totally different approach for remote control and monitoring autonomous systems will be needed. The eM/S Salama, combined with our situationally aware industrial metaverse platform, will be an excellent test platform. We aim to conduct studies where the iterative evolution of UI design will be evaluated in various test-generate cycles for UI improvements. We foresee that the amount of information and the information priority level (relevant information) will generate various research questions to be solved.

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Jussi Haapasaari, Dennis Bengs & Mikael Manngård

A Virtual-Reality Remote-Pilotage Concept

A technological proof-of-concept for VR-assisted remote pilotage has been created to enhance situational awareness during remote operations. This concept involves a VR interface for pilots on the shore communicating with XR and tablet applications used by the ship's captain. The aim has been to incorporate functionalities that cannot easily be replaced by verbal-only communication. The setup necessitates transferring navigation data and a 360-degree camera feed from the ship to the shore.

Pilotage in shipping is a safety practice where pilots guide vessels through specific challenging areas. Pilots have extensive knowledge of local conditions, which are crucial for safe navigation. In many regions, ships must use pilots when entering specific ports or waterways. Pilotage is a dangerous task where communication between the pilot, crew, and master is essential for safety [8]. Boarding a ship as a pilot poses significant risks to the pilots [1]. The transfer process, often carried out using a ladder or pilot hoist, can be challenging and is subject to weather and sea conditions, making it a hazardous operation. Remote pilotage aims to reduce the risks associated with pilotage while ensuring safe operations of the ships. In remote pilotage, the pilots do not have direct access to the ship's navigation data but rely on remote communication between shore and ship.

Remote piloting can potentially improve safety by removing human elements from onboard pilotage operations and could result in substantial cost savings [1]. However, critics of remote pilotage claim that it may reduce situational awareness by limiting human-to-human interactions. To address this critique, we are exploring Extended Reality (XR) technologies as tools for aiding remote operations. Previous studies utilizing VR technologies to improve situational awareness include the remote operation of remote-controlled tugboats [2]–[4]. The introduction of Virtual Reality (VR) applications in pilotage could represent a significant leap forward in remote pilotage technology, offering increased safety and convenience by eliminating the need for pilots to board ships while physically maintaining the desired situational awareness. This project consists of a VR pilotage application for the pilots' side and an XR or tablet application for the onboard captain. The aim is to incorporate various functionalities to enhance the precision and efficiency of remote pilotage. In this paper, the focus is on presenting user interfaces and design guidelines for VR remote pilotage.

Methodology

In this Section, the XR remote pilotage concept is outlined.

A. The VR-aided remote pilotage concept

This remote pilotage framework is divided into three different applications, allowing seamless communication between the pilot and captain:

- **Pilot VR interface:** The pilot interacts with the captain through a VR interface with virtual sea charts, navigational data and a 360-degree camera view from the vessel.
- **Captain XR interface:** The captain can interact with the pilot using an XR interface, allowing him to perform tasks as usual but with additional information overlayed on the sea surface.
- **Captain tablet application:** The captain can interact with the pilot through a tablet application, giving him access to the same interactive chart view as the pilot.

An essential component of this concept is the shared chart functionality, allowing both the pilot and captain to place markers on their respective displays, highlighting objects or areas and measuring distances. These markers synchronize in real-time, facilitating collaborative navigation and allowing the pilot and captain to communicate information that otherwise would be inconvenient through verbal communication. Furthermore, the captain's vessel is equipped with a 360-degree camera, and both the video stream and the ship's operational data are transmitted to the VR application used by the pilot on the shore. The remote-pilotage concept is illustrated in Figure 1.

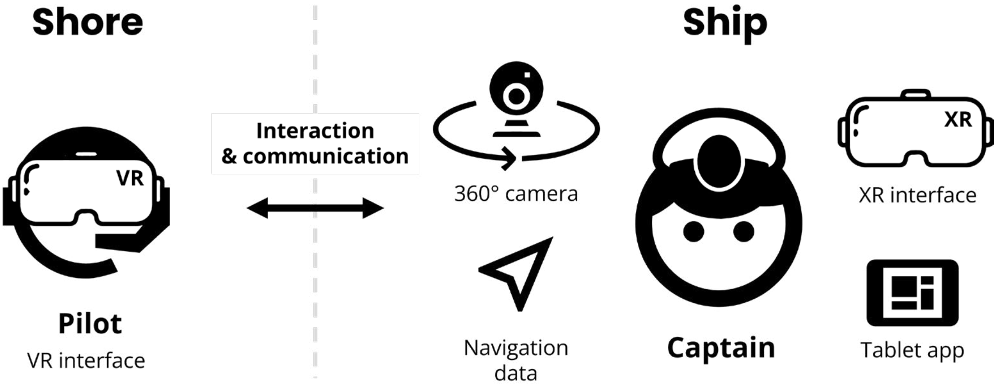

Figure 1.
Interaction and communication between pilot and captain require the exchange of 360-degree camera and navigation data between ship and shore.

B. Data transfer

The application employs the Message Queuing Telemetry Transport (MQTT) protocol for seamless data transfer, ensuring swift exchange of Automatic Identification System (AIS) data from nearby ships and marker information between the applications. The transferred data, such as the marker information and the AIS data between the applications, are handled using the MQTT protocol, which ensures that all the AIS data is synchronized and any marker placed by one user is immediately visible to the other party, enabling real-time collaboration. Leveraging the capabilities of Ngrok, the MQTT broker has been configured using MQTT Explorer on a separate computer, establishing a secure tunnel for remote connections for PCs over the Internet.

C. Simulated test environment

Given the challenges of conducting tests on an actual ship, an alternative approach is to assess the data transfer processes between the applications in a simulated environment. Within this simulated environment, a scenario is constructed using AILiveSim's environment simulation platform [5], which includes a remotely operated ship that the captain can manage with a console similar to that used for navigating real ships. Additionally, there are sensors, such as cameras affixed to the ship, and AIS transmitters on both the ship and the neighbouring vessels. The setup of the simulation test environment is illustrated in Figure 2.

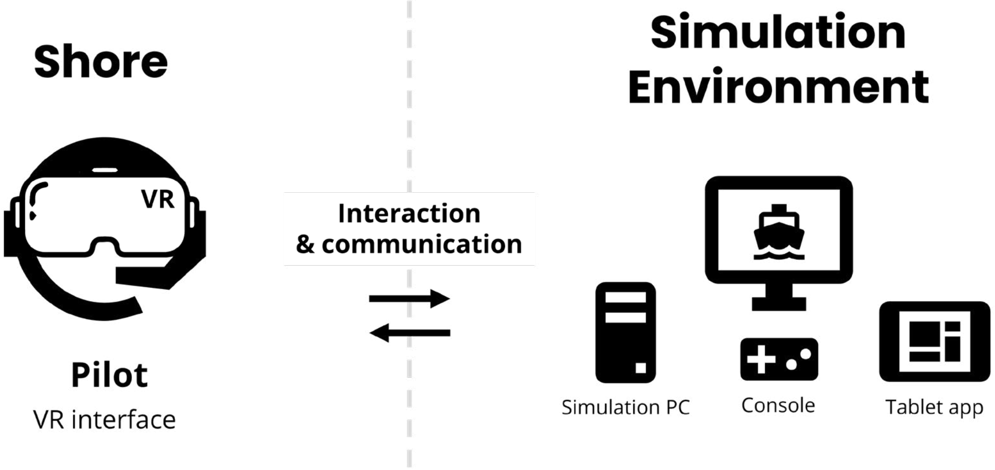

Figure 2.
Simulated test environment setup for testing the pilot VR application

User interfaces

The designs of the User Interface (UI) for the VR and tablet applications are largely similar to each other. Still, the VR version is built around a few additional well-founded VR design principles. The design principles are explained in Section III B, and UI functionalities are explained in the following section.

A. Design principles

The VR component of this application stands by a few fundamental design principles specific to virtual reality environments. These include maintaining the UI canvas in world space, ensuring a clean and organized UI layout, upholding consistency and legibility in icons and fonts, and prioritizing immediate feedback for user interactions with UI elements. The font style for text within the VR application was 'Avenir Black', selected for its enhanced legibility in virtual reality due to its broad and easily discernible strokes. Most of the text elements within the application are presented in a stark white colour against a dark background, creating a high-contrast visual for improved readability. The exceptions to this rule include dynamic texts such as the latitude and longitude values displayed atop the chart and ship status information, which employs other lighter colours while maintaining a dark background.

In contrast, the tablet application offers only the primary panel as its canvas within the screen space. However, it still maintains a design closely resembling the primary panel of the VR iteration. There are, however, two notable distinctions: The user interface is entirely two-dimensional, and for better legibility in a non-VR environment, the chosen font style is 'Liberal Sans'.

Most vector images used as button icons were sourced from an open-source online icon database [6]. These icons share a consistent style with clean, well-defined shapes and bold strokes. The few icons not found in the free database were hand-drawn to imitate the same artistic style. Side-by-side comparisons of the pilot chart UI and tabled application UIs are presented in Figure 3. Design inspiration has also been drawn from the OpenBridge Design System [7].

Figure 3.
Top: VR chart UI with 360-camera view in the background.

Bottom: Tablet application chart UI.

B. The VR-pilotage UI

The VR application was developed with a Varjo XR-3 headset, and since the application was designed to be used with hand tracking, visual feedback from any interactions with the UI elements is essential, as there can be no tactile feedback from the controllers. The presence of 3D buttons with interactive animations emphasizes the significance of the visual cues. These components confirm the accurate tracking of the user's hand movements and function as a guiding mechanism for effective interaction. Moreover, the application features a proximity indicator that visually conveys the distance between the user's fingers and the UI elements. It offers a reference point for the user to gauge their proximity and precisely engage with the 3D buttons.

The primary chart panel, seen in Figure 3, consists of three sub-panels. The middle part features a detailed nautical chart and is approximately 70% of the size of the whole main panel; the left side shows the captain's ship information and a compass, and all the interactable buttons are located on the right-side panel. Left and right-side panels are tilted towards the player at a 35-degree angle to reduce distortion and enhance depth in the virtual environment. All the buttons are three-dimensional and play a distinct animation when interacting.

In addition to the primary panel, the VR application incorporates a palm menu (Figure 4) that users can activate by rotating their left palm towards their face and deactivate by turning their palm away. In this palm menu, users will find a compact rendition of the chart and a selection of essential settings, including options to adjust the distance between the user and the main panel and customize the size of the palm menu.

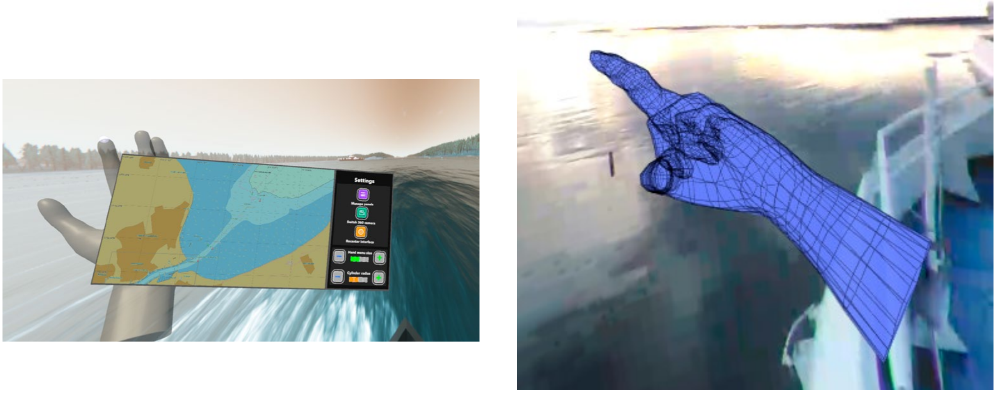

Figure 4.
Left: Palm menu and compact chart view. Right: Pointing virtual hand.

The shared sea chart, accessible on both the VR and tablet applications, draws upon the 7Cs chart database to dynamically generate an image based on the selected coordinates. In the VR version, users can navigate the chart by moving their fingers to the edges of the chart, while in the Windows tablet version, the chart can be moved by simply dragging it. While the marker icon and colour can be changed at will, the users are also given a range of marker types to select from, each offering their distinct functionality. Depending on the chosen marker type, users can highlight a single point or define an entire area, perform distance measurements, and even visualize the ship's turning radius, enhancing their maritime capabilities. Furthermore, the chart's zoom functionality is accessible in both versions. In the VR version, users can utilize dedicated zoom buttons for this purpose, while in the tablet version, zooming can be achieved with a pinching gesture.

To convey directional information, the pilot can point in a direction. This pointing gesture is translated into coordinates and turned into a 3D model of a hand pointing that way. This information is then sent to the captain using MQTT. The pointing 3D hand is illustrated in Figure 4.

Discussion and Conclusion

A novel concept for VR-aided remote pilotage has been presented. The concept explores the benefits VR can bring to improving the situational awareness of remote pilotage. This study should be seen as a successful first proof-of-concept of XR remote pilotage, highlighting the technological capabilities of the concept. Further research, including empirical tests, is needed to draw decisive conclusions on the benefits of XR technologies for remote pilotage.

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A Concept of Maritime Automatic Speech Recognition

Maritime automatic speech recognition is designed to accurately transcribe and interpret spoken language in maritime environments. In this paper, we developed a concept for automated transcription and speaker recognition for VHF communications. The proposed framework relies on state-of-the-art open-source models for speaker-speaker and text embedding and similarity clustering.

Automatic speech recognition (ASR) is a technology that converts spoken language into written text. It involves transcribing or recognizing the words and phrases spoken by a person into a textual format that can be used for various applications. ASR systems have many practical uses, including voice assistants [1], transcription services [2], and mobile applications [3].

Lately, with the release of open-source ASR software such as OpenAI's Whisper [4], there has been an immense increase in applied ASR research. Speaker embeddings play a significant role in ASR systems, especially in tasks related to speaker recognition. Speaker recognition typically solves three tasks: speaker identification, verification, and diarization. Speaker identification aims to identify the speaker, whereas speaker verification seeks to verify whether the speaker is who they claim to be [5], [6]. Speaker diarization, on the other hand, is the task of dividing the audio into segments into speaker-homogenous speakers based on the unique characteristics of a speaker's voice. Speaker diarization typically distinguishes speakers by mapping audio segments to a point in a (high-dimensional) vector space using a speaker embedding.

ASR has been applied in maritime communication to transcribe maritime VHF communications [4]. Maritime automatic transcription can, for example, have a paramount role in aiding search and rescue missions [7] and as an aiding tool in remote operations and pilotage. ASR has also been previously applied for enhancing education [9], [10]. Thus, we believe ASR techniques can positively impact maritime education by analysing and transcribing conversations in simulated exercises. This paper proposes a maritime ASR concept for automatic transcription, speaker recognition, and content analysis for very high frequency (VHF) radio communications.

Methodology

This section presents the proposed framework for maritime ASR and speaker recognition. The proposed method makes use of state-of-the-art ASR and embedding techniques. Maritime ASR is aimed at transcribing and analysing audio content from VHF radio communications to answer the following questions:

- What is the person saying?
- Who is speaking, and to whom is the person speaking?
- What is the main message of the communication?

ASR performs the transcription of messages, answering the first questions. Recognizing the speaker is generally not possible. However, since maritime communications abide by Standard Maritime Communication Phrases (SMCPs; [11]) when communicating over VHF radio, identifying the speaker and content of the message becomes possible. In addition, when standard communications protocols are not followed, we resort to speaker diarization to map the content to an SMCP. The maritime ASR concept is summarized in Figure 1.

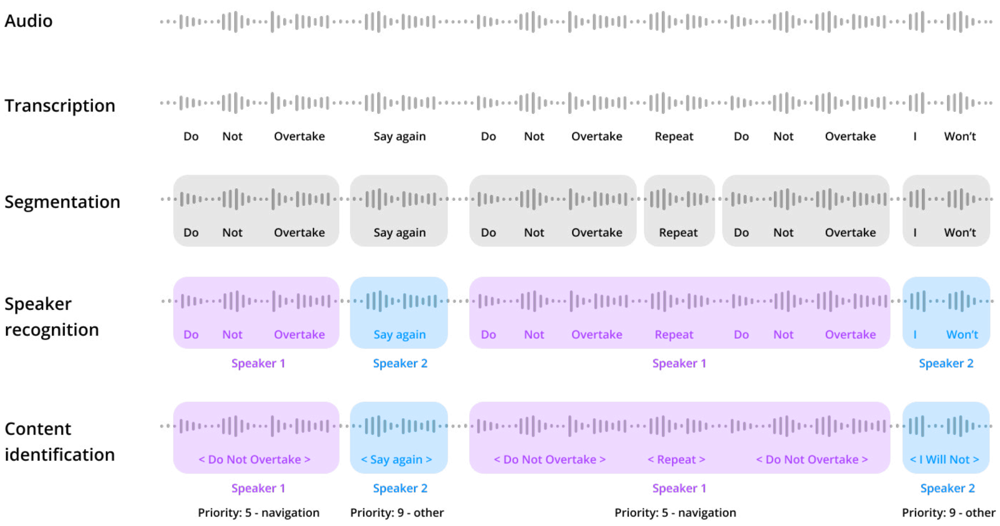


Figure 1.
The stages of maritime ASR.

Automatic transcription

ASR is the ability to recognize words from audio signals, which is a complex task that is being actively tackled by industry and researchers. The challenge is the diversity of the human voice. As different people have different accents, intonations, and pronunciations, making a machine-learning model that can recognize all of them is no easy task. As a result, the primary aim of ASR is overcoming these challenges to achieve speech detection and transcription.

Our current approach to speech-to-text transcriptions utilizes OpenAI's open-source ASR model Whisper [4]. The model is trained to recognize a variety of languages, with the primary one being English. Whisper's primary source of training data is the Internet, as the research team used data available on the Internet to construct a dataset of 680,000 hours (about 77 and a half years) to train the model, resulting in a robust model that can perform well in various languages, cf. [4]. As we aim to make an implementation specific to the maritime field, we need to consider the unique challenges of the task. While listening to VHF radio communications, a considerable amount of noise is always present. Although other models outperform Whisper at low noise levels, Whisper shows better results at higher noise levels [4]. Since VHF communications are often corrupted by noise, we used Whisper for transcription.

Speaker recognition

In the domain of text-independent speaker recognition, the emphasis lies on characterizing speech based on audio rather than the semantic content of the utterance. This process involves the transformation of speech into fixed-length vectors, so-called speaker embeddings so that similar vector embeddings are close to each other in the embedding space. The speaker embeddings are optimized through training on extensive datasets to maximize the separation between distinct speakers in the embedding space. The introduced framework of maritime speaker recognition inherently encompasses two principal stages: (1) the extraction of speaker embeddings and (2) the real-time clustering techniques to distinguish speakers, as illustrated in Figure 2.

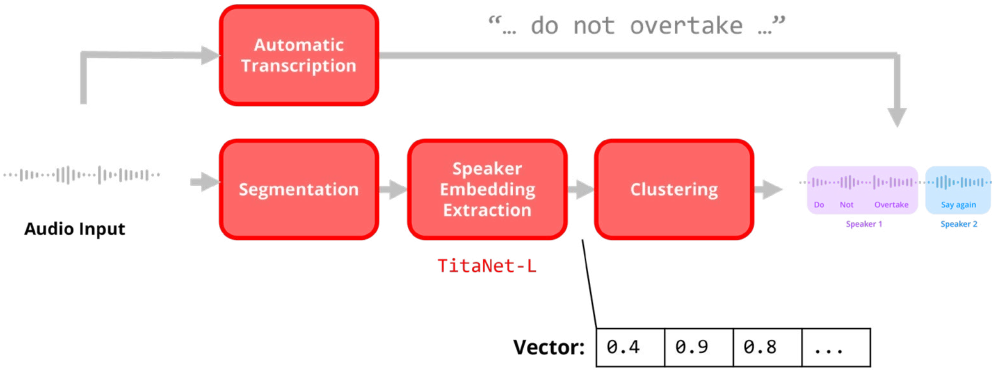


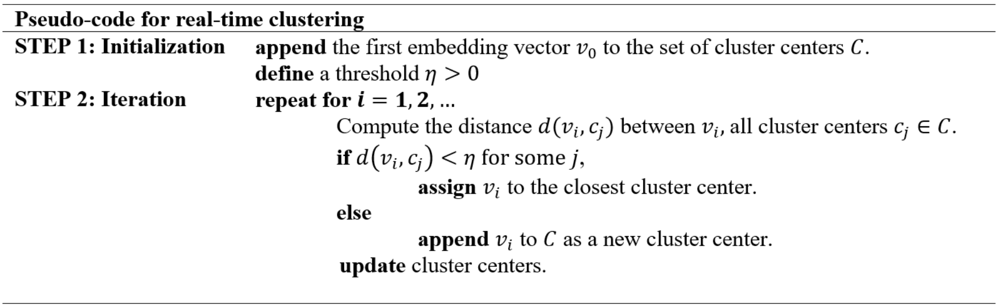
Figure 2.
Speaker recognition using speaker embeddings and clustering.

1) Speaker embeddings and similarity

To distinguish different speakers in VHF radio communications, we perform speaker diarization by extracting speaker embedding from audio segments using the Nvidia 'TitaNet-L' model [5]. The model maps an audio segment to a 192-dimensional embedding vector. The TitaNet-L model was chosen due to its state-of-the-art performance, open-source, and ability to handle audio segments of variable lengths [5]. The distance between speaker embeddings was quantified using the cosine distance.

2) Clustering

A real-time clustering approach was implemented, similar to the one proposed by J. Ajmera and C. Wooters in [12]. The purpose of the real-time clustering approach is to assign cluster centres to embeddings that are close to each other. The following pseudocode can summarize the real-time clustering algorithm:



Pseudo-code for real-time clustering

```
STEP 1: Initialization   append the first embedding vector $v_0$ to the set of cluster centers $C$.
                         define a threshold $\eta > 0$
STEP 2: Iteration        repeat for $i = 1, 2, ...$
                             Compute the distance $d(v_i, c_j)$ between $v_i$, all cluster centers $c_j \in C$.
                             if $d(v_i, c_j) < \eta$ for some $j$,
                                 assign $v_i$ to the closest cluster center.
                             else
                                 append $v_i$ to $C$ as a new cluster center.
                             update cluster centers.
```

Since the threshold η is unknown before clustering, it would be useful to have an approach for updating it based on the seen embedding vectors. The threshold can be determined by calculating the average distance between points in the clusters.

Content identification

Since maritime communications are supposed to follow SMCP protocols, the main message of a sentence can be obtained by comparing the similarity between common SMCPs and subsentences of the transcriptions using text embeddings. The SMCP-mapping procedure is illustrated in Figure 3.

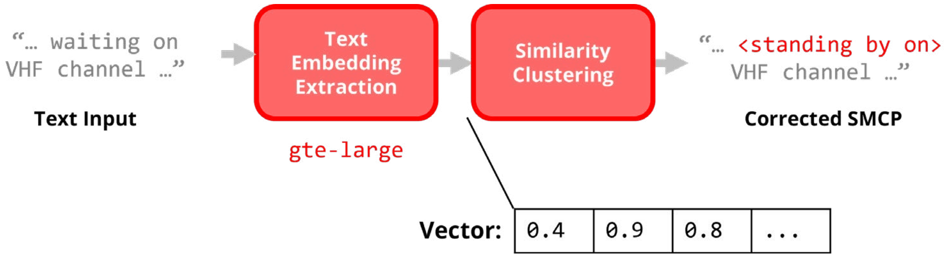


Figure 3.
SMCP mapping with text embeddings and similarity clustering.

1) Text embeddings and similarity

To identify SMCPs in the transcriptions, we computed embedding vectors for a predefined list of common SMCPs using the General Text Embedding (GTE) model [13]. The 'gte-large' model was selected because it achieved the highest score for clustering tasks on the Massive Text Embedding Benchmark (MTEB; [14]) as of October 2023. The embedding model was obtained via the sentence-transformer library [15], converting each SMCP to a 1024-dimensional embedding vector. The similarity between transcribed sentences and SMCP was quantified using the cosine similarity between their embedding vectors.

2) Visualization

To visualize the 1024-dimensional embedding vectors, they were converted into two-dimensional embedding vectors using the uniform manifold approximation and projection technique (UMAP; [16]). This UMAP embedding maps transcribed subsentences to

2D points close to the matching SMCPs. A Dash application for visualizing the UMAP projections of the SMCP mapping together a list of the closest matching SMCP phrases was created. For example, as seen in Figure 4, the incorrect SMCP sentence ‘waiting on’ got correctly mapped to the most semantically similar SMCP ‘standing by on’.

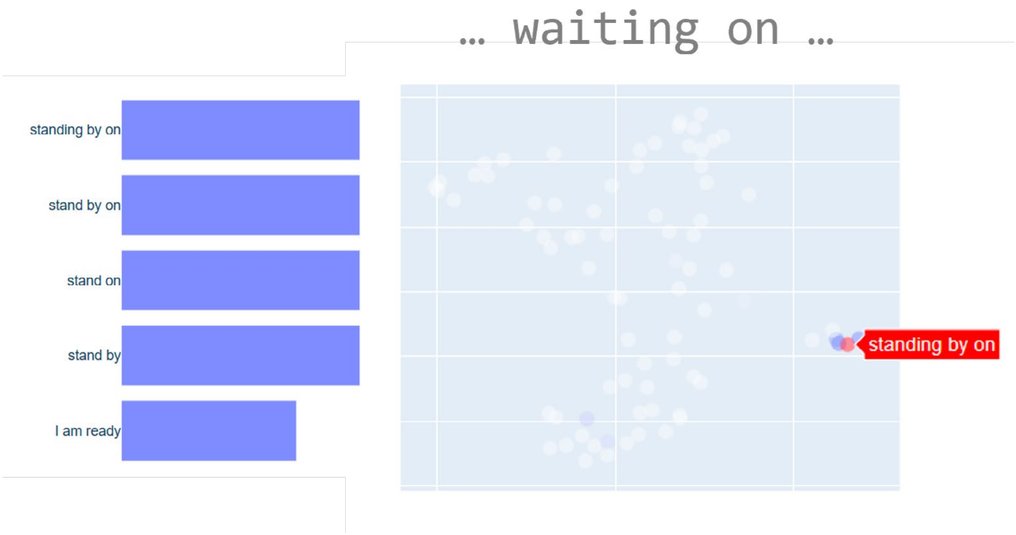


Figure 4.

Figure 4. A UMAP-based 2D scatter plot of the SMCP embeddings with neighbouring points corresponding to semantically similar phrases. A list of the five most semantically similar phrases to the transcribed subsentence ‘waiting on’ is illustrated in the bar chart to the left.

Results

Two different datasets were used to evaluate the algorithm's accuracy: The 'Mini Speaker Diarization' Teacher and Student dataset [17] and a five-minute VHF radio audio recording. The individual speech segments for both datasets were extracted. Segments were further preprocessed by cropping the audio segments for at most three seconds to ensure consistency between experiments.

Student-teacher dataset

The first publicly available dataset is 'Mini Speaker Diarization' [17]. The dataset consists of two people speaking: the teacher and the student. The dataset has a training and validation part. However, because the algorithm did not require any previous training, the entirety of the dataset was used for the accuracy measurement. Embedding vectors were calculated for each of the audio segments using TitaNet-L. The distance matrix obtained by computing the cosine distance between each embedding vector is presented in Figure 5. The dataset consists of clean audio recordings without any noise and, as a result, an evident separation. The experiment on the teacher and student dataset showed that the method works in idealized conditions.

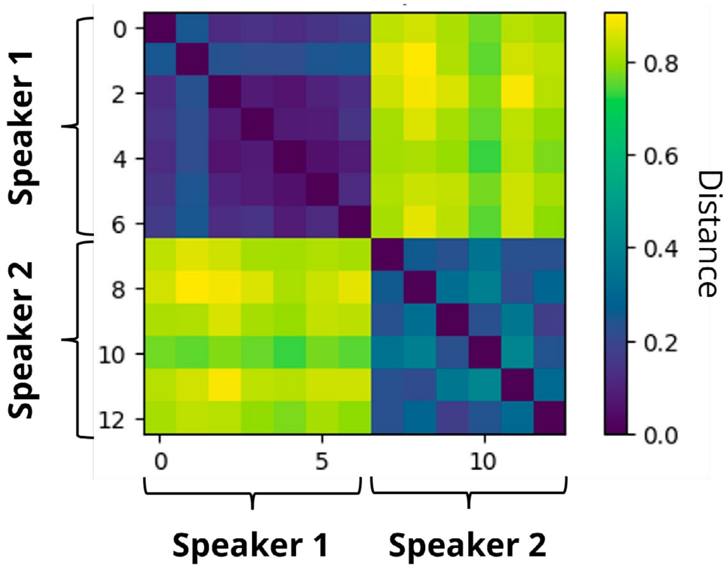


Figure 5.
Distance matrix between the embedding vectors of the teacher and student audio dataset.

VHF communication dataset

Experiments were performed on VHF radio data to evaluate the performance of the proposed speaker recognition method in a realistic setting. The dataset consists of three speakers communicating over VHF radio for five minutes. The audio was segmented into segments up to three seconds long and embedded using TitaNet-L. The cosine distance between vector embeddings is illustrated in Figure 6. The clustering was performed in the embedding vector space and presented in a 2D scatter plot using UMAP. There is a clear separation between the speakers, which can be seen from the distance matrix and the UMAP representation in Figure 6, confirming the applicability of the proposed method for maritime speaker recognition.

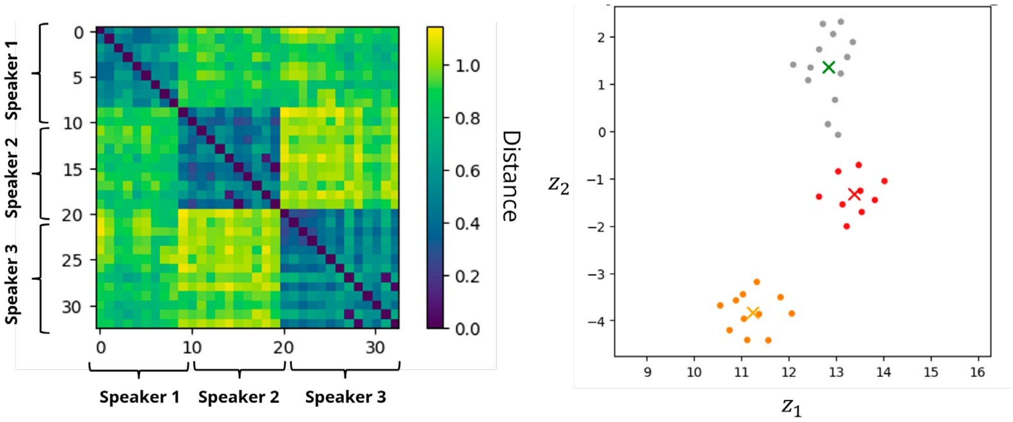


Figure 6.

(Left) Heatmap of VHF audio distances. (Right) UMAP projection of the embedded dataset. VHF audio UMAP with cluster centres visualized.

Conclusions

A novel approach to maritime automatic speech recognition (ASR) has been introduced, consisting of four main steps: (1) automatic transcription, (2) generating speaker embeddings from audio, (3) creating text embeddings from transcriptions, and (4) real-time clustering. This maritime ASR framework addresses critical aspects of VHF radio communication: understanding the spoken content, identifying the speaker, and capturing the main message. It automatically transcribes conversations using open-source tools like OpenAI's Whisper, while speaker embeddings and real-time clustering help distinguish speakers. Extracting the core message involves transforming transcriptions with a text transformer and comparing the resulting vectors to SMCP embeddings.

The effectiveness of this method was assessed using two datasets: one simulating teacher-student interactions and another consisting of VHF radio communications. Implementing the maritime ASR framework for transcribing and analysing maritime communications can alleviate the mental workload in remote operations and pilotage. Additionally, it could support maritime education by helping students adhere to communication best practices.

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The Data
Platform

Tommi Tuomola & Anne-Marie Tuikka

Data Platform Design

As we transition toward autonomous maritime operations with the promise of improved safety, efficiency, and environmental sustainability, the role of data becomes pivotal. The quality of the data that we use in teaching our AI algorithms directly affects the efficiency and reliability of our autonomous decision-making.

An autonomous marine vessel is required to make reliable decisions based on the virtual model it can form of its situation at any given time. This situational awareness is supported by a multitude of different sensors producing diverse types of information. Acquiring data from the sensors in a format actionable by the AI algorithms is one challenge; collecting and storing the data for further analysis and AI development is another.

The data from the sensors can vary in many aspects. The AIS data can give us information about other marine vessels near us with simple messages, whereas the data streams from RGB cameras and Lidars produce a considerable volume of data at potentially high velocity.

The ARPA data platform aims to offer a solution for storing data from diverse sources. The data is stored in such a way that it enables the development of various algorithms for autonomous navigation and remote maritime operations.

Data storage implementation

To solve the problem of needing to store data in various formats and volumes, we decided that a system with multiple different databases would be needed. With this hybrid approach, we were able to handle the challenges related to managing our data objects.

Relational databases are structured and dependent on a predefined schema. They are very efficient in situations where relationships between data are complex and need to be reliably maintained. Relational databases offer mature support for concurrency and data integrity. Most importantly for us, they provide transaction support that ensures all database transactions are processed reliably and by the ACID (Atomicity, Consistency, Isolation, Durability) properties. For this reason, we wanted the data search queries to be processed in a relational database.

In our solution, we used PostgreSQL to store the index of all our data objects together with the related metadata. In addition, we temporarily store AIS data in PostgreSQL while it is in hot storage. PostgreSQL is a mature open-source object-relational database that has been developed for over 30 years. It meets our requirements for reliability, robustness, and performance.

For unstructured data, such as images, video content, and many other typical sensor formats, object storage is often a better storage architecture. Object storage is highly scalable and typically easily accessible by HTTP APIs. For our purposes, this was exactly what we needed.

For the ARPA data platform, we chose LinkedIn's Ambry as object storage. Ambry has a REST front end and a non-blocking i/o backend. It is highly performant for storing immutable data, and it is open source. LinkedIn uses Ambry to store their media files, which is similar to our use case.

As cold storage, we use an object storage, Allas, provided by CSC–IT Center for Science Ltd. Allas is built to handle vast amounts of data, something that our on-premises Proxmox-based cloud environment cannot handle.

Figure 1 illustrates the dataflow between the data platform gateway and the hybrid data storage.

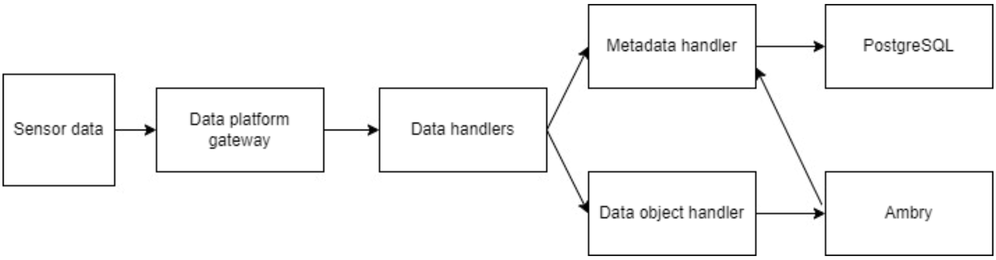

Figure 1.
Simplified diagram of the dataflow from the data platform gateway to the storage.

The data platform service architecture

The overall service architecture of the data platform aims for modularity, flexibility in the choice of used technologies, and resilience through service isolation. This is what microservice architectures excel in. While some of our services might not follow the principles of microservices to the letter, they have been the overall ideology behind the service design. A diagram of the data platform architecture is presented in Figure 2.

All our services are deployed on Turku University of Applied Science's on-premises cloud. This Proxmox-based system provides us with a platform where we can securely deploy the servers that run our services. The virtual machines on the platform are by default isolated from the Internet, and only our gateway services can be connected from outside Proxmox.

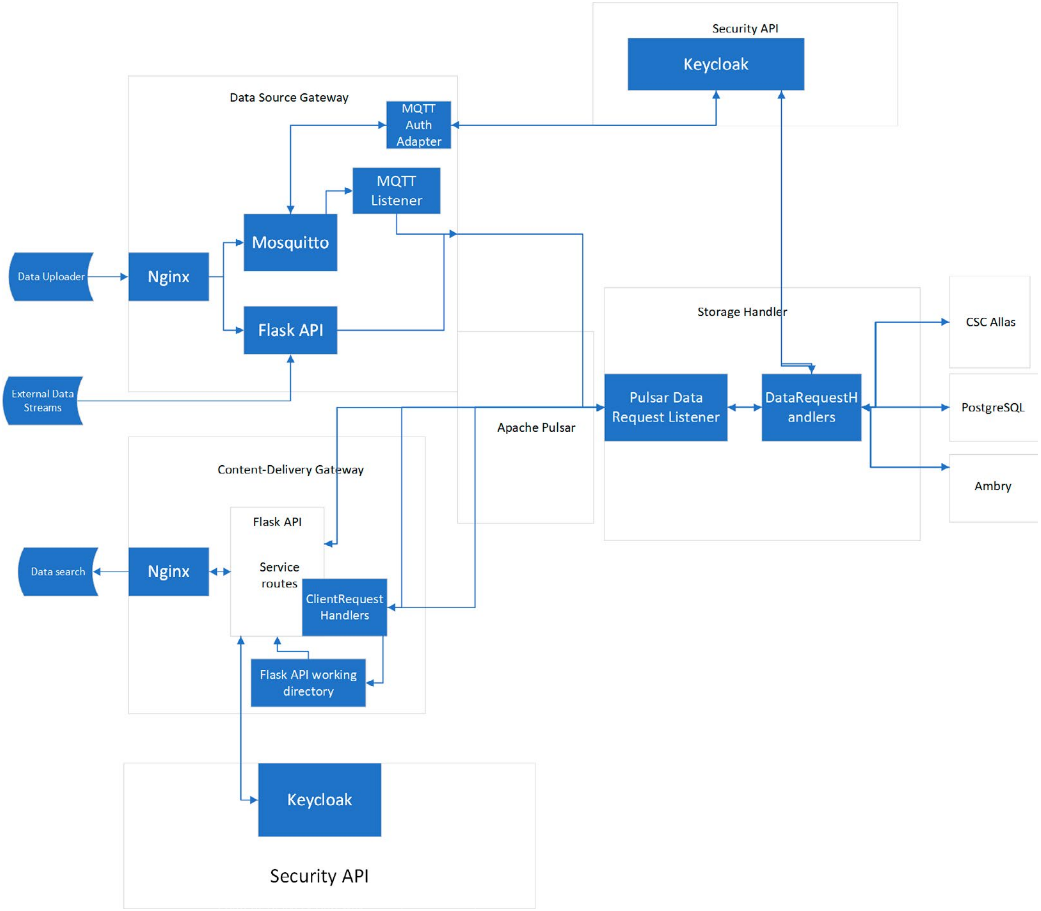

Figure 2.
Data platform services.

To communicate between our services, we needed a reliable distributed message queue system. In addition to the classic requirements of performance and durability, we needed the chosen system to be capable of handling data streams and multi-tenancy. In the end, we chose Apache Pulsar over Apache Kafka. Both systems can do everything we needed them to do, and they use partly the same technologies; but while Pulsar is less mature, it is deliberately designed for multi-tenancy. Managing dynamic amounts of communication channels added less complexity to the system with Pulsar.

For identity and access management, we chose to use Keycloak. Keycloak is open-source, lightweight, and easy to deploy. It offers functionalities that enable our services to authenticate themselves against each other and authorize their actions. We also use Keycloak to authenticate our end users and their access to data.

There are two important service clusters within the data platform: the Data Source Gateway and the Content Delivery Gateway. These are responsible for transferring data between the data sources, data platform, and end users.

The Data Source Gateway consists of services that handle incoming data. Their main responsibility is to authenticate the sources and send valid data to storage handlers. The currently used interfaces for data acquisition include Flask APIs and an MQTT broker.

The Content Delivery Gateway is responsible for handling search queries and delivering the data to the end users. The data can be delivered as downloadable packages or played back as video or MQTT data streams.

Data governance issues to consider in the development of a platform

Platforms that are used for research, development, and innovation can sometimes be considered as research infrastructures. Research infrastructures have multiple definitions, some proposed by researchers, others in policies directing the development of research infrastructures and research investments. In general, they can be seen as enablers of innovations and sources of resources for research.

In prior research, the material and social aspects of research infrastructures have provoked the interest of researchers. Ribes & Polk (2014) define research infrastructures as 'assemblages of people, instruments, and techniques oriented to the investigation of particular objects of research'. Fecher et al. (2021) understand that research infrastructures are deeply relational and adaptive systems that are part of the social practice of research and are influenced by the environment.

In the Finnish context, an influential definition is given by The National Research Information Hub of Finland – research infrastructures are nationally significant services, data sources, equipment, or devices that enable research and development while supporting rigorous research work and higher education activities (CSC 2021). Finland's national policy for open access to research methods and infrastructures complements this definition by stating that research infrastructures can provide infrastructure services, and they can often be used to collect data and store it in databases (Open Science Coordination in Finland 2023). The organization responsible for research infrastructure can provide support services to use its resources and support the use of machines and equipment to carry out successful experiments. All the aforementioned services can have either virtual, remote, or physical access.

To identify essential data governance issues regarding the ARPA data platform, research infrastructure serves as an useful conceptualization. The ARPA data platform is designed to support data sharing between academic and private organizations on a mutual basis. The goal has been that each user can access all the data shared on the platform for research and development purposes. However, this raises a concern about how to ensure the quality of data shared on this platform and the appropriate use of data. To better understand, how can data be governed on a platform, academic studies alongside policy documents and significant guidelines are reviewed. To conclude, example of data governance practices for mature research infrastructure is presented and discussed from the viewpoint of the ARPA project.

Data governance in the context of the Data platform

The data governance structure is more complex for platforms than in single-organization cases (Nokkala 2020). To be successful, platforms need data governance that includes clear roles, shared data management practices, and a definition of different user groups (Otto & Jarke 2019). It should be considered already when designing the platform, its architecture, and access rules. In the context of platforms, Lee (2019) proposes a set of decisions and practices that are an integral part of data governance: regulatory environment, data access, data ownership, data use cases, and contribution measurements.

Regarding the quality of data, the FAIR principles are a widely acknowledged set of guidelines to improve it (GOFAIR). FAIR principles focus on digital assets and how they can be findable, accessible, interoperable, and reusable.

Data management policy is a document that can be used to plan and demonstrate data governance on a platform. When creating a data management policy for a platform, guidelines for research infrastructures are valuable resources. For example, EU-level principles and guidelines have been published for accessing

research infrastructure. These guidelines acknowledge three access modes: excellence-driven access, market-driven access, and wide access. Access restrictions should be clearly communicated to users through access policy and user instructions. In addition, there are national-level guidelines, like the one offered by the Research Council of Finland. Each research infrastructure funded by the Research Council of Finland needs to have a data management policy that includes agreements on ownership and user rights, tools and guidance for documentation and metadata, a description of data storing services, and an approach to sharing data (Research Council of Finland).

Conclusions

The collection and analysis of excellent quality datasets enable the development of AI models that are widely used in autonomous maritime operations. The data platform developed in the ARPA project can be used to share this data within the research community. Data of varied types can be stored on the platform, the metadata can be queried, and interesting data can be either downloaded or played back from the data platform.

In Finland, some platforms have been acknowledged as an important research infrastructure worthy of FIRI funding through the Research Council of Finland. Their data management policies provide interesting examples of data governance possibilities for the ARPA project. A prominent example of a well-established, incredibly well-managed platform is Aila, which provides access to data archived in the Finnish Social Science Data Archive (FSD). The data management policy of FSD clearly states the roles of the platform owner, the data providers, and the platform users. Every data provider needs to sign an agreement for storing their data in the data archive of FSD. They also need to state how openly the data can be shared with users of FSD’s services. In addition, FSD offers services for data providers to anonymize and describe their data.

If a platform, such as the one developed during the ARPA project, aims to become a mature research infrastructure, data governance is in a key role. It is essential to ensure the success of the platform and enable its usage in the long run.

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Towards a Roadmap of Maritime Digital Twins

Digital twins are becoming increasingly common in the maritime sector. Here, we developed and published an interactive tool to characterize the current research topics on maritime digital twins using a novel text-embedding approach. We observed six general research themes, identified some knowledge gaps, and laid out a roadmap towards future digital twins of the whole ship.

The concept of digital twins (DTs) has been around for a while. However, they are quickly becoming a reality due to ongoing digitalization and AI trends. (DTs can now even be visualized by AI; see Figure 1.) The core idea of a DT is to create a virtual twin of a physical object that can exchange information with the real-world object in real time [1]–[3]. The virtual twin receives sensor data from the physical object, and processed information is returned to the physical object. This technology enables the virtual twin to perform simulations, optimization, health monitoring, performance tracking, and even control the physical object [1], [2], [4]. In addition, the virtual twin is expected to exist throughout the physical object's lifetime and thus function as a comprehensive access point to all data available about the object [5], [6]. The latter has also been brought forward as a requirement for autonomous shipping, as it is not possible to test for unexpected emergent behaviours without connecting all parts [6].

Creating a DT for complex physical objects like ships can be tricky in practice. Ships consist of multiple components and parts from various vendors. Collecting and linking all the available data is a challenging task requiring much standardization [1], [4]. Consequently, current maritime DT technology primarily focuses on monitoring and simulating certain aspects of the ship [7]. However, given that DTs are hierarchical [1], with the DTs of components and parts making up the DT for the whole, one could also conclude that maritime DT technology has not yet progressed to the level of a whole ship. Here, we explored progress toward this vision of a DT for the whole ship using a text-embedding approach that grouped research abstracts based on semantic content.

Figure 1.
AI-generated image of a container ship and its DT (Midjourney v5.2).

Methodology

In this section, the methodology for conducting the literature review is presented. The analysis process was automated and performed on a large set of publications to avoid imposing personal biases on the results.

a. Dataset

We created a dataset of DT abstracts by performing a Google Scholar search for the term: ‘digital twin’ ‘maritime’ ‘ship’. The abstracts for the first 99 hits were downloaded together with the title, number of citations, year of publication, journal, and keywords (if available).

b. Text embeddings and similarity

We computed embedding vectors for abstracts, words, and topic sentences using the General Text Embedding (GTE) model [8]. The model selection was based upon ‘gte-large’ obtaining the highest score for clustering tasks on the massive text embedding benchmark (MTEB; [9]) as of October 2023. The embedding model was obtained via the sentence-transformer library [10], converting each abstract, word, or topic sentence to a 1024-dimensional embedding vector.

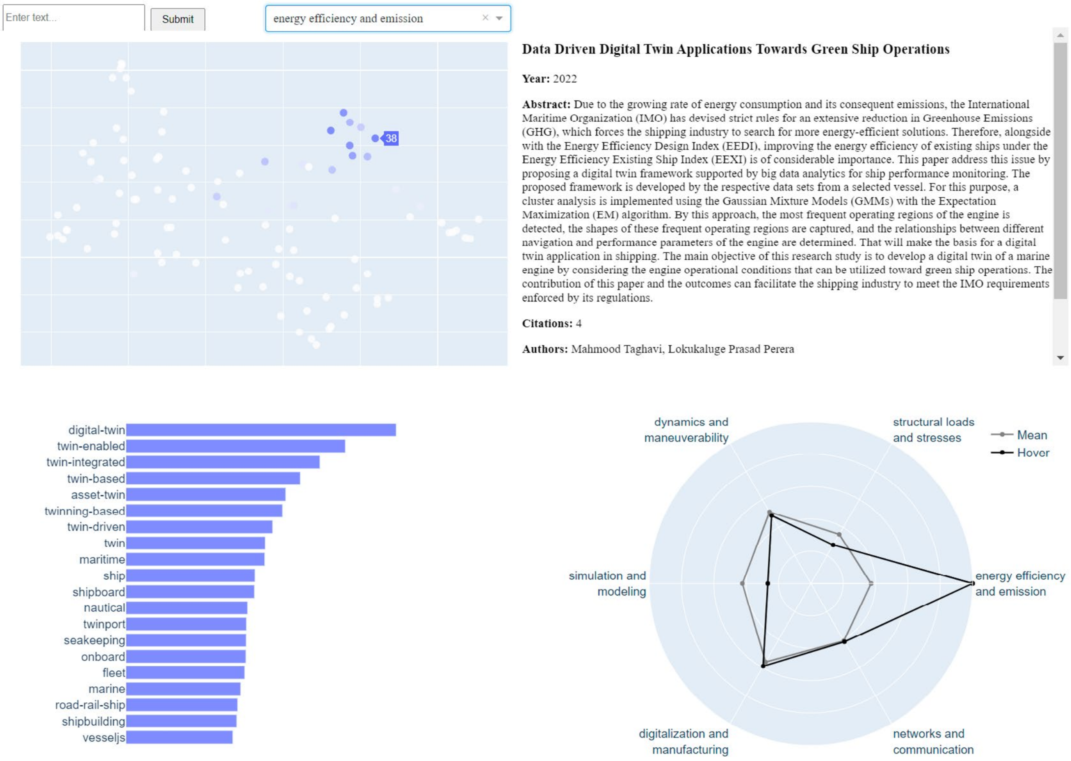
The similarity between words, topic sentences, and abstracts was quantified using the cosine similarity between their embedding vectors. We quantified the similarities between (1) the embedding vectors for every word (lemmatized) found in all abstracts and the embedding vectors for the whole abstracts and (2) the embedding vectors for selected topic sentences and the embedding vectors for the whole abstracts. The topic sentences were empirically chosen based on exploring which words had the most similar embedding vectors to various regions and clusters in the scatter plot (using the Dash app described below).

c. Visualization

The 1024-dimensional embedding vectors were converted into 2-dimensional embedding vectors for visualization using the uniform manifold approximation and projection technique (UMAP; [11]). This second UMAP embedding tries to give similar 2D coordinates to abstracts with similar embedding vectors, thus making it possible to inspect the whole dataset in a 2D scatter plot visually. The core idea is that similar abstracts (similar semantic content) should be located near each other in the resulting scatter plot. We further created a Dash app to visualize and explore the dataset interactively. (See Figure 2.) The app allowed the user to (1) read the abstract corresponding to a point in the 2D scatter plot, (2) see which words were most similar to the abstracts on average, and (3) see the similarity between a selected abstract and six example topic sentences (themes) identified by using the app. In addition, the app had an input field for colour-coding each data point based on similarity to an input query and a dropdown for colour-coding data points based on similarity to a selected topic sentence. The app and the used dataset are available from [12].

d. Categorization into themes

The identified topic sentences were used as proxies for themes common to neighbouring abstracts in the UMAP-generated scatter plot. We thus thematically categorized each abstract based on the similarity between its embedding vector and the embedding vector for each identified topic sentence. The categorization lets us compute average similarities between the abstracts in each category and every topic sentence (theme), making it possible to visually depict the general theme emphasized in each category using a spider chart.



Data Driven Digital Twin Applications Towards Green Ship Operations

Year: 2022

Abstract: Due to the growing rate of energy consumption and its consequent emissions, the International Maritime Organization (IMO) has devised strict rules for an extensive reduction in Greenhouse Emissions (GHG), which forces the shipping industry to search for more energy-efficient solutions. Therefore, alongside with the Energy Efficiency Design Index (EEDI), improving the energy efficiency of existing ships under the Energy Efficiency Existing Ship Index (EEXI) is of considerable importance. This paper address this issue by proposing a digital twin framework supported by big data analytics for ship performance monitoring. The proposed framework is developed by the respective data sets from a selected vessel. For this purpose, a cluster analysis is implemented using the Gaussian Mixture Models (GMMs) with the Expectation Maximization (EM) algorithm. By this approach, the most frequent operating regions of the engine is detected, the shapes of these frequent operating regions are captured, and the relationships between different navigation and performance parameters of the engine are determined. That will make the basis for a digital twin application in shipping. The main objective of this research study is to develop a digital twin of a marine engine by considering the engine operational conditions that can be utilized toward green ship operations. The contribution of this paper and the outcomes can facilitate the shipping industry to meet the IMO requirements enforced by its regulations.

Citations: 4

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Figure 2.
Interactive Dash app developed to explore text embeddings of abstracts. Top left: A UMAP-based 2D scatter plot of the text embeddings with neighbouring points corresponding to semantically similar abstracts. Top right: The abstract of the hovered-over point (abstract) in the UMAP-based scatter plot. Bottom left: bar graph showing the average similarity between included words and all abstracts (or a selection). Bottom right: spider chart highlighting the average similarity for all abstracts and the hovered-over point (abstract) to the six topic sentences. Additional functionality: the input field and the dropdown in the top left corner allow the user to colour the UMAP-based scatter plot based on similarity to identified topic sentences or a user-provided input.

Results

a. Literature review

We employed a cutting-edge text-embedding model to visually examine research articles on maritime DTs. The text embeddings allowed us to depict the abstracts as points in a 2D space, with nearby points representing abstracts with similar semantic content. We created an interactive dashboard to delve into the themes characterizing groups of abstracts, identifying six key themes:

- **Energy efficiency and emissions:** abstracts focused on optimizing engine usage and energy efficiency.
- **Structural loads and stresses:** abstracts seeking to monitor structural loads and stresses of structures.
- **Dynamics and manoeuvrability:** abstracts about simulating ship movement through water.
- **Simulation and modelling:** abstracts emphasize more general aspects of computer-based simulations.
- **Digitalization and manufacturing:** abstracts of more general reviews and comparisons to manufacturing.
- **Networks and communication:** abstracts for DT implementation of maritime communication networks.

Based on similarity, we categorized each abstract as belonging to one of the six themes. Figure 3A depicts the results, with the six colours representing the six different themes and the colour saturation representing the degree of similarity. The thematic description for each category (colour) is given in Figure 3B, which shows the average similarity against all six themes for every category. The abstracts categorized as belonging to a particular theme are clearly more similar to that theme on average than any other, indicated by the sharp peak towards a single theme for each of the six differently coloured spider charts in Figure 3B.

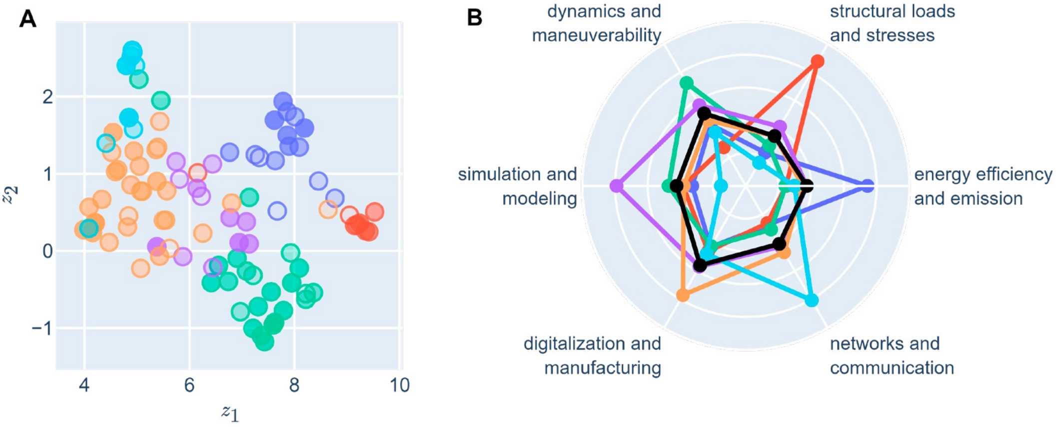

Figure 3.
Categorization of all analysed abstracts into six themes. A UMAP-based scatter plot of the text embeddings for all abstracts, with the colour representing the categorized theme for each abstract and the colour saturation representing the degree of similarity to the theme. B A spider chart highlighting the average similarity of all abstracts in each theme to six topic sentences.

The identified themes highlight the complex process of creating a DT of the whole ship with parts delivered from multiple vendors. Research seems focused on DTs for certain parts or aspects of the ship rather than on obtaining a DT of the whole ship. The development seems driven by specifically envisioned subtasks for a DT of the whole ship, as evident from themes like energy efficiency and emissions, structural loads and stresses, and dynamics and manoeuvrability. These are all important parts but do not represent a DT of the whole ship alone. The parts would need to be integrated into one entity. Interestingly, the simulation and modelling theme focuses on some elements necessary for integrating parts by exploring functional mock-up interfaces that combine models from different vendors into a single larger model. Overall, the identified themes thus highlight that the development progresses from DTs aimed at specific subtasks or specific parts toward integration into larger and larger DT entities.

b. Predictions

The research on DTs in the maritime industry exhibits some fragmentation, with research spread across several distinct themes. Although the research in maritime DTs is extensive, most efforts have been on implementing DTs of ship subsystems and components. There is still a knowledge gap between creating DTs of individual ship processes and system-level solutions. Maritime DTs are expected to be enablers of sustainable and energy-efficient shipping, provide autonomy to ships through improved situational awareness, and act as a human-machine interface in remote operations. However, current technology and research have yet to demonstrate this full potential. It remains to be seen how to bridge the gap between implementing DTs for individual ship processes and how to integrate the component DTs into a complete ship model.

We expect that recent advances in maritime co-simulation [13], [14] and standards supporting model exchange [15] will help bridge the gap between process-level and multi-system, multi-vendor DTs. Furthermore, as model-based design and virtual commissioning [16], [17] are slowly becoming the new standard in the shipbuilding industries, process models will become available to system integrators earlier in the shipbuilding process, which, in turn, makes the path for creating ship-level DTs more attainable. In the upcoming years, we expect new maritime digital-twin concepts to appear. So-called ’green DTs’ get implemented to improve the overall ship energy efficiency. Port and fairway DTs might be the solution to increasing situational awareness of remote operations and remote pilotage. With ship-level DTs becoming attainable, holistic data-management systems can enable the autonomy of future ships.

Although the literature review did not reveal maritime autonomous ships as a key application area of DTs, we predict that DTs can have an important role in improving the operational safety and sustainability of maritime autonomous surface ships (MASS). Both the European Maritime Safety Agency (EMSA) and the International Maritime Organization (IMO) highlight the importance of operational safety and sustainability in the deployment of MASS systems [18], [19]. The regulatory scoping exercises by IMO revealed an extensive range of issues with the deployment of MASS, including operational safety, liability, interactions with ports, and pilotage [14].

DTs of MASS could help improve onboard and onshore situational awareness, thus addressing some of the concerns by the IMO regarding operational safety and remote pilotage. DTs have already been adopted for improving situational awareness in other fields. Remote operation and pilotage can benefit from digital-twin technologies by fusing the available onboard information and transmitting it to shore [20]. In [21], it was stated that the DT enables mission managers to make knowledgeable decisions regarding the consequences of possible in-flight changes to NASA and U.S. Air Force missions. In [22], progress towards developing DTs for cyber situational awareness by advanced monitoring, inspection, and testing capabilities was presented. DTs and virtual sensors have also been applied for condition monitoring in rotating machinery [23], [24].

c. Roadmap

A roadmap towards maritime DTs consists of the following stages.

- **S1. Component DTs:** Combines dynamical models of individual ship processes with real-time sensor data. Component-level DTs rely on sensor fusion, optimal control methods, signal processing, optimization, and IoT technologies for improved monitoring and condition-based and predictive maintenance.
- **S2. Co-simulation:** Standardized modelling formats such as the functional mock-up interfaces (FMI) allow the exchange of dynamic simulation models between system integrators and vendors. Initiatives like the Open Simulation Platform (OSP) make system-level DTs feasible.
- **S3. Virtual commissioning:** Virtual commissioning requires that process models get integrated and tested early in the shipbuilding process. Virtual commissioning paves the way for the creation of ship-level DTs.
- **S4. Fairway and port DTs:** DTs of ports and fairways are enablers of remote pilotage and operations by providing information on the ship’s environment by collecting and fusing data.
- **S5. Ship DTs:** A ship-level DT integrates and simulates all relevant onboard systems, acts as a data management and sensor fusion system, and communicates with fairway and port DTs.

The roadmap is visualized in Figure 4.

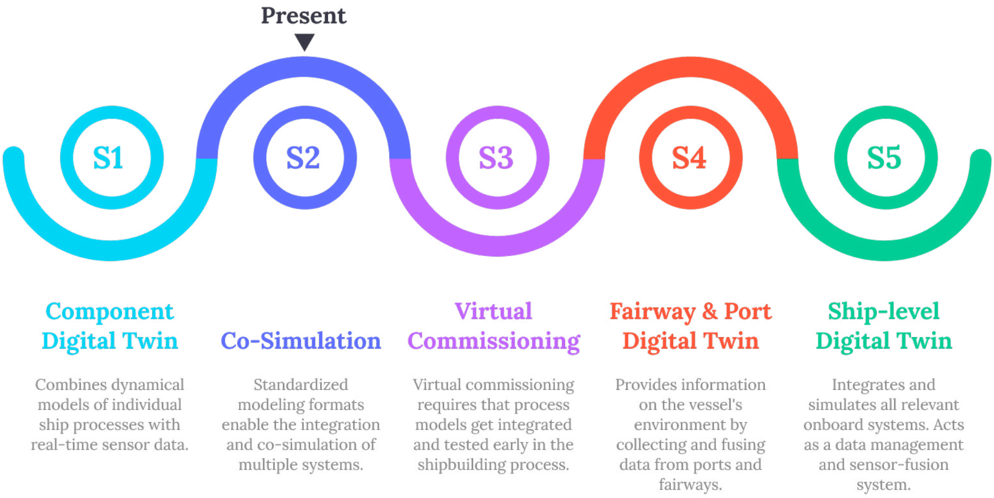

Figure 4.
A roadmap of maritime DTs.

Conclusions

A review of current research trends in maritime DTs was presented. An automated analysis approach based on text embeddings of abstracts was developed and made public to avoid enforcing personal biases on the review results. The review revealed six topics related to maritime DTs. Somewhat surprisingly, the review did not identify topics like autonomous ships and remote pilotage. A suggested explanation was the existing knowledge gap between implementing component DTs and ship-level DTs.

The literature review concludes that future research should be aimed at integrating component DTs. We predicted that advances in co-simulation, standardized model sharing, and virtual commissioning are still needed to achieve the goal of a ship-level DT. The roadmap presented in this paper can be used as a guide for future research aimed toward holistic integrated DTs of ships.

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Jani Vanharanta, Jarkko Paavola & Juha Kalliovaara

Cybersecurity threat information sharing for the maritime environment

Cybersecurity is a critical component in autonomous system safety. ARPA focuses on threat information sharing methodologies for the maritime environment. Autonomous systems are intricate, multi-tiered, and interconnected information and communication technology (ICT) infrastructures. Security threats to these systems can exhibit complex and cascading consequences. With the ever-increasing prevalence and sophistication of connected devices (like sensors) and the integration of artificial intelligence (AI), the attack surface expands, intensifying the risk of threat propagation. In response to these challenges, the need for robust tools to automatically monitor and mitigate security risks – especially those linked to data and algorithms – becomes very important.

An important element in this landscape is maritime threat information sharing, facilitated by platforms such as MISP (Malware Information Sharing Platform & Threat Sharing). MISP plays a crucial role in bolstering cybersecurity by enabling organizations to share, store, and correlate data pertaining to targeted attacks, threat intelligence, vulnerabilities, and counter-terrorism information. This platform is widely embraced by the cybersecurity community, including national Computer Emergency Response Teams (CERTs), military Computer Security Incident Response Teams (CSIRTs), NATO, the Maritime Security Centre of Excellence, and the European Union Information Sharing and Analysis Centers (EU-ISACs).

Considering the growing trend of integrating common ICT technology into operational technology (OT) environments, including maritime operations, the cybersecurity landscape has evolved. Ships, which were traditionally perceived as isolated from cyber threats, now find themselves exposed to cybersecurity risks. This shift underscores the significance of developing advanced threat intelligence tools like MISP, which can effectively address the security challenges facing autonomous systems, including those in the maritime sector.

Maritime cyber risks

A large naval ship with many electronic onboard components forms a complex cyber-physical system of systems. Navigation, propulsion controls, electrohydraulic ballast tanks, stabilizers, and other industrial control systems (ICS) are vital to the safe operation of the ship. The OT onboard, similarly to control systems in the past, are often considered isolated and disparate control systems that are manually operated by onsite personnel in physically controlled limited access areas.

In practice, however, the number of ICT information systems interfacing with OT has also been on the incline on naval ships, effectively exposing some of the OT to the Internet and ultimately increasing the cybersecurity risks onboard. Most of the recent research seems to concentrate on the ongoing turns of cybersecurity events and not on the anticipation or assessment of possible future events, which in their report in 2019 was recognized as an area needing further work [1].

The Maritime Security Committee already in 2017 annexed the International Safety Management (ISM) Code (code for ships), encouraging administrators to ensure the appropriate addressing of cyber risks in safety management systems. The International Maritime Organization (IMO) issued a collection of high-level cyber risk management guidelines, whose purpose was to support effective risk management and ultimately to support safe and secure shipping that is resilient to cyber risks.

Situational awareness in maritime cybersecurity

Situational awareness, in the context of maritime cybersecurity, involves three key stages:

- **Perception:** Understanding the current state of the protected environment, including assets on the networks, existing protective controls, records of previous security events, and more.

- **Comprehension:** Analyzing data and log sources from both ICT and OT assets, collected from network sensors, host and network intrusion detection systems, and control systems. This stage also assesses the significance of the protected assets and how an attack on them could impact the ship's operations.
- **Projection:** Anticipating and assessing the future state of the environment, enabling proactive decision-making and action selection based on threat information.

In essence, situational awareness helps organizations prepare for, mitigate, or avoid cyberattacks by providing insight into the current state, understanding the implications of potential threats, and proactively planning for future security challenges.

Cyber Threat Intelligence

Cyber threat intelligence (CTI) plays a crucial role in bolstering proactive cybersecurity and cyber resilience. CTI comprises data that has undergone analytical processing and is presented in a usable form that can be evaluated in context. This information's value is determined by its relevance, accuracy, timeliness, specificity, and completeness for the company's business operations.

To a company, this means being able to analyze the threat potential against the company's business processes as well as to prepare for being targeted by certain threat actors and threat actor groups. CTI can provide detailed knowledge of real targeted cyber-attack techniques, tactics, and procedures that can be used proactively to plan and prepare for, sustain, mitigate, or avoid a cyber-attack that has been successful elsewhere.

MISP

MISP, an open-source threat intelligence platform, is instrumental in sharing, storing, and correlating data related to targeted attacks, threat intelligence, financial fraud, vulnerability information, and counterterrorism. It enjoys widespread adoption in the cybersecurity community, including national CERTs, military CSIRTs, NATO, Maritime Security Centre of Excellence, and EU-ISACs.

As a versatile threat intelligence platform, MISP seamlessly connects to various threat information sources, such as open-source intelligence (OSINT) and intelligence analysis systems (I2). Furthermore, MISP can be enriched with diverse threat data from numerous external sources via common API interfaces, including complex darknet and dark web information indexing services.

What sets MISP apart is its adaptability. Users can create custom enrichment modules, allowing them to connect to virtually any proprietary data source. Additionally, MISP allows for the creation of personalized taxonomies, promoting efficient and compatible information exchange. This feature is particularly beneficial in intra-sectoral sharing groups that share a common classification baseline, and it allows for the establishment of automatic information dissemination plans based on taxonomy.

In MISP, users can also define their threat information-obsoleting algorithm, ensuring the relevance and usability of shared threat information. This comprehensive approach to threat intelligence ensures that data is not just collected but also delivered in a meaningful context.

Maritime threat information sharing

The value of technical data, such as IP addresses and software checksums, lies in its contextualization. Mere lists of technical details are of limited use without the proper context. To be actionable, this data should answer several critical questions:

- What does the list contain, and why is the data included?
- Why is this data relevant to the company?
- What is the potential damage to the company's assets or business processes?
- How long is the data relevant?
- What actions should be taken based on this information?

In the maritime sector, MISP facilitates threat intelligence at multiple levels:

- For executives: Strategic, high-level information provides insights into the long-term risk potential for businesses in the maritime sector, logistics companies, and port operations.
- For security managers and officers: High-level and short-term insights, trends, details of ongoing attack campaigns, and data for adversary attribution enhance decision-making and proactive defence.
- For analysts and incident responders: Low-level and long-term information on indicators, artefacts, tools, and methodologies specific to maritime and port operations assist in tactical security operations.

In summary, MISP is a vital tool for maritime organizations seeking to leverage threat intelligence effectively, ensuring that data is not just collected but also presented in a meaningful and actionable context. Maritime-specific threat intelligence information in MISP will benefit companies in at least three out of the four subtype levels shown in Fig. 1.

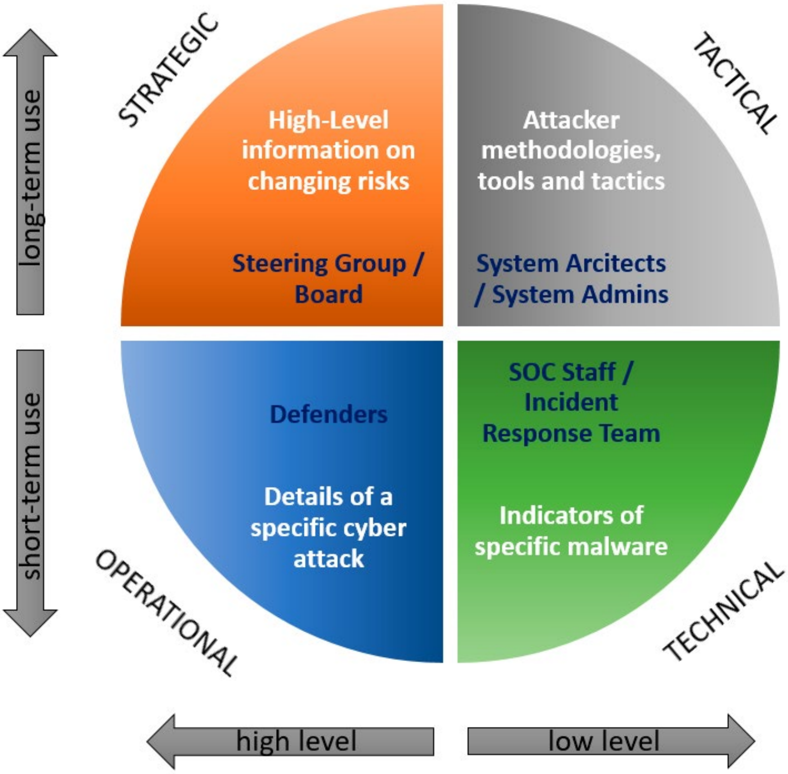

Figure 1.
Threat intelligence subtypes.

Conclusions

The utilization of cyber threat intelligence and platforms like MISP in the maritime industry has far-reaching benefits. It enhances situational awareness, enabling timely responses to cyber threats while reducing the burden on individual defenders. The shared information is most potent when organizations within the same industry collaborate, as threats often target common features and systems. Given the maritime sector's reliance on a functioning supply chain and the collaboration of various stakeholders, shared situational awareness of cyber threats is imperative.

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Industrial RDI Environments

Antti Nousiainen & Teppo Mattsson

RDI environment for advanced robotics and autonomous work machines

Introduction

The aim of the ARPA project has been to enhance the Turku University of Applied Sciences' competence and capabilities in autonomous technologies. Related to the industrial theme of the project, this was achieved by, among other things, extending our existing factory automation system, acquiring an advanced 3D camera and acquiring an affordable mobile robot designed for research and education and then exploring and understanding these technologies.

The factory automation system was extended with an industry grade control room hardware and software with additional programmable logic controllers and other equipment forming a comprehensive full-scale factory automation system.

The 3D camera can be used to detect and accurately measure objects in three dimensions, which is necessary for applications such as material handling in factories, warehouses, and agriculture. These tasks are difficult for robots to perform, so there is a lot of research and development potential in this area. The acquired 3D camera will be installed in an existing robot cell, creating a capable research platform that is also suitable for education.

An important application for mobile robots is indoor logistics, which is applicable to various sectors such as industry, commerce, and health care. For instance, a mobile robot can improve hospital efficiency by delivering linen and food, while nurses can focus on patient care.

All of these technologies are required for robotic and autonomous solutions, for which there is a demand, as human labour becomes increasingly scarce for certain jobs.

The devices are also compatible with the open-source Robot Operating System (ROS) framework, which is a collection of tools, libraries, and conventions that simplify the development of complex and robust robot applications. ROS has become a standard in research robotics and is increasingly adopted in industrial and commercial settings.

The combination of the acquired devices and systems, ROS, and the existing robotic hardware form an enhanced RDI environment that offers many opportunities for research and education of important and relevant applications in the field of automation and autonomous work machines.

Siemens SCADA, the distributed control systems

The factory is a modern development and learning environment for mechanical engineering at Turku University of Applied Sciences. It includes facilities such as a workshop, automation laboratory, and other spaces. The factory is also used for real workshop production.

Objective

The goal of the project was to create an environment in Turku University of Applied Sciences' machine automation laboratory similar to a distributed automation system. This environment allows the connection of training equipment and systems through communication networks. With the help of a distributed system structure, data can be collected from or control operations in these entities through the operating environment. In the future, similar functions can also be expanded to production cells and MES (Manufacturing Execution System) environments.

Control Room SCADA System

An integrated control room has been built alongside the automation system, where the monitoring and control of connected equipment as well as data collection and data processing functions are centralized. The functions of the control room (SCADA) are implemented using Siemens' WinCC software, which was installed on a separate server platform. In addition to the functions required for user interface screen designing, the software also includes features necessary for process data management, such as data storage and related analysis and reporting software. In the future, these capabilities can be used to develop production methods more towards data-driven operations.

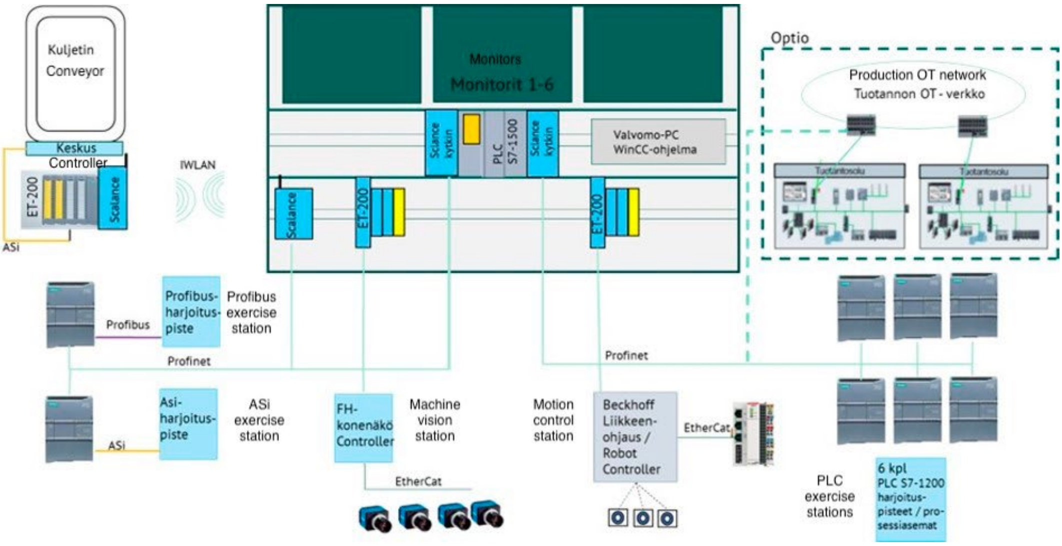

Figure 1.
System diagram of the automation system implemented in the laboratory.

Control System

The assembly of the control system consists of Siemens' S7 1500 series PLC (Programmable Logic Controller). It includes some direct IO connections as well as all network switch-based Profinet communication interfaces for various distributed modules and practice points. The master logic allows for configuring all different control and management software that is not sensible to run on distributed stations. For example, this includes the implementation of motion control or safety software in the main logic. Additionally, the Master PLC (S7 1500) enables the use of Siemens ET 200 S distributed units as IO modules, allowing the actual control and management applications to be implemented on the main logic side as well.

Automation Networks

The Profinet network type used in the system is based on the industrial Ethernet standard, where time-critical functions are made possible through real-time protocol additions. In addition to non-time-critical functions, the network allows real-time and cyclical data transfer simultaneously on the same network without disrupting real-time data transfer. Real-time data can also be transmitted synchronously, ensuring sufficient response times for demanding motion control applications (less than one millisecond). Due to its real-time capability and determinism, it can be used at the lowest level of the automation hierarchy. Profinet enables the construction of an automation network from the supervisory and OT (Operational Technology) production network level down to the field level (see Figure 2). Additionally, Profinet is based on Ethernet protocols, enabling wireless communication through access points to ET200S distributed sub-stations, which will be utilized in the future for production equipment data collection applications (see Figure 1).

Currently, the physical network is a line topology, but as the data collection needs in the production environment expand, the network topology can be changed in the direction of the OT production network shown in the options section of Figure 1. Various segments, such as the equipment of the current automation laboratory, can be connected to it as individual segments.

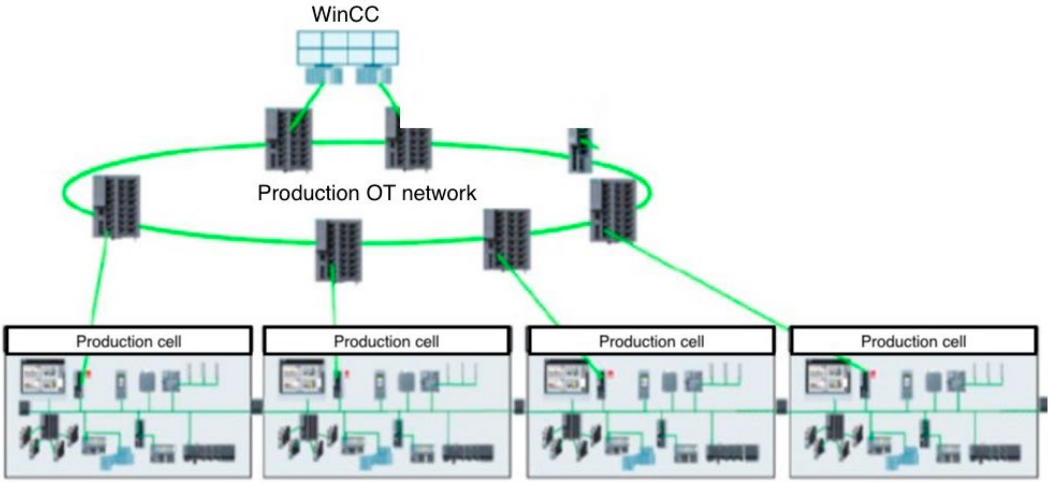

Figure 2.
Topology of the OT network in the production environment.

Process Stations

In the automation laboratory, the tasks of process stations were simulated by creating production programs for the practice point PLC logic (Siemens S7-1200). In these programs, specific sequence logics were built for each process. The processes were phased in such a way that the manufacturing sequence of the previous process had to be completed before the next subprocess sequence could start. The progress of production can be monitored through HMI (Human-Machine Interface) panels connected to the process stations, as well as from the actual control room displays, where operating screens for process monitoring were also set up. The Profinet network is built into the communication between the process stations and the Master PLC.

Results

Based on the experiences obtained so far, the system can be used to carry out exercises that illustrate the functions of an automation system concerning user interfaces, hardware, software, and networks. The development of the system has primarily involved students, and this approach is intended to continue for future projects. The environment provides a comprehensive view of the functions and possibilities of a full-scale factory automation system, which has been found to be beneficial in the students' experiences. In the future, manufacturing processes can be connected to the OT network, as shown in Figure 2, making tasks like data collection from production machines easy.

Advanced machine vision

Autonomous systems, both factory automation and mobile robots, depend on their ability to accurately detect the position and orientation of objects in the environment. For that purpose, we have invested in an advanced, structured light-based 3D camera from Ensenso. Among its other applications, the N35 camera can handle demanding pick-and-place applications in different fields, including industry, commerce, and agriculture. The camera, designed for rough environments and conditions, can be installed on a mobile robot, work machine, or in an industrial robot work cell. Other applications the camera is suitable for include quality assurance, measuring, and other autonomous tasks such as robotic assembly work (Figure 3).

Figure 3.
Ensenso 3D-camera whose operating principle is based on structured light.

One of the reasons the N35 camera from Ensenso was chosen is the camera's compatibility with the open-source Robot Operating System (ROS) framework. ROS provides a robust data transmission architecture, software tools, and libraries that enable the research and development of autonomous applications. The camera is also compatible with cutting-edge commercial machine vision software suites. Some of these can be affordably licensed for educational use.

The goal of the procurement is to develop expertise related to machine vision, robotics, and autonomy, as well as to provide companies and educational institutions in the region with an advanced research platform for research and development. Additionally, the goal is to promote the adoption of these technologies across various industries and study their applicability and impact on different scenarios. The procurement encourages the collaboration between student groups, university staff, and companies to work together to innovate, learn, and practice the design and testing of advanced robotic applications that could offer future innovations and improvements for the companies.

Mobile robots for learning autonomy

Mobile robots are becoming increasingly useful in various fields as technology advances and becomes more affordable and accessible. In this project, a mobile robot – Duckiebot, designed for research and education – has been acquired. While Duckiebots are low-cost mobile robots, they still contain a relatively powerful computing unit and various sensors. Although these robots may seem simple, with them, it is possible to learn and develop skills required in autonomous systems, e.g. using the open-source ROS program library (Robot Operating System). As software development skills become increasingly important for mechanical engineering students, the acquired Duckiebot will help students learn to code by providing a concrete and interactive way to apply their skills, offering various challenges and projects that require different levels of programming knowledge and creativity (Figure 4).

Figure 4.
With Duckietown you can build your own robot, follow along with our lectures, and interact with a global community of learners.

Duckiebot robots originated from a project at MIT in 2016. The robot and its educational platform were designed to be small in scale and cute, yet still preserving the real scientific challenges inherent in full-scale real autonomous robot systems. The motto of the Duckietown robots is ‘State-of-the-art Robotics and AI made tangible, accessible, and fun!’ Several reputable educational institutions use Duckietown robots.

High-quality learning material, which the Duckietown community develops and maintains, is also of great importance and a major reason for investing in the platform. There is plenty of free, open, and high-quality teaching material and even courses available. The Duckietown community is backed by the non-profit Duckietown Foundation.

Conclusion

We are happy that we have had the opportunity to invest in and study the acquired equipment, and we believe that the equipment and systems will serve the university, our students, and our partners for a long time in the future. We have gained insights into different technologies that serve as a starting point for future research and education work. We have also learned valuable skills and knowledge that are relevant and important for the development of autonomous systems and work machines.

However, we also realize that there is still work to be done to integrate these technologies with the existing hardware and the student curriculum. We also acknowledge that these technologies increasingly require software development competence from our mechanical engineering students. One important outcome of the project has been bringing the computer science and mechanical engineering departments, both staff and students, closer together through cooperation and knowledge sharing.

We also want to emphasize that the technology by itself does not improve things, but what actually does is the enthusiastic and skilful individuals and teams who can apply technologies creatively. We hope that the acquired hardware will inspire and motivate our current and future students to become proficient and innovative in the field of autonomous technologies.

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Industrial Metaverse Approach

How to Remotely Control Robots in a Multiuser Environment

This paper presents our industrial metaverse approach by introducing a multiuser environment, where different robots can be controlled remotely. It briefly summarizes our visions for the next-generation industrial revolution. The technology industry is one of the spearhead domains in the Turku region, and tight industry-academic cooperation can generate innovations to increase productivity in global competition. As an example case, we have chosen two robots, a XiaoR Geek tank robot and a Universal UR5 cobot, which are now available in our multiuser metaverse environment. The first one is an example of unmanned ground vehicles that could be replaced with drones, unmanned forklifts, or vessels. While the first one is a toy robot, the second one, as a cobot, is widely used in industry along with humans and thus illustrates potential on production lines and could be replaced with industrial robots such as the Yaskawa or ABB robots we have in the Turku Machine Technology Center.

Background

According to Bai et al. (2020), autonomous robots and cobotic systems will have a significant impact on environmental sustainability. This revolution (Industry 4.0) is currently happening in the Finnish technology industry. This paper focuses on the next revolution, called Industry 5.0, where increased collaboration among humans and machines is at the centre, where the humans' role is essential and moral decision-making and where robots are more autonomous (Alojaiman, 2023). In the environmental sustainability dimension, autonomous robots and cobotic systems seem to have a high impact on the automotive and electronics industries.

Turku University of Applied Sciences (Turku UAS) is a member of European Digital Hubs called Robocoast. As a member, it has the possibility to become visible in a large European network focusing on robotics. The technology industry is one of the spearhead domains in the Turku region. Valmet Automotive is well-known for its investments in robotics. For example, in 2016, it bought 250 ABB robots for welding to increase productivity and respond quickly to market demands (Promaint, 2016). Pemamek, in turn, is one of the leading robot welding system providers in the Meyer Turku business ecosystem. In 2021, we studied with Pemamek the usage of 3D scanners in welding (Fernandez, 2021). These examples show that Industry 4.0 is already widely adopted in the Turku region, and together with our industrial partners, we are currently exploring when and how Industry 5.0 should be adopted next. The Finnish Metaverse Strategy launched in November 2023 emphasizes Nokia's vision of the industrial metaverse – by 2030, the industrial metaverse will be the first widely used metaverse technology in Finland (Digital Finland).

Industrial Metaverse Approach

Futuristic Interactive Technologies, a research group developing its own metaverse technology at Turku UAS, has participated in the ARPA project, where various prototypes have been explored in the areas of the industrial metaverse. In Batallier (2021), we introduced a system that uses virtual reality to monitor the behaviour of a robotic arm (the Braccio Tinkerkit) and fully control it remotely. This study provided us with information and documentation about the required protocol support and data flow requirements for integrating further embedded system solutions. We have developed the metaverse as a technology that consists of features for social communication, hands-on experience, and digital twin integration (Limuli et al., 2022). Next, we will introduce two prototypes developed on the top of our industrial metaverse.

At the European Robotics Forum 2023, the teleoperation prototype was introduced (Pieskä et al., 2023). The aim was to create a self-contained system for teleoperating robots by using VR and smart gloves as the user interface based on the experiences collected from the Tinkerkit prototype. In this study, we focused on visualizations by visualizing a digital twin of the physical robot (a XiaoR Geek tank robot) to improve a realistic user experience. A low-latency communication layer between the digital and physical twins was implemented by using the MQTT protocol. WebRTC enabled the streaming of the video of the physical robot to the industrial metaverse with low latency. The industrial metaverse environment called Arpaverse also contained our laboratory, which was scanned by utilizing a laser scanner to enable a matching virtual environment for the tank robot. An accelerometer was used to update the position of the virtual robot according to the movements of the physical robot. In addition, massively multi-user operations were demonstrated at ERF2023 by implementing a movement system through a Web interface, which allowed the audience to participate in the demonstration (Pieskä et al., 2023). In the demonstration, a voting system was implemented to determine the next command sent to the robot. This was done to show concretely that the robot can be controlled with lightweight additional interfaces as well via direct command streaming to the virtual environment. To increase the user experience, a real-time video was included so the user was able to control the robot remotely with an advanced user interface introduced in Figure 1 (Kaarlela et al., 2023).

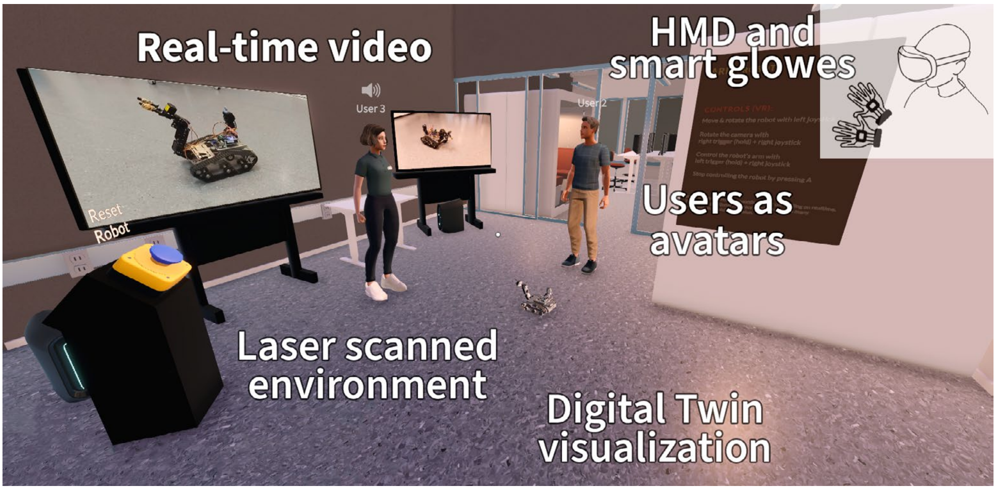

Figure 1.
Remote controlled robot environment was introduced at the European Robotics Forum.

Just lately, we have focused on the Universal UR5 cobot. This robot is again remotely operated with VR headsets and controllers, and it will be introduced to the audience as part of the launch event for the Finnish metaverse strategy. The robot will be visualized again as a digital twin for the users with real-time video information. Our objective is to showcase the opportunities in the industrial metaverse emphasizing collaborative elements. A Finnish pavilion (already used in previous MatchXR events, a side event for Slush) has been chosen as the metaverse environment where presentations of the National Metaverse Strategy will be duplicated to concretize the possibilities of using the industrial metaverse, seamlessly combining the phenomena of the digital and real worlds. Operating in the environment requires an access token that grants the right for the operator to control the robot remotely. In practice, a collaborative construction task will be carried out with the robot, where users represented by avatars can take turns participating in the construction project independently of their real-world physical location. In other words, the solution enables work shifts to continue without interruption, regardless of time and place.

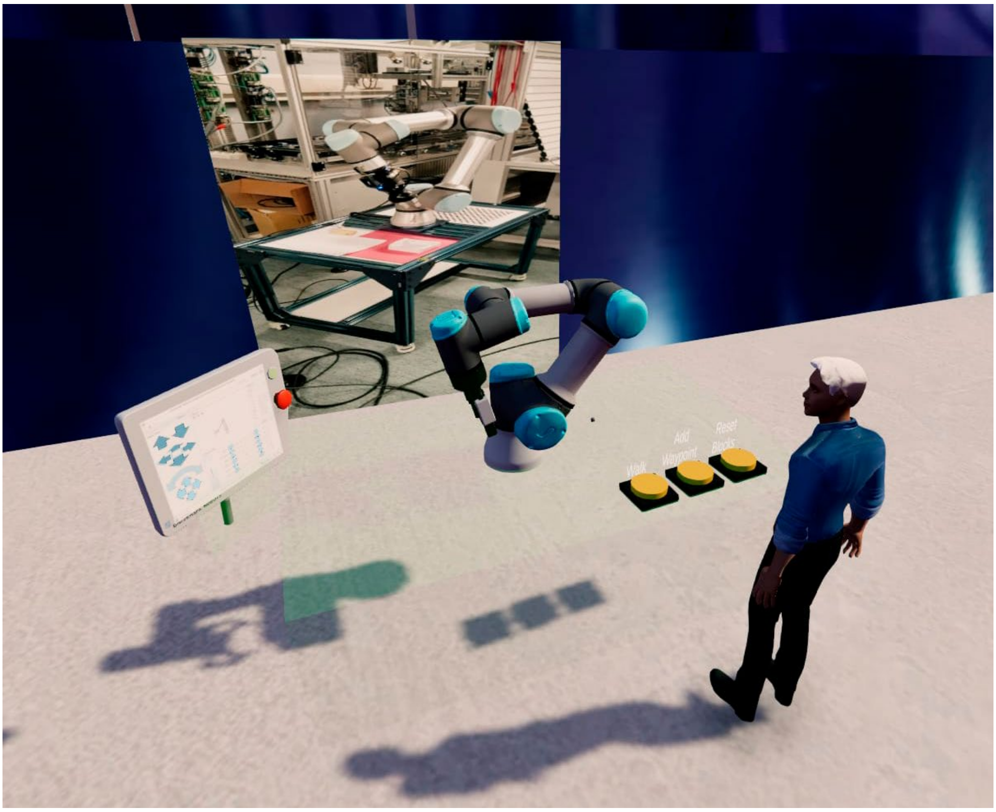

Figure 2.
Controlling the Universal UR5 remotely in a metaverse environment.

Future Directions

In the near future, we plan to replace this robot with a Universal UR10 cobot that is instrumented for welding (Figure 3, left). This would require special cameras to be used to increase situational awareness. One camera will be needed to be attached to the robot itself (close to the welding instrument) and another one (for example) hanging on the roof to get a better understanding of the whole environment where the cobot is operating. Additional camera streams and sensor arrays could be implemented as required by the processes and integrated and visualized directly in the virtual environment. Our ultimate goal will be to enable remote control of a laser-welding robot cell located at the Machine Technology Center, capable of collaboration, training, and seamless work rotation, improving the utilization rate of the robots in general. During the process, data streams would be collected in the backend system for further analysis, paving the way towards neural network and artificial intelligence implementations. Further studies would be required in the selection and development of the neural network architecture, eventually providing high-quality training datasets needed for training an automated assistant, then progressing towards higher levels of automation, and eventually an autonomous system. Additional studies in protocols, safety aspects, and regulations would also be required. These aspects will be used in the future in the Robocoast learning environment, which is under development with Business Turku and ProVerse (Figure 3, right).

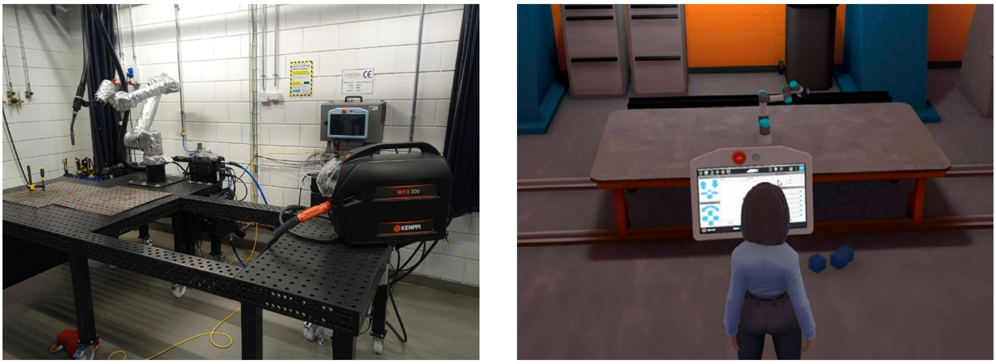

Figure 3.
Replacing a Universal UR5 with a UR10, enabling remote welding (left) and the UR5 learning environment under development with Robocoast (right).

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