The Atlantic Testing Platform for Maritime Robotics

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Virtualization layer for robotics

VTT, SPACEAPPS

Actions

	Action	Organisation	Date
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Deliverable Responsible	Prepared draft of the deliverable.	VTT	15.8.2022
Technical Manager	Approved the draft as the first version.	VTT	22.8.2022
Quality Manager*	Approved the final version of the document and saved to the "Final" folder.	UdG	30.08.2022
Project Coordinator	Approved the final version and sent to the EC.	INESC TEC	31.8.2022

Disclaimer

This project has received funding from the European Union's Horizon 2020 research and innovation programme, under the Grant Agreement no. 871571.

Acronyms

AD	Advisory generation
AI	Artificial Intelligence
API	Application Programming Interface
BEM	Boundary Element Method
CFD	Computational Fluid Dynamics
CV	Control Volume
DA	Data Acquisition
DAQ	Data Acquisition System
DDS	Data Distribution Service
DB	Database
DM	Data manipulation
DT	Digital twin
FEA	Finite Element Analysis
FEM	Finite Element Method
FSI	Fluid Structure Interaction
HA	Health Assessment
IMR	Inspection, Maintenance and Repair
ML	Machine Learning
O&M	Operation and Maintenance
PA	Prognostics assessment
RANS	Reynolds-averaged Navier–Stokes equations
REST	Representational State Transfer
ROS	Robot Operating System
RUL	Remaining useful life
SCC	Supervisory Control Center
SD	State Detection
TLP	Tension-leg platform
UxV	Unmanned Vehicle

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1. Introduction

1.1. Scope of work

This document presents the planned architecture and requirements for the virtualization of the ATLANTIS pilot site and the Coastal Testbed in particular. The virtualization layer connects the Supervisory Control Centre (SCC), the robots and the pilot site sensors with the Operations and Maintenance (O&M) module for predictive maintenance. This document describes the communication between the different assets and the virtualization layer as the assets have variable connectivity requirements related to e.g. latency and data rates.

The virtualization layer is a part of the O&M module that analyses the input from robots and sensors and provides output to the SCC. Most of the information flow to the O&M module goes through the SCC and external sensors, but the virtualization layer could also have a capability to receive data directly from the robots.

A central part of the virtualization layer is the virtual representation of the Coastal Testbed structure as it provides a platform for sensors and demonstrations of robotic based O&M, as well as an O&M analytics case. The virtual representation of the structure is assembled as part of the work in WP4 but the main features of the model are shortly represented here.

1.2. Main objectives

The main objectives of Task *T2.7 Integration and Virtualization of Systems (Cyber-Physical Units)* are to

- Define the virtualization layer as part of the ATLANTIS general software architecture
- Define what is virtualized and how
- Analyze the communication needs and the requirements for connectivity between the different assets connected by the virtualization layer
- Preliminary testing of connectivity to enable virtualization of the ATLANTIS pilot site

1.3.Structure of the document

This document provides an overview of the components of the virtualization layer and how they relate to each other and the general ATLANTIS software architecture. The document consists of the following sections:

Section 1 Introduction describes the scope of the work, the main objectives and the structure of the document.

Section 2 Virtualization layer architecture describes how the virtualization layer relates to the general ATLANTIS software architecture and the key components of the virtualization layer, including the data inputs and outputs.

Section 3 Virtualization layer communication needs and requirements describes in more detail the components of the virtualization layer

- The O&M module communication with the SCC for
  - obtaining data from the robots for the predictive maintenance analysis

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- and for providing the analysis results to the SCC database
- The O&M module communication with the external data and the Coastal Testbed digital twin for the predictive maintenance analysis
- The virtualization of the Coastal Testbed as a digital twin and the outputs the model provides for the O&M module using the external data

Section 4 Results from preliminary connectivity testing shows how data exchange between the O&M module and the SCC database takes place using the SCC User Interface.

Section 5 Conclusions summarizes the key features of the virtualization layer and how it is realized.

2. Virtualization layer architecture

2.1. Virtualization layer as part of the ATLANTIS general software architecture

Figure 2-1 shows the general ATLANTIS software architecture as given in D2.6. The virtualization layer is a part of the O&M module and its database and includes the digital twin (DT). In the context of this project, the main communication channel between the virtualization layer and the rest of the software architecture is through the SCC user interface and the external Testbed sensors provide data directly to the O&M module. Nevertheless, it is also possible for the O&M module to get data directly from the robots.

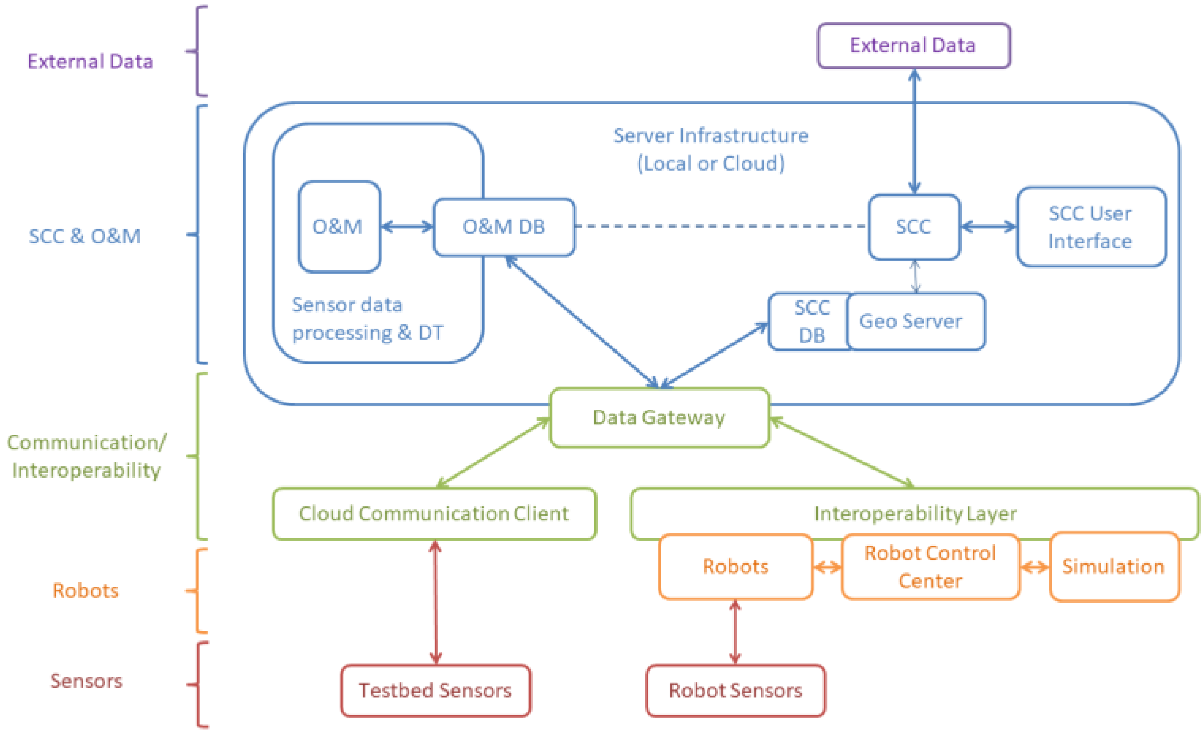

Figure 2-1. ATLANTIS software architecture, where the virtualization layer is a part of the O&M module

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2.2. Internal architecture and O&M connection

Figure 2-2 presents the O&M module and its connection with external data, robot data and the SCC, in the framework of the ATLANTIS Coastal Testbed. In Figure 2-2

- A is processed parameter information (vibration, inclination, stresses etc.)
- B is robot sensor data (pictures, videos, location, etc.)
- C is textual information (state detection, operation limits, inspection work order requests, etc.)
- D is mission and historical data from SCC database (DB).

Robotic data is collected by various unmanned vehicles (UxV) tested for different operation and inspection purposes above, around and below of the Coastal Testbed. The data is transmitted to the SCC and its database (DB). This is reported more in detail in deliverable D2.6. O&M module reads selected data from the DB, e.g. based on the id-information and set time frame. When the data becomes available, targeted processing is carried out in the O&M module. Processing is based on the separate requirements related to the circumstances and data content, and its target is to upgrade data to information. After the data is transformed into information, e.g. as inspection outcome, it is pushed back to SCC, and stored into its DB. Historical analysis and e.g. trend analysis can be carried out by selecting data from the same spot over a wider time range.

The external data in Figure 2-2 above is collected and analyzed by a separate system in order to test methodology e.g. for short-term and long-term structural loading and stress analysis and to evaluate the operation criteria for the Coastal Testbed. Since the ATLANTIS Coastal Testbed is located at a harbor, the operational environment is less harsh compared to the real offshore conditions. In addition, the Coastal Testbed structure is not a real wind power unit. Based on these, the external measurements and derived analytics here will be used to demonstrate possible methodologies and measurement options that could be used for the stochastic and deterministic environmental factor analysis (see Figure 2-3). The developed methodologies can be transferred after the testing to a real wind power unit e.g. to support stochastics analysis and deterministic decision making for IMR.

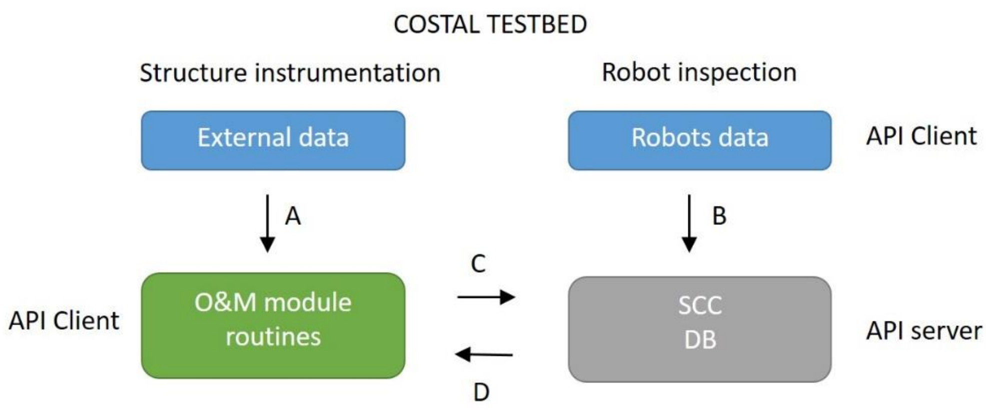

Figure 2-2. O&M module as part of the Atlantis SCC Software Architecture.

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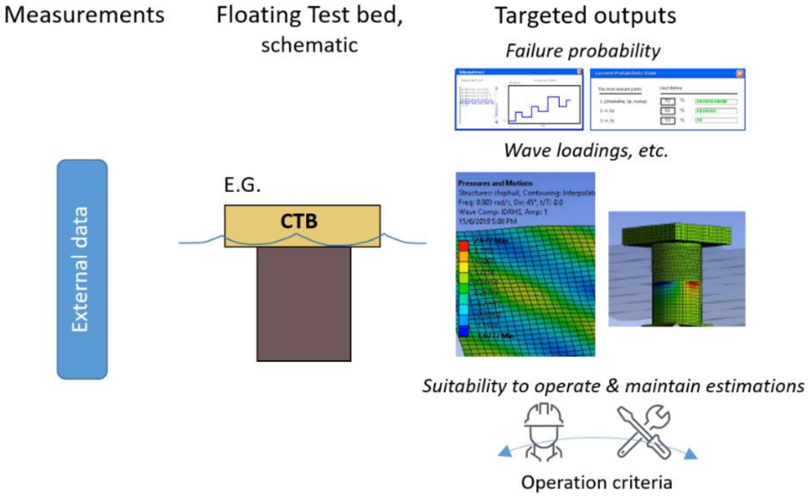

Figure 2-3. Development targets for measurements labelled as external data.

3. Virtualization layer communication needs and requirements

3.1. O&M module and database

The purpose of the O&M module is to monitor, process and analyze data and information for relevant and actionable information. The target of condition monitoring is to produce information of the probabilities of certain assets' failures over time through diagnostics and prognostics. Whereas diagnostics is focused on the present state of the assets (component, machine, process etc.), prognostics means looking forward into the future, predicting the future performance or developments.

In the virtualization layer, the data comes from several sources, including data from robots performing their inspection, maintenance and repair (IMR) activities as well as any external data related to the performance and characteristics of the Coastal Testbed. The actual analytic procedure in O&M is to be divided in to different modules utilized consecutively or parallel in cascade between connected data and information modules. According to ISO 13374, these data processing modules are divided into data acquisition (DA), data manipulation (DM), state detection (SD), health assessment (DA), prognostics assessment (PA) and advisory generation (AG). The purpose of each of these modules is to refine the data, its quality and information strength for a required support in decision-making. In addition to data itself, information about the operation is essential for drawing relevant conclusions.

Routines running in the O&M modules can be based on first principle, knowledge driven analytical equations, statistics and/or data, e.g. artificial intelligence or machine learning (AI/ML) based. In the former cases, basic understanding of affecting causalities are required while with data base approach the fitting is quite straightforward. However, pure data based approach might miss the transparency and expandability required for critical decision-making. Thus in many practical cases hybrid based solution is used to compose the best out of these.

Final purpose of the applied modules are case and data dependent, and the actual routines will be tailored in WP4 as part of the O&M activity developments. At the moment, the planned modules are for pattern recognitions, life estimation and operation assessment (see Figure 3-1 below). Further modules will be applied based on the needs met during the actual testing at the Coastal Testbed. Each of the modules contain selected submodules required to support decision-making.

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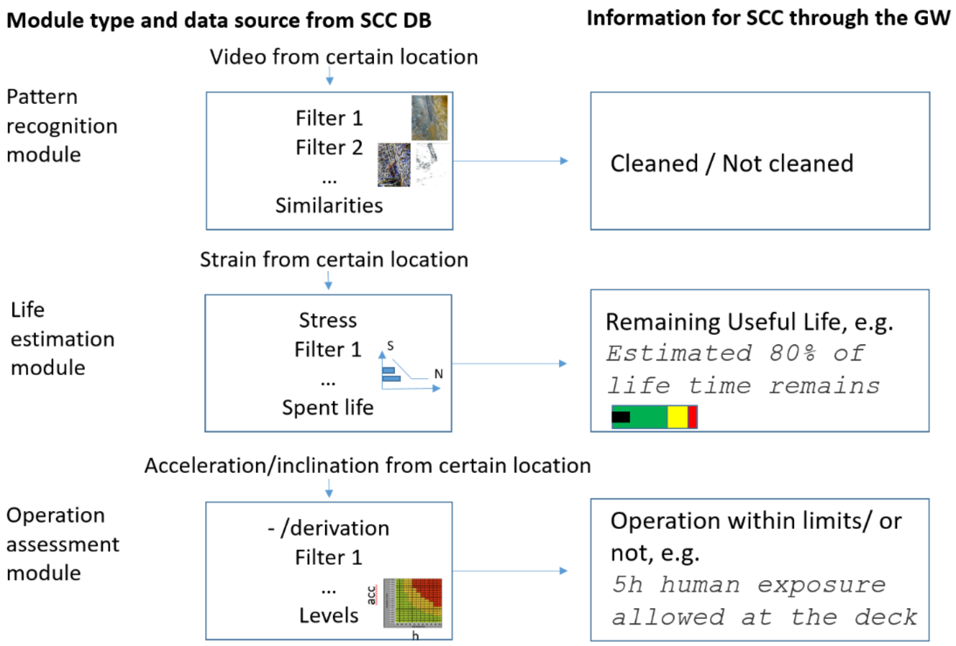

Figure 3-1. O&M modules communicating with the SCC data architecture.

All the data is stored in the database within SCC according to the Atlantis SW architecture. The whole database is large and covers e.g. all the mission data, and data collected by the inspection robots, and later the outcome information pushed from the O&M module. A sample of the database is shown in the Figure 3-2 below.

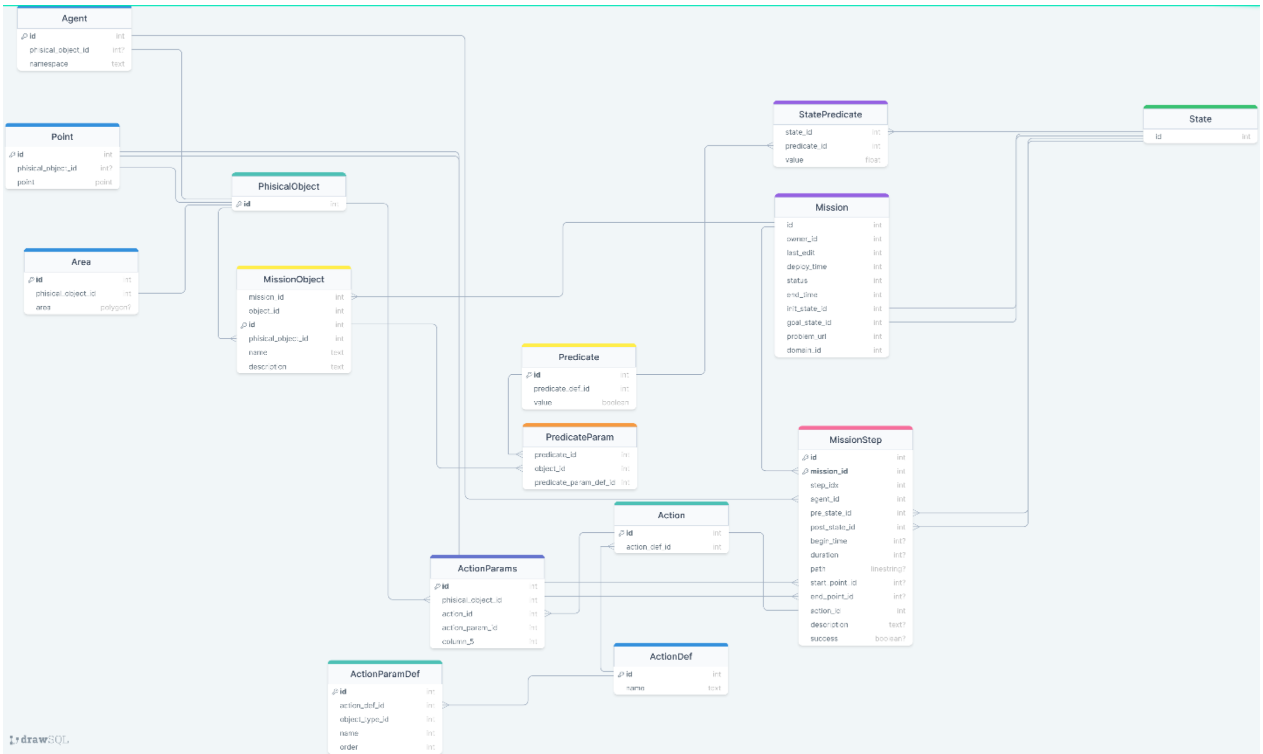

Figure 3-2. A snapshot of the database.

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Database agents have been constructed to manage database data and to service different application requests. Figure 3-3 below shows how an agent is connected to the telemetry, perception, positioning and commanding data/tables in the database.

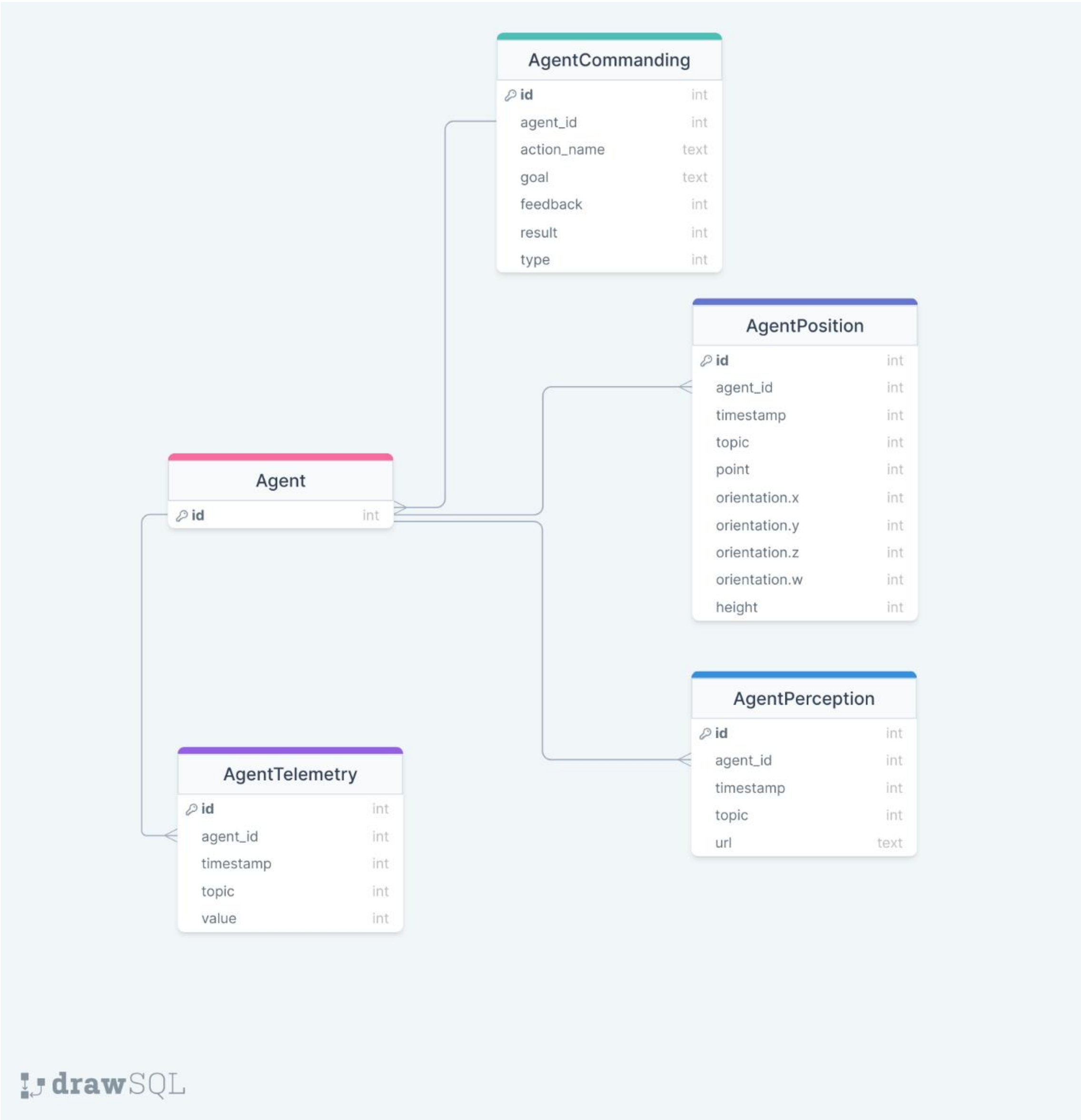

Figure 3-3. A snapshot of an agent used for database and request management.

3.1.1. Communication with SCC

The SCC has a REST API allowing the interaction with the database. The REST API exposes resource endpoints, which allows to get, post, update and delete data from a specific resource. The REST API comes with an auto documentation using Swagger. Figure 3-4 shows a sample of resource accessible.

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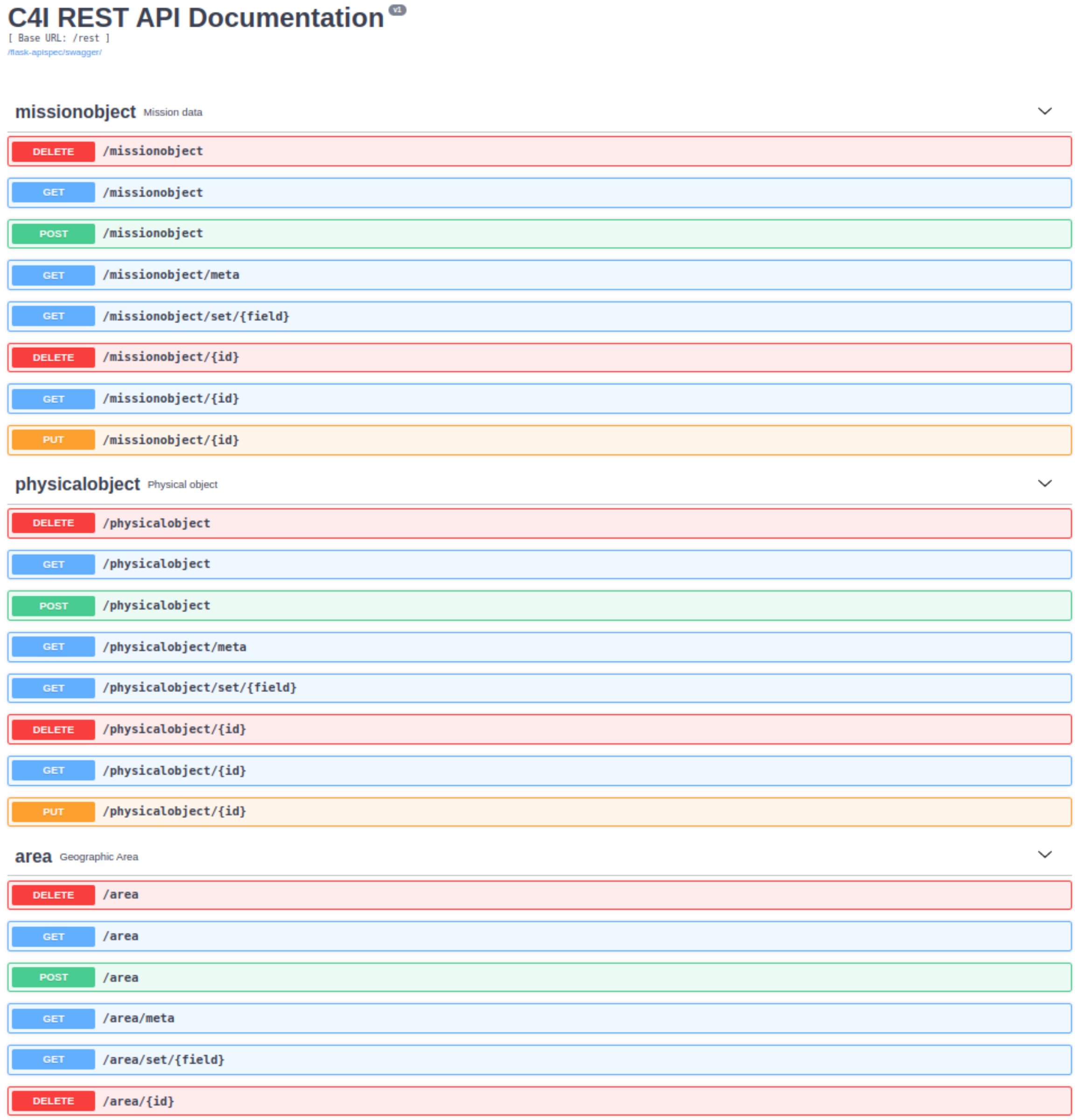

Figure 3-4. Auto documentation of the REST API using Swagger.

From outside of the SCC, the Swagger application can be used e.g. for planning and managing the missions and to retrieve the mission data for further analysis, e.g. for O&M purposes. In addition, the existing Swagger application can be used to test the API (Figure 3-5). All authenticated robots can connect to the SCC via a token generated for a specific amount duration. This allows only robot with a token to connect to the SCC. An example of the token is shown in Figure 3-6.

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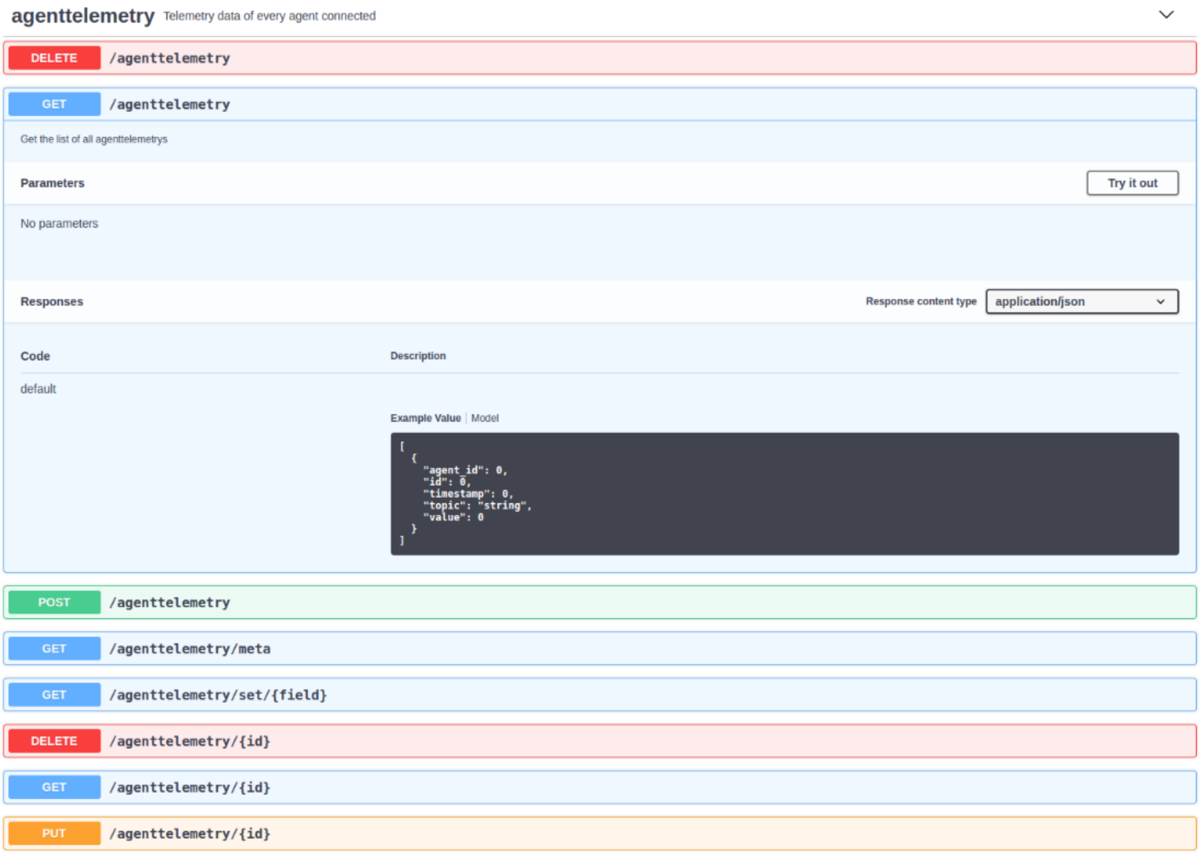

Figure 3-5. Using Swagger auto documentation to test the API.

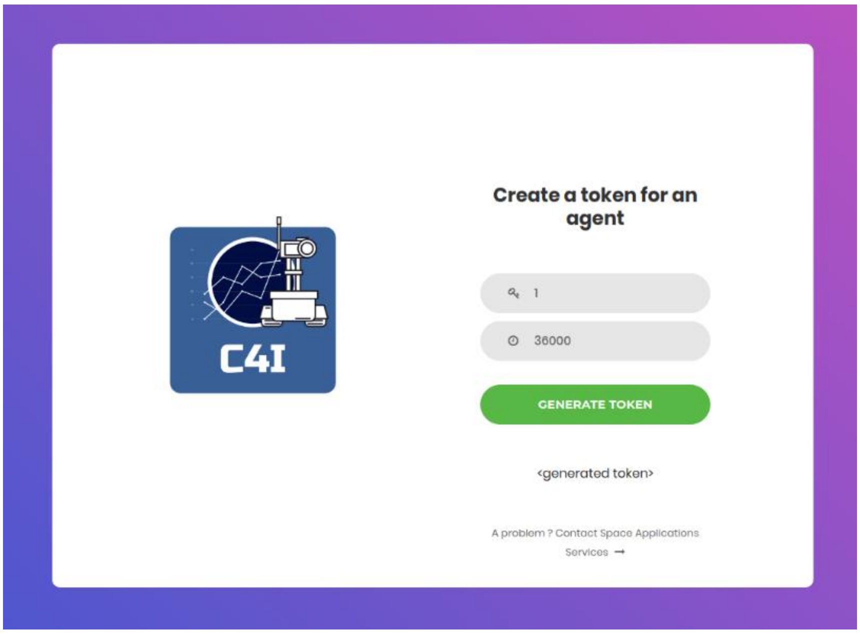

Figure 3-6. Generating a token using the user interface.

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3.1.2. Communication with robots

The communication protocol that is used within the interoperability layer for onshore to offshore communication is Data Distribution Service (DDS). DDS is a messaging exchange protocol developed by the industry in order to communicate within a distributed system having strict operations requirements. Using this protocol will allow us to strictly control the delivery of data from one side to the other. DDS is designed as a publish-subscribe system in which any component can broadcast data for any of the other components to listen to. When the data is broadcast, parameters can be set in order to configure the messaging system for management of message delays, delivery failure, communication latency etc.

DDS existed in the Industrial ecosystem for a long time. In recent years there was a high interest presented by the robotics communities to integrate the DDS standard as the main message exchange modality in the robotics system. The choice is based on the long history of DDS being successfully used in safety-critical systems. Due to this increased interest, the second generation of the Robot Operating System (the most used middleware for robotics projects) is built on top of the DDS protocol. In ATLANTIS , most of the robots support ROS natively, so the main way of message exchange between the robots and the interoperability layer will be done through it.

The Robot Operating System, ROS is used to help robots from different manufacturers to communicate together. ROS provides standardised message formats for basic data types, such as strings or numbers, and more complex data types such as poses, images or point clouds. ROS is based on a fully distributed ecosystem allowing all the robots being part of the same network to communicate. The second version of the robotic operating system, ROS2, is using DDS by default on the communication layer allowing it to benefit from all the advantages of DDS using the features offered by ROS.

Since the ROS2 communication protocol is different from the one used in the first version of ROS, ROS2 also provides a bridge to allow ROS1 code to be compatible with ROS2 and DDS.

3.1.3. External data from sensors

The Coastal Testbed structure will include external measurements. The objective is to develop models for targeted O&M analysis based on these measurements. The measurements are sampled during the Testbed operation. A simulation model combines the measurement data and a priori knowledge of the structure, such as its material properties and dimensions. Environmental loads, and wave loads in particular, are estimated for evaluating critical loadings at different locations of the Testbed. Both short-term (e.g. 3 hours) and long-term (whole lifetime) predictions for the loads and stresses can be made. Both frequency and time domain approaches are utilized. In addition, simulations are also due to support operative criteria/limits analysis, and to estimate, based on the movements in different areas, the suitability for onboard operation and maintenance work. Further on, certain stochastics loading analytics are planned to be carried out for deterministic decision-making, e.g. to support for the deployment of robots for further inspections. These activities are developed mainly in task 4.2.

The actual instrumentation assembly for the measurements at the Costal Testbed will consist of VTT's measurement sensors and systems. The setup will function as an external data acquisition (DAQ) system running separately on the Testbed edge 24/7. The measurements are planned to be assembled on different location of the Costal Testbed structure, its close vicinity and on the pier, if possible (see Figure 3-7). The external measurements include

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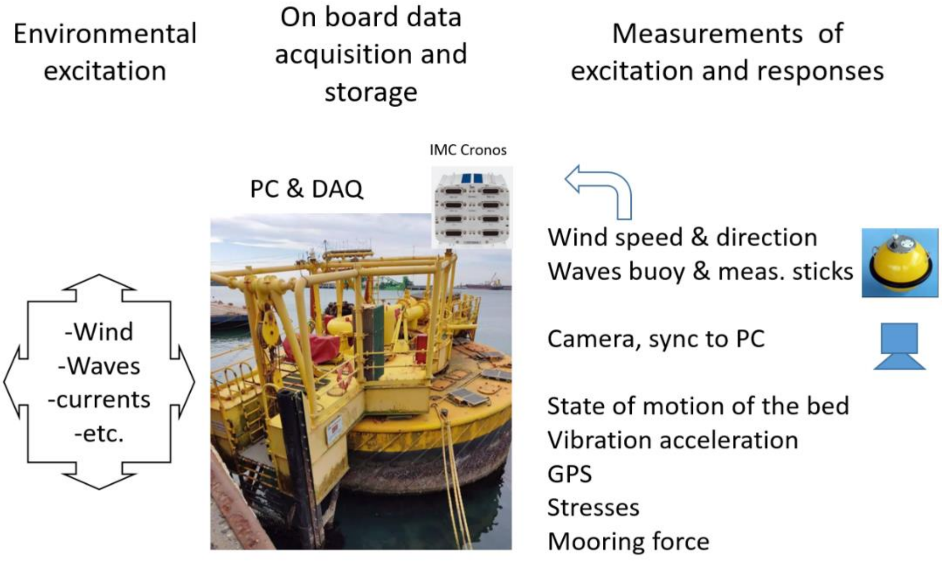

Figure 3-7. Excitation and response measurement system on the Coastal Test ed and its vicinity.

- Three 3D vibration acceleration sensors on the Testbed
- One state of motion sensor on the Testbed
- Strain gauges in a selected position for measuring structural stresses in the Testbed
- A camera for wave monitoring
- A floating wave buoy. For further measurements of waves, there will be wave sensor sticks on the Testbed (and if possible, also on the pier side)
- Wind speed and direction measurements on the Testbed
- If possible, a mooring force measurement system will be assembled on the expected wave side.

All the measurements except the data from the wave buoy are sampled simultaneously with separate DAQ units connected to a PC for data storage and measurement management. Wave buoy data are synchronized with the rest of the data based on time and offline. Applied sampling frequency depends on the measurements, and at maximum, it will be about 100 Hz, which is suitable for structural and structure movement analysis.

The measurements are running continuously for a limited time period. Analysis and model development for the O&M modules will happen mainly offline after the testing period due to limited data connectivity from the Coastal Testbed.

While the models are up and running in the O&M modules, the external measurement communication happens through them according to the internal architecture. Communication between the O&M module and the other assets, including the SCC, the external data from the Coastal Testbed structure as well as the robots is handled through the Virtualization layer.

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3.2. Virtualization of the Coastal Testbed

3.2.1. Digital twin of the Coastal Testbed

The digital twin comprises of the seakeeping model of the Coastal Testbed together with the structural model. The models will be integrated into each other, so that the loadings from the seakeeping model can be transfered to the structural model. Both short-term and long-term predictions will be conducted – that is, the short-term forecast will be applied for hours and long-term predictions typically for the lifetime. The short-term predictions will be mainly utilized for operational topics and long-term forecast for structural issues.

Virtualization of the Coastal Testbed can be employed to predict stochastically the most critical loading locations and the critical operational conditions. The digital twin benefits also from the instrumentation, that is, the essential sensors will be installed on the testbed so that the combined data with the digital twin can be utilized to detect anomalies and produce more enhanced understanding about the related phenomena.

Figure 3-8 shows a flowchart for a combined seakeeping and structural analysis for a ship. For the virtualization layer, a similar procedure will be implemented for the Coastal Testbed. The analysis will provide both operational information and data for the long-term stress effects evaluation, e.g. in terms of fatigue damage accumulation and required structural health monitoring intervals.

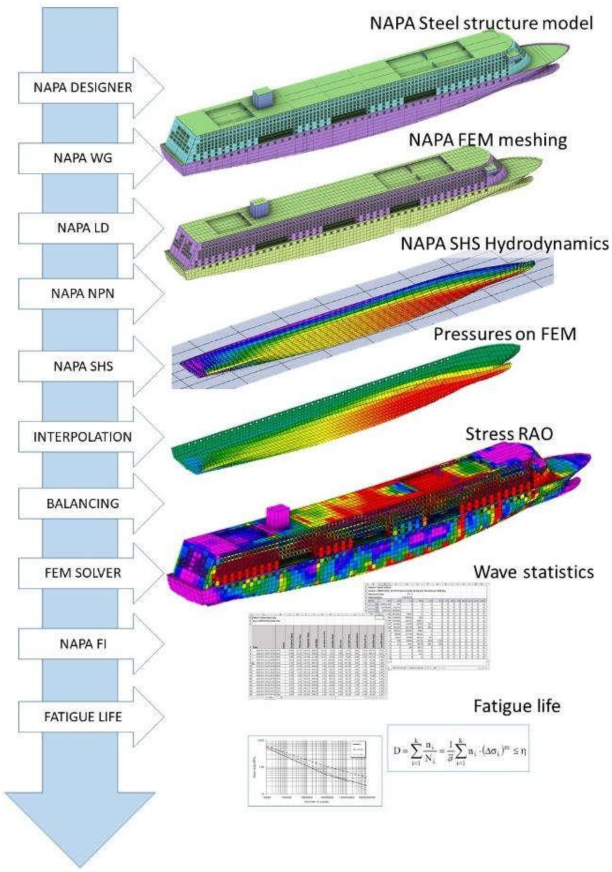

Figure 3-8. Overall procedure of strength analysis for a ship (Hulkkonen, 2019).

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3.2.2. ANSYS AQWA/CFD analysis

ANSYS AQWA is a state-of-the-art toolset which provides methods to investigate the effects of waves, wind and currents on floating and fixed offshore and marine structures. The possible structures include spars, semi-submersibles, tension leg platforms (TLPs), ships, renewable energy systems including floating wind turbines, and breakwater design. ANSYS AQWA can be described as a weakly non-linear seakeeping analysis method, which solves the potential flow problem with 3D combined panel method.

As an example, Figure 3-9 illustrates the model of a 5 MW wind turbine in ANSYS AQWA. In this specific case, the electrical cable was modeled in ANSYS AQWA.

AQWA employs several modules; the AQWA Hydrodynamic Diffraction module is responsible for evaluating the wave excitation forces and structure responses. The analysis can be carried out in frequency and time domains, that is, AQWA Hydrodynamic Time Response can be applied to determine the dynamic phenomena at the time domain. Pressures and inertial loadings produced by the AQWA Hydrodynamic Diffraction module can be directly transferred to ANSYS Mechanical finite element model for further assessment. ANSYS AQWA includes all essential environmental models such as regular and irregular waves, wind and current. Moreover, the complex cable moorings can be evaluated by sophisticated physical models. Regarding irregular wave modelling, ANSYS Hydrodynamic Diffraction module includes several ideal wave spectras as follows:

- Jonswap
- Pierson-Moskowitz
- Gaussian
- User specified spectrum

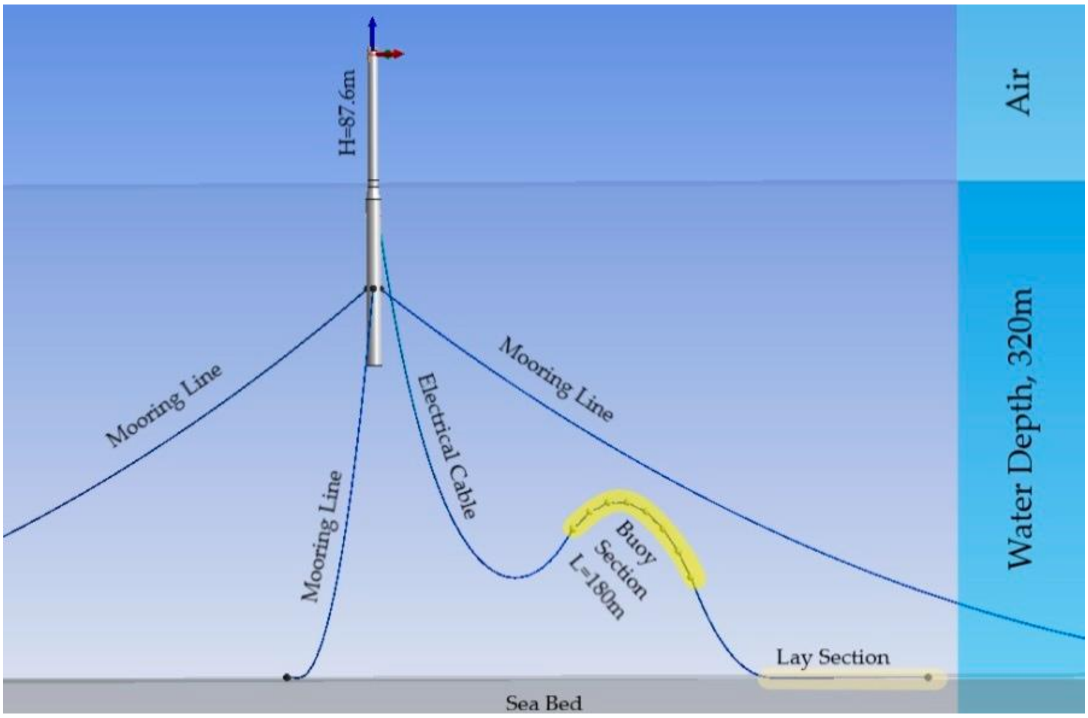

Figure 3-9. Wind turbine ANSYS AQWA model (Sobhaniasl, 2020).

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Currents can be modelled to supplement the wave forces applied to the structure. This can either be a simple constant entry or a range of depths, velocities, and directions.

ANSYS AQWA compromises of several wind spectra in order to evaluate the wind forces at realistic wind conditions. The options are as follows:

- Constant Velocity
- Time Dependent Velocity
- Ochi and Shin Spectrum
- API Standard Spectrum
- NPD Standard Spectrum
- ISO Standard Spectrum
- User Defined Spectrum

AQWA supports four types of cables, each with their own input requirements:

- Linear Elastic
- Non-Linear Polynomial
- Non-Linear Steel Wire
- Non-Linear Catenary

The extension of the cable, at any stage of the analysis, is calculated by subtracting the unstretched length from the distance between the position of the fixed point and the current position of the connection point on the structure.

In principle the extension is calculated by subtracting the unstretched length from the distance between the connection points on the two structures at the current position of the respective structures. The direction of the force on a structure is given by the vector going between the two connection points. The forces on each structure will therefore always be equal and opposite and hence the selection of start and end connection points can be interchanged.

Furthermore, the fenders alllowing the contact between the structures can be included to the ANSYS AQWA model. Depending on the relative positions of the structure, on the type of Fender (floating, fixed unidirectional, fixed omnidirectional), and on their positions on the structures, they create a varying force acting on the structure and added to the other forces used for computing the structures' motions.

Computational mesh can be created with ANSYS AQWA meshing tool or ANSYS Meshing tool. The mesh is automatically generated on the bodies in the model; its density is based on the defeaturing tolerance and maximum element size parameters. Figure 3-10 presents an example of a calculation mesh created for ANSYS AQWA analysis.

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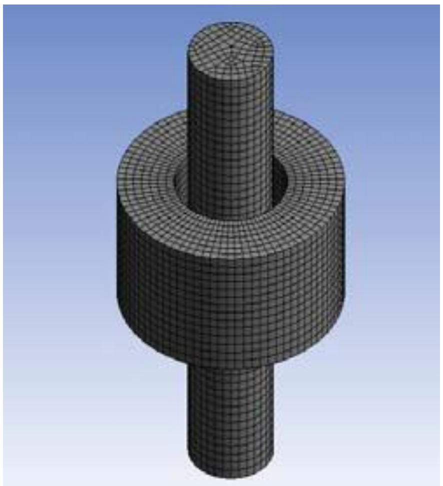

Figure 3-10. An example of ANSYS AQWA panel mesh (Ghassemi, 2019).

ANSYS AQWA solves the equation of motion in six degrees of freedom.

$$A_{ij}\ddot{x}_i + B_{ij}\dot{x}_i + C_{ij}x_i = F_i$$

where A_{ij} is the mass matrix, B_{ij} represents the damping matrix, C_{ij} is the stiffness matrix and F_i is the excitation force vector. x_i is the motion component into the ith direction. The mass matrix A_{ij} contains the so-called added mass terms besides the structure inertia, that is, the mass of the water accelerated around the body. Stiffness matrix C_{ij} represents essentially the hydrostatic force components.

Excitation forces include both Froude-Krylov and diffraction force terms. The Froude Krylov force represent the wave contributions due the undisturbed wave field, where as the diffration forces take into account the existence of the floating body. The matrices Aij and Bij contain so-called radiation force components, that is, the wave forces due the moving body.

Another option to evaluate the hydrodynamic forces is to utilize viscous computational fluid dynamics (CFD) codes. OpenFOAM method is a open source CFD tool available within GNU licence. OpenFOAM solves the Navier-Stokes equations by Control Volume (CV) method. The ANSYS AQWA method is based on the unviscous flow solution, that is, the potential flow assumption. The viscous flow field has to be discretized throughout the field, whereas the potential flow solution can be obtained with Boundary Element Method (BEM). That is, only the boundaries of the flow field will be discretized, so the numerical solution can be achieved easier. It will be still decided, if the OpenFOAM solver will be applied during the ATLANTIS project.

Viscous flow solution includes turbulence effects, so the viscous flow solvers incorporate turbulence modelling. Usually two-equation Reynolds-averaged Navier–Stokes (RANS) models can be applied, that is, for example k-epsilon or k-omega turbulence models.

Wave condition can be introduced to RANS solver by adding the potential wave condition into inlet. Both regular and irregular wave systems can be modelled at the time domain. The potential flow solution can be evaluated in principle in the frequency domain or directly at time domain. A simulation snapshot of a floating offshore wind turbine platform is presented in Figure 3-11.

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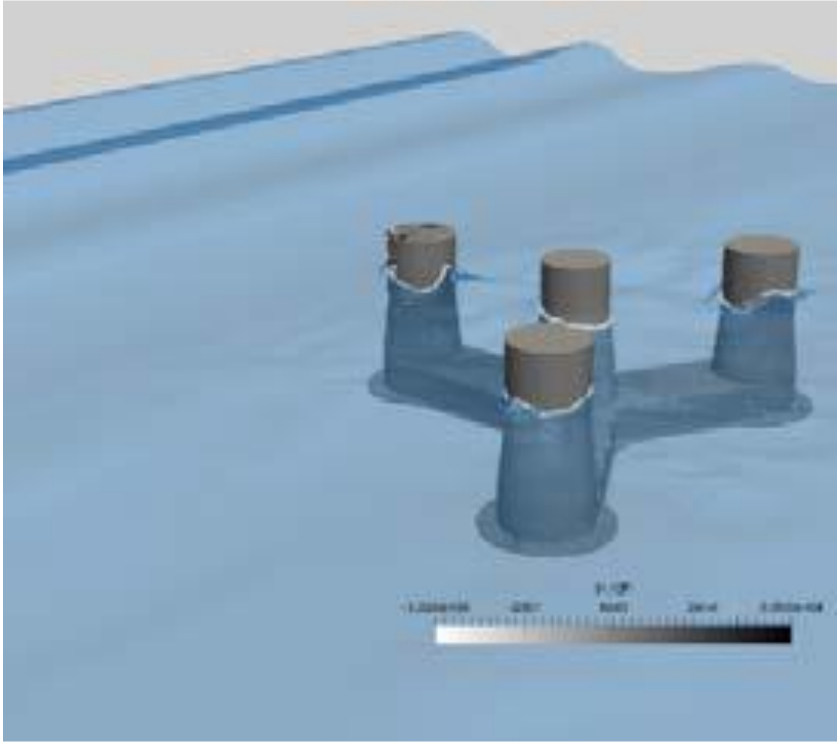

Figure 3-11. An example of wind turbine OpenFOAM simulation (Sarlak, 2018)

3.2.3. FEM analysis

Structural analysis can be conducted using the Finite Element Method (FEM). FEM is a very powerful numerical method to solve especially elliptical partial differential equations. The body is discretized and divided into elements and the elements are connected into each other with nodes. The subdomains can be solved by shape functions for each element. ANSYS Mechanical provides a flexible environment for the Finite Element Analysis (FEA). Figure 3-12 shows an FEA applied to offshore wind turbine, where the analysis considers wind, wave and current loads, and the resulting deformations in terms of maximum displacement.

In principle, ANSYS supports two options for Fluid Structure Interaction (FSI) simulations: one-way and two-way couplings. With the one-way coupling the hydrodynamic loadings are introduced to FEM and the stresses and deformations can be evaluated. Utilizing the two-way coupling the structural deformations will be transferred back to flow analysis, that is, the structure deformations contribute to the flow solution. During ATLANTIS project, at least the one-way coupling will be employed for the analysis.

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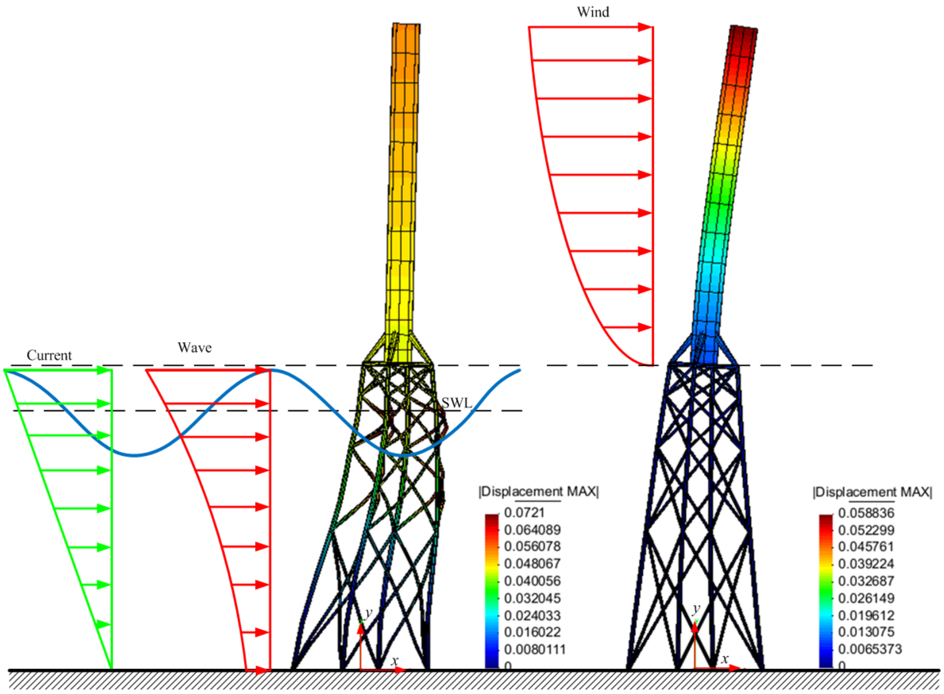

Figure 3-12. An example of a wind turbine Finite Element Analysis (Norachan, 2011).

4. Results from the preliminary connectivity testing

4.1. Connectivity with robots

Robots with connectivity to the SCC include the following

IQUA – Sparus

- Remote integration via VPN
- Mission Planning – defining the goals and triggering the automated planner on UI to successfully deploy it to the robot
- Monitoring - Numerical data such as battery, temperature, boolean switches for activation/deactivation
- Position view of the robot on the map interface

UdG – Girona 1000

- Remote integration via VPN
- Mission Planning – defining the goals and triggering the automated planner on UI to successfully deploy it to the robot
- Monitoring - Numerical data such as battery, temperature, boolean switches for activation/deactivation
- Position view of the robot on the map interface

INESC - AUV

- Remote and on-site test with Raven AUV in July 2022 at Viana do Castello

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- Interface Images from the AUV to the C4I – integration issues are being addressed
- Remaining telemetry and mission planning integration planned during the September tests at Viana Do Castello

4.2. Connectivity with O&M

The data connectivity between the SCC and the O&M module was tested in two ways: first by reading data from the SCC and then by pushing analysed data back to SCC. In both cases, the data transfer between VTT's O&M analytics and the SCC database is carried out via the REST interface provided by SpaceApps. Since real inspection data is not yet available (the Coastal Testbed is about to arrive on the test site), the data used in this chapter for reading and pushing purposes are shown as examples of possible data.

VTT's O&M analytics module collects mission data, such as images taken by robots during inspection missions, for targeted analysis. The mission data is stored in the SCC database. Any type of stored data can be retrieved from the database by the O&M module. Figure 4-1 shows an example of a Python code script that retrieves inspection image data stored by a certain robot. The program first logs in to the login page by entering the username and password required for logging in, after which the images can be retrieved with a request message either/or based on the robot's id value or by defining the time interval from which the images are to be retrieved. The REST interface returns information about the URL address, from which the images can be retrieved with a separate request command (see Figure 4-2).

The actual retrieved image data is binary coded (see Figure 4-3) and can be converted to an image file, e.g. as a JPEG file. Further, in Figure 4-4, an example of two fictive inspection data images read from the SCC are shown. The images represent segmented marine growth inspection data images that are taken by a robot to inspect the amount and locations of shells on a pre-selected key point of an underwater structure at i) one time point (left) and ii) after some time has passed (right). The difference in time can be used e.g. for trend monitoring, and in greater series for estimating remaining clean/useful life for the structure in question.

```python
with requests.Session() as session:
    # Authentication
    session.post(base_url + "/login/", json={"email": email, "password": password})

    # Get agent perception metadata
    metadata = session.get(base_url + "/rest/agentperception/3")

    # Get image from metadata
    response = session.get(base_url + f"/rest/{metadata.json()['url']}")
    image = response.content

    # Write image to file
    with open("./image11.jpeg", "ab") as file:
        file.write(image)
```

Figure 4-1. An example of Python program for retrieving image data from the database.

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Response json body of perception image metadata
{
"agent_id": 3,
"agent_namespace": "/zarco",
"id": 3,
"thumbnails": null,
"timestamp": 1655903266955,
"topic": "compressed",
"url": "store/pictures/compressed_1655903266955.jpeg"
}

Figure 4-2. Response JSON body image metadata with the returned URL.

Image binary data
content:
b'\xff\xd8\xff\xe0\x00\x10JFIF\x00\x01\x01\x00\x00\x01\x00\x01\x00\x00\xff\xdb\x00C\x00\x02\x04\x03\x04\x06\x05\x06\x06\x06\x05\x06\x06\x06\x07\t\x08\x06\x07\t\x07\x06\x06\x08\x0b\x08\t\n\n\n\n\n\x06\x08\x0b\x0c\x0 .... \xb9\xfcI\xfe\xb51\x84\x9a4\xebt\x7f\xff\xd9'

Figure 4-3. An example of the content of the image data.

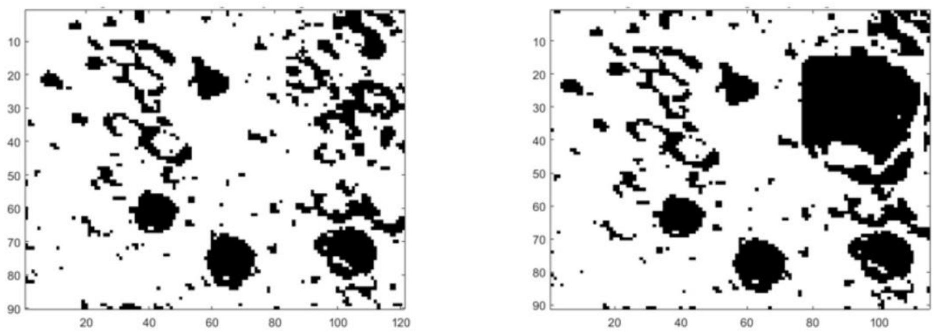

Figure 4-4. Example segmented image data retrieved from the SCC at two different time points.

Another connectivity case is posting data towards the SCC DB. After the O&M module analyzes the original data, and further translates it to information, the outcome is pushed back to SCC, e.g. to support the on-site decision making for IMR activities. Also here, the REST interface is used to post the data/information into the SCC database. In Figure 4-5 and Figure 4-6 are shown two examples using JSON body messages. In the first example estimated remaining useful life (RUL) value is pushed from O&M module to SCC DB, and in the second one an RMS value is pushed respectively.

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```
POST http://atlantis.c4i.spaceapplications.com/rest/RUL HTTP/1.1
content-type: application/json

{
  ”id": 5,
  "meas_loc_id": 102,
  "gmt_assessment": "2022-08-24T13:58:01.123",
  "est_remaining_life": 8760,
  "gmt_created": "2022-08-24T13:58:05.123",
  ”unit": ”hours”
}
```


Figure 4-5. A fictive example of request message for posting remaining useful life estimate to the database.


```
POST http://atlantis.c4i.spaceapplications.com/rest/vibration HTTP/1.1
content-type: application/json

{
  ”id": 5,
  "meas_loc_id": 104,
  ”data_value": 10,
  "gmt_created": "2022-08-24T13:58:05.123",
  ”unit": ”m/s2”
}
```


Figure 4-6. A fictive example of request message for posting vibration RMS measurement to the database.

In both messages, the object, the measurement location (meas_loc_id) and the engineering unit of the measurements are shown. The id defined in the JSON body refers to the object to be monitored (e.g. id of test bed/windmill) and the measurement location id (meas_loc_id) refers to the asset location measured. Here, the given structure shows a fictive example. During the real data push, the message structure will follow the existing, pre-populated hierarchy in the SCC database.

5. Conclusions

The virtualization layer connects the Supervisory Control Centre (SCC), robots and external sensors with the Operations and Maintenance (O&M) module for predictive maintenance by using a digital twin model of the ATLANTIS Coastal Testbed.

The Coastal Testbed digital twin model is built based on the geometry and weight distribution of the structure to model realistically the response of the structure in wind and waves. Mooring of the structure is modelled as the stiffness of the mooring in selected directions. The model consists of combined Ansys AQWA/CFD and FEM models with which stuctural loads in possible wave and wind conditions can be pre-calculated. The model can then be used to estimate hotspot locations for inspection as part of the O&M module predictive maintenance analysis together with the operational limits. The O&M module obtained data from the external sensors at the Coastal Testbed, the digital twin model and the data from robots

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via the SCC User Interface. This data is used in the predictive maintenance analysis and provided to the SCC for the operators. Both the O&M module and the digital twin model are realized as part of WP4 Task 4.2 Data Mining and Predictive Maintenance and will be described in more detail in deliverable D4.4 Results of the predictive maintenance centered on robotics use.

The data connectivity between SCC and the O&M module was tested in two ways: first by reading data from the SCC and then pushing analysed data back to SCC. In both cases, the data transfer between VTT's O&M analytics and the SCC database is carried out via the REST interface provided by SpaceApps and by using a Python script and JSON body messages to request and push specific data. The connection was tested by successfully requesting image data from the SCC and by pushing information on remaining useful life to the SCC. These cases constitute the key types of communication between the O&M module and the SCC.

6. References

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