Toward Remote Control Center for Marine Operation: A Case Study of R/V Gunnerus

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***Abstract*—Today, with the rapid development of emerging technologies such as the Internet of Things and digital twins, remote management of ship operations has promising prospects. In this paper, we present a remote control center solution, with an emphasis on sensor data collection, transmission, storage and representation. A research vessel named R/V Gunnerus is used a test bed. Taking advantage of onboard sensor data transmitted by MQTT and saved into local database, a dashboard is designed and developed to monitor marine operation and provide decision support in real time, and playback historical operations. Three case studies including real-time crane operation monitoring, ship docking replay, and ship motion prediction show that the proposed solution is effective in remote ship management.**

***Index Terms*—Remote control center, marine operation, real-time monitoring**

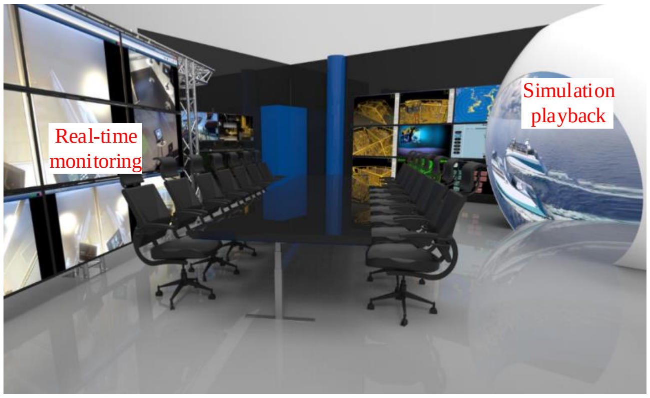

Fig. 1: Layout of RCC for R/V Gunnerus at NTNU Ålesund.

I. INTRODUCTION

There is a trend to consider developing more advanced vessels that have intelligence and are capable of executing different levels of autonomy for maritime operations. The term levels of autonomy is often used to describe what degree the plant can act on its own. As regulated by International Maritime Organization (IMO) in 2021, ship autonomy can scale from a machine being completely controlled by human, i.e., manned-operated, to the machine being fully autonomous and without any interaction from human [1]. Fully autonomy may not be applicable to the entire maritime operation but are most useful when applied to subtasks of the operation. For example, ship navigation in the open sea can be nearly autonomous whereas for some part of the voyage like passing narrow water, it will require close supervision and decision making, or even full manned-operation.

As the technologies, especially sensor technologies for perception and communication has been developed, the prospect of autonomous ship will become a reality. Multiple sensors including not only internal status of machineries, propulsion system, engines, but also camera, lidar, radar, sonar and GPS/INS external sensors for operation and navigation, could be integrated into the ship [2]. On the one hand, in the light of sensor information the ship is able to make decision in an optimum way to combine operational reliability and cost efficiency. The benefit is obvious that human errors will be reduced, as well as the cost. Yet, on the other hand, it is challenging to conduct autonomous navigation and unmanned marine operation under different environments like open sea with different wave or weather conditions. Moreover, new types of risks with human involved, such as the communication with other human controlled vessels [3], the visual focus uncertainties [4], the interpretation of international maritime rules and regulations [5], and other safety and security issues, will arise. Therefore, developing autonomous ships cannot accomplish at one stroke, but should take human factor into account and improve in a gradual and iterative process.

To date, industrial demand shows that although at present there are global location and traffic management systems such as the GPS system and the traffic separation system for ship status monitoring, ship owners are eager to have their own control center used for condition based monitoring or traffic

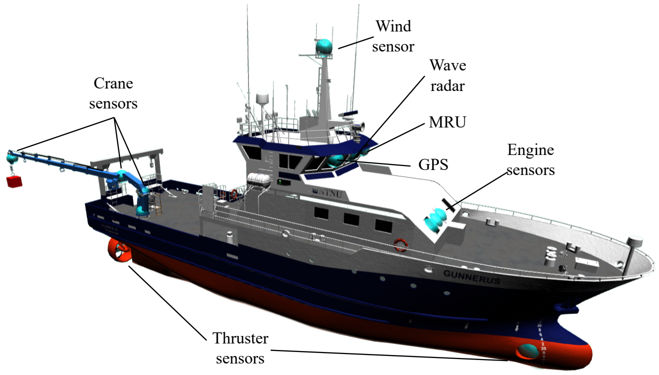

Fig. 2: Onboard sensor location.

TABLE I: Ship sensors for RCC development.

Sensor type	Description	Unit
Thruster	Azimuth angle feedback	deg
	Azimuth angle order	deg
	RPM feedback	%
	RPM order	%
MRU	Ship pitch, roll and heading	deg
	Ship heave	m
	Rate of ship pitch, roll and yaw	deg/s
GPS	Latitude, longitude	deg
	Surge, sway speed	knot
	Speed over ground	knot
Anemometer	Wind direction	deg
	Wind speed	m/s
Wave radar	Significant wave period	s
	Significant wave height	m
	Total energy mean direction	deg

control for vessel regular maintenance, and task dynamics distribution. Ship management will move towards "total awareness" with remote monitoring, support and operation. The onshore teams and ship crew will become a more integrated unit and it will be hard to distinguish between ship and shore tasks [6]. Offerings such as remote access, enabled by remote operation and control centers, are already providing customers with superior real-time connectivity that make these solutions a reality [7].

The capability for remote human interaction and control has to be enabled for situations where the ship autonomy cannot resolve or is not allowed to handle by itself. Furthermore, relaying the data gathered by ship's onboard sensors to a remote operator may require the transfer of significant amount of data, whereas the practical constraints, e.g. satellite communications often limit this types of applications. In this paper, we present our attempt to develop a remote control center (RCC), as shown in Fig. 1, for our research vessel R/V Gunnerus. The highlights of the study include an Internet of Things (IoT) solution for sensor data collection, transmission and storage, as well as advanced functions, taking advantages of digital twin technology—a digital replica of physical assets, for decision support of marine operation [8].

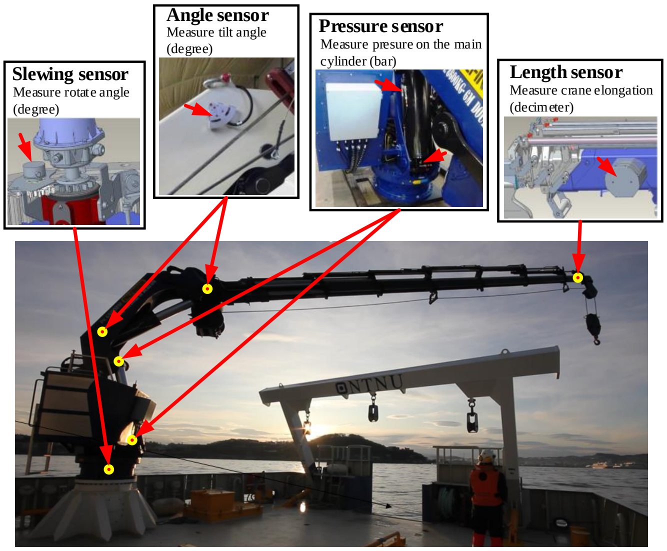

Fig. 3: Sensors deployed on Palfinger crane onboard Gunnerus.

II. DATA INFRASTRUCTURE

R/V Gunnerus is a research vessel owned by Norwegian University of Science and Technology (NTNU). The ship is 36.25 m long and 9.9 m wide, with a dead weight 165 t[1]. It is equipped with two permanent magnet rim-drive azimuth thrusters and one tunnel thruster. In order to perceive the surrounding environment and ensure safe marine operation, a variety of different sensors are deployed onboard the R/V Gunnerus. Fig. 2 illustrates rough location of these onboard sensors.

There are three diesel engines on the vessel. Engine data such as engine speed, temperature, and oil pressure etc. contributing for identifying engine status in different work modes are collected. The ship motion data, which is of great significance to reflect ship status, are gathered from the two azimuth thrusters on Gunnerus, including desired and actual RPM and azimuth angle. Moreover, the data from onboard MRU containing the attitude of the vessel, such as heading, pitch, roll and their corresponding change rate, are also collected. In addition to these interior information, exterior sensors are applied onboard Gunnerus to perceive environmental changes. Based on the global positioning system (GPS), ship position information including latitude, longitude and its course could be obtained, together with the ship speed over ground and the planar motion speed of the ship in the surge and sway directions. An anemometer and a wave radar are deployed at the top of the Gunnerus vessel, which provides information of wind direction and speed, and wave related information such as wave height and wave period. Table I lists the key sensor data that are used for the RCC development.

Cranes are important deck equipment in many offshore and subsea applications for lifting, transferring, and handling objects and personnel. There is a Palfinger crane onboard

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[1] https://www.ntnu.edu/oceans/gunnerus

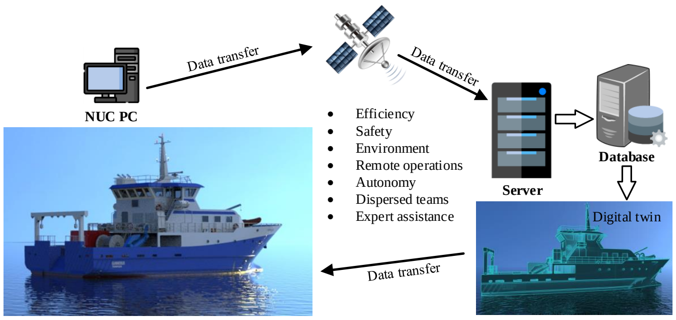
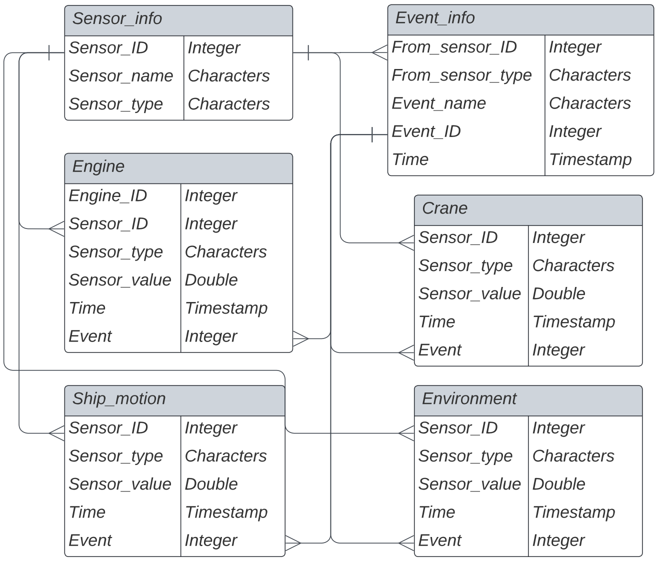


Fig. 4: Data transmission and storage scheme for digital twin system development.



Sensor_info	
Sensor_ID	Integer
Sensor_name	Characters
Sensor_type	Characters

Event_info	
From_sensor_ID	Integer
From_sensor_type	Characters
Event_name	Characters
Event_ID	Integer
Time	Timestamp

Engine	
Engine_ID	Integer
Sensor_ID	Integer
Sensor_type	Characters
Sensor_value	Double
Time	Timestamp
Event	Integer

Crane	
Sensor_ID	Integer
Sensor_type	Characters
Sensor_value	Double
Time	Timestamp
Event	Integer

Ship_motion	
Sensor_ID	Integer
Sensor_type	Characters
Sensor_value	Double
Time	Timestamp
Event	Integer

Environment	
Sensor_ID	Integer
Sensor_type	Characters
Sensor_value	Double
Time	Timestamp
Event	Integer

Fig. 5: Entity relationship diagram model in Gunnerus database.

Gunnerus that plays such a role and servers the needs of biological and geological experiments. The crane can reach out up to 20.5 m with safe working load around 2200 kg. In order to grasp the crane operation situation, four types of sensors have been installed on it, as illustrated in Fig. 3. A slewing sensor was installed inside crane column, between the slip ring unit and the hydraulic swivel connector. Two pressure sensors were installed on the main cylinder, aiming to get the corresponding pressure in crane operation. Two angle sensors, one on the main boom and the other one on the outer boom, were installed for measuring tilt angle of crane booms. A length sensor was installed inside the cable drum on the outer boom of the crane, thus enabling the measure of crane elongation.

III. DATA TRANSMISSION AND STORAGE

To develop a digital twin system, a huge amount of field data sensed by onboard sensor is needed. However, in most cases, the physical counterparts have lower computational power due to space and budget constraints. Therefore, it is challenging to directly develop the twin system onboard. Instead, establishing the twin system onshore in RCC would be an alternative solution, from where one can make use of high performance computers to model and train the twin system.

To this end, we build a remote control center, as shown in Fig. 1, for twin system implementation. Three control levels are considered, from monitoring, decision making, to emergency takeover. In the first level, one just need to monitor what is happening in the operation; whereas in the second level, supporting information could be generated at the center for more comprehensively understanding operation condition, not only at the present, but also in short future. If needed, the support information could be further forwarded to the onboard operator. The final level deals with contingencies, especially when the onboard operators take no action during an emergency. This paper only focuses on the first two levels of remote control.

Sensor data, from the context, is the fundamental of RCC. In this study, we utilize the message queuing telemetry transport (MQTT) network protocol — a standard messaging protocol for IoT data transmission. The MQTT has a publish-subscribe architecture that contains four components, i.e., publisher, subscriber, broker, and topic. The topic could represent a concrete sensor channel, represented by a string consisting of one or more levels separated by a forward slash. In our case, sensor data from the engine, the ship propulsion, the Palfinge crane and the environment could be considered the topics of MQTT. The broker serves as a hub that routes and distributes all messages. The publisher is responsible for sending messages with topics to the broker, and the subscriber receives messages by subscribing to topics of interest from the broker.

Here, we briefly introduce how the onboard sensor data is transmitted onshore and stored into a database for modeling and training of the twin system. First, a next unit of computing (NUC) PC is deployed on Gunnerus. It performs as an MQTT publisher to publish data messages at a frequency of 1 Hz from different data sources on demand. Then, a local server at the RCC is set up as an MQTT broker for forwarding received messages from the NUC PC. Next, a local PC is utilized as an MQTT subscriber. It not only receives MQTT messages, but also processes and stores sensor data into a PostgreSQL database. After that, proper datasets are generated from the database for developing the twin system. Finally, the twin system is applied to analyzing real-time data from Gunnerus to enhance operational planning and decision making. The scheme for Gunnerus data transmission and storage is illustrated in Fig. 4.

Regarding data storage, we use PostgresSQL — an advanced, enterprise-class, and open-source relational database system for data management, including insert, update, select and delete. Fig. 5 illustrates an entity-relationship diagram, which represents how we add information including column name, column data type, and relationships between tables to the database. A sensor table is created, containing the all sensor IDs and their corresponding types and names. In addition, four categories of tables, corresponding to the sensor data from Palfinge crane, ship engine, ship motion and environment, respectively, are incrementally generated. A threshold is set so that a new table could be created once its predecessor table's rows exceed that threshold. The purpose is to ensure that all tables in the four categories would not affect the efficiency of the query.

It is noted that in Fig. 5, the four categories of tables contain a column "Event". An event is a special user-defined condition associated with a table in the four categories. It can be defined based on either a single sensor source or a combination of multiple sensor sources. The event concept serves two purposes. First, it could facilitate generating datasets based on specific events for digital twin development. Second, it will be helpful to reduce the database size significantly if deleting sensor data that does not contain any events. An event table is thus established, as shown in Fig. 5, to summarize the currently defined events, including engine pressure alarm, crane in lifting, ship maneuvering, ship docking, and high sea state alarm. More events can be added into the table if required by any new applications.

IV. DASHBOARD DEVELOPMENT

To find out what has happened, or is happening, or may happen to Gunnerus, it is necessary to find a way of displaying various types of sensor data in one place. A dashboard is such an information management system that can convey different, but related information in an easy-to-digest form. It is useful for monitoring, measuring, analyzing relevant data and provide decision-making support in key areas. In our case, considering the facts that both live sensor data via MQTT from Gunnerus and collected sensor data in database from the RCC are available, a dashboard is designed to translate these data into easily understood visuals, such as charts, graphs and 3D animation, enabling crews at the RCC to stay informed about current/historical situation at a glance.

Data visualization especially environmental mapping is the most important element for dashboard development, as it is the fundamentals for representing ship operation status in RCC. There are multiple ways the mapping process can be performed and what kind of presentation of the world is created depends on the application, where the maps are needed and what sensors are used for perceiving the environment. Here, Mapbox is utilized for ship location positioning and environment visualization. Assets such as 3D models of the ship engine, the Gunnerus hull, the components of the Palfinger crane are built and converted to the format compatible to ThreeJS loader, from which these 3D models can be added into Mapbox. Moreover, Javascript is used at the backend for logical processing with human-computer interaction, such as data query, data visualization, and ship-crane assembly and animation.

Fig. 6 depicts the functional scope of the dashboard system. Taking advantages of MQTT, 1 Hz sensor data flow could be fed into the dashboard and the states of Gunnerus including the engine, the crane and the ship motion itself could be presented in a form of animation and dynamic charts in real time. This means, onshore crews in RCC could monitor marine operation by locating the Gunnerus vessel and manipulating the 3D visualization from any angle. In addition, if any of the predefined events as described in Section III is identified, the event name and the corresponding start time will be displayed in the monitoring interface.

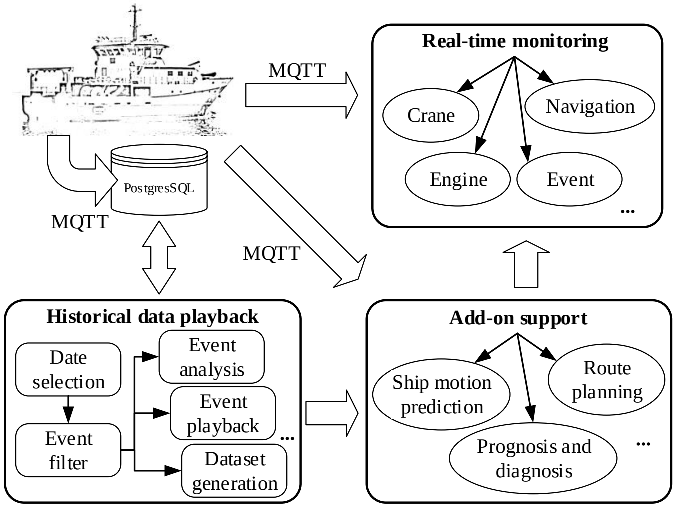


Fig. 6: Gunnerus dashboard system.

To find out what has happened to the Gunnerus vessel, a "historical data playback" function has been implemented in the dashboard. It is based on an event-driven concept that data are categorized by date and different types of events. Simple statistical analysis on certain type of events is provided, such as total fuel consumption, total operation time and distance traveled. For any event of interest, one can replay that specific event in animated form as fast as in real time or even faster. It is noted that the "historical data playback" function also provides an interface for event collection and dataset generation, which facilitates digital twin modeling and training.

The last highlight of the dashboard is the "add-on support" function. The word "add-on" here indicates a means of integrating advance tools into the dashboard. From our previous work in [8], a digital twin of Gunnerus was built, in which advanced tools such as ship motion predictor, auto-docking controller and engine anomaly detector are available and thus can be added into the dashboard for decision support of marine operation. As a result, the dashboard could make use of the tools from the twin system and display the support information to the front end of "real-time monitoring".

V. CASE STUDIES

In this section, we present three case studies to verify the effectiveness of the dashboard deployed in our RCC at NTNU Ålesund.

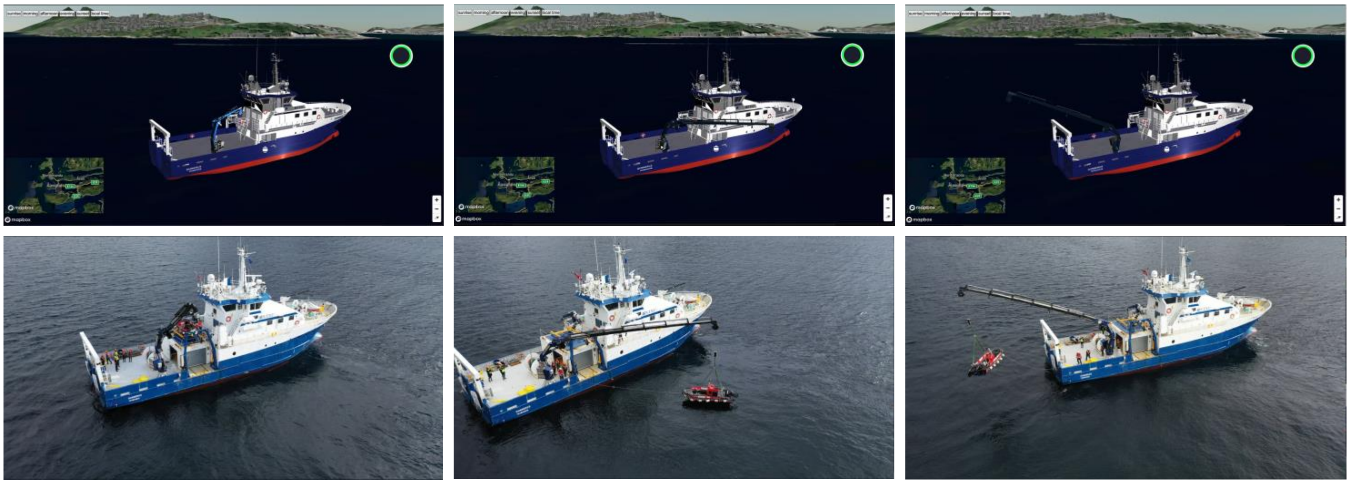


Fig. 7: Real-time monitoring of ship-crane operation on Gunnerus.

A. Real-time ship-crane operation

A field experiment of Gunnerus was conducted at Ålesund, Norway. The task is to perform dynamic positioning of Gunnerus while manipulating the onboard Palfinger crane to lift a lifeboat up and down around the ship. In the meantime, we run the real-time monitoring in the dashboard at RCC. The experiment lasted about 20 minutes and a drone video of the field operation is recorded, with the purpose for post analysis and comparison with the animation displayed at RCC.

Fig. 7 shows the comparison between the field operation and the animation [2]. They are video screenshots at time 72 s, 442 s and 658 s, corresponding to the moments when hooking up the lifeboat, lowering the lifeboat starboard, and lifting up the lifeboat aft, respectively. It could be seen that the movement in the animation is close to what happened in reality. Due to the low frequency of data transfer, the animation is not smooth enough, but potential improvements can be achieved by interpolating sensor data.

B. Ship docking replay

From our previous work [9], we have set proper thresholds on several variables, such as ship speed over ground, fuel consumption, and thrust RPM order for defining ship docking events. The data from the docking moment back to 8 10 minutes prior to docking is considered the corresponding data segment for representing a complete docking operation. Through the "historical data playback" function, how the Gunnerus ship approaches a dock could be visualized for analysis or evaluation.

Fig. 8 is a replay example of ship docking at Ålesund port. The replay interface not only provides a drag-and-drop time bar, but also supports fast replay, allowing animation playback up to be 10 times faster than real time. In addition, the dynamic charts aside present the status changes of Gunnerus ship over time, facilitating remote operators to fully understand ship behavior. For example, from Fig. 8, it is obvious to see the drop down of fuel consumption and the decrease of surge speed when Gunnerus approaching the port. It is considered that further analysis and comparison of docking behaviors via the replay interface can be implemented in future if the data

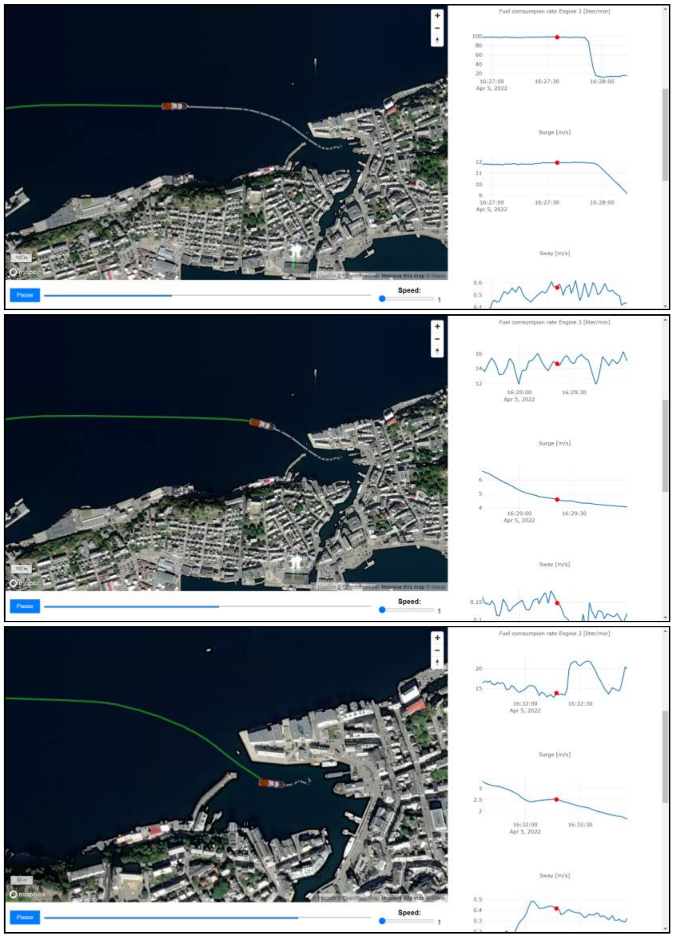


Fig. 8: Ship docking replay at Ålesund port.

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[2] https://org.ntnu.no/intelligentsystemslab/gunnerus/dt_realtime_crane_monitor.html

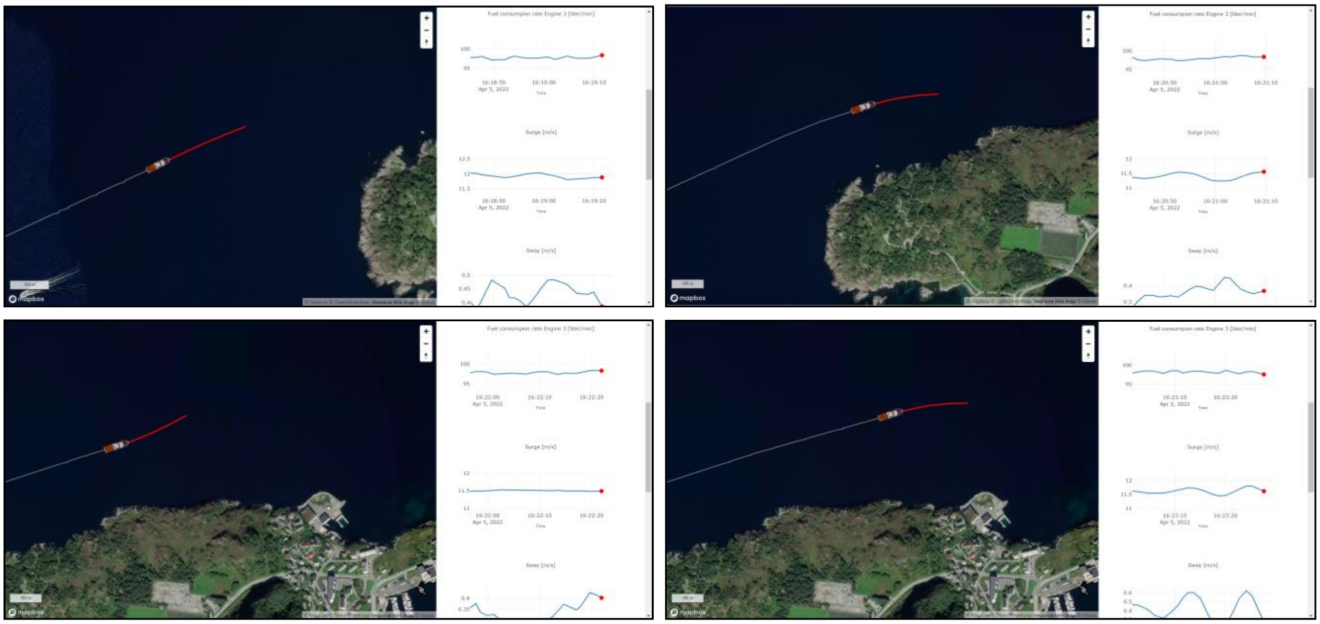

Fig. 9: Ship motion prediction during Gunnerus voyage.

segments of multiple docking events at the same port are detected.

C. Ship motion prediction

Ship motion prediction is considered as a way of decision support for ship navigation. There are plenty of methods that can achieve the goal, including data-driven methods [10], model-based methods [11], and their combinations. To verify the "add-on support" function of the Gunnerus dashboard, a simple kinematic model based predictor is applied to "real-time monitoring" interface. The predictor running in a twin platform from [8] takes current ship position, heading, surge and sway velocity and yaw rate as inputs, and produces future ship position in 20 s ahead. Fig. 9 illustrates the prediction results for Gunnerus ship in navigation at a speed around 11.5 m/s. Since the computational cost of the predictor is low, real-time predictions can be achieved. The prediction performance may be relatively low compared to other prediction methods but acceptable to onshore crews in RCC, as the target is to reveal navigation intention rather than high precision of ship trajectory in short future.

VI. CONCLUSION

This paper presents a preliminary implementation of RCC for R/V Gunnerus vessel. A variety of onboard sensors from ship engine, Palfinger crane, thruster, to those sensors used for environmental perception are utilized as the data source of the RCC. Sensor data are transmitted via MQTT and saved into a PostgreSQL database at RCC. A dashboard is developed, which enables real-time monitoring of Gunnerus together with advanced decision support and historical replay. Through three case studies, we verify the effectiveness of the proposed RCC solution.

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