RiaSoR2

RELIABILITY IN A SEA OF RISK

# Requirements and Needs

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Marine operations at EMEC, Orkney © Mike Brookes-Roper

# Project Information

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# Revision

| Revision no. | Revision Text | Initials | Date |
|---|---|---|---|
| 1.0 | First version with template | MJ | |
| 2.0 | Revised version | MJ | |
| | | | |

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# Executive Summary

This document described requirements and needs for a condition monitoring framework targeting marine energy devices, particularly wave energy converters. High level architectural design considerations are also identified and discussed.

# 1 Introduction

## 1.1 RiaSoR background

**The goal of the RiaSoR project is to consistently learn from the physical interactions between the devices and their environments, while embedding this understanding and building robustness into marine energy technology designs to improve reliability.**

Marine energy devices operate in harsh environments but still need to perform reliably and produce an expected amount of energy, which gives rise to huge engineering challenges.

The OceanERANET-funded RiaSoR 2 project will use the theoretical reliability assessment guideline for wave and tidal energy converters (WEC/TEC) developed in RiaSoR1 and apply it to the field.

This will enable WEC/TEC developers to validate their findings, and establish a practical condition based monitoring platform to prepare for future arrays where big data handling and processing will be vital to drive down operational expenditures (OPEX).

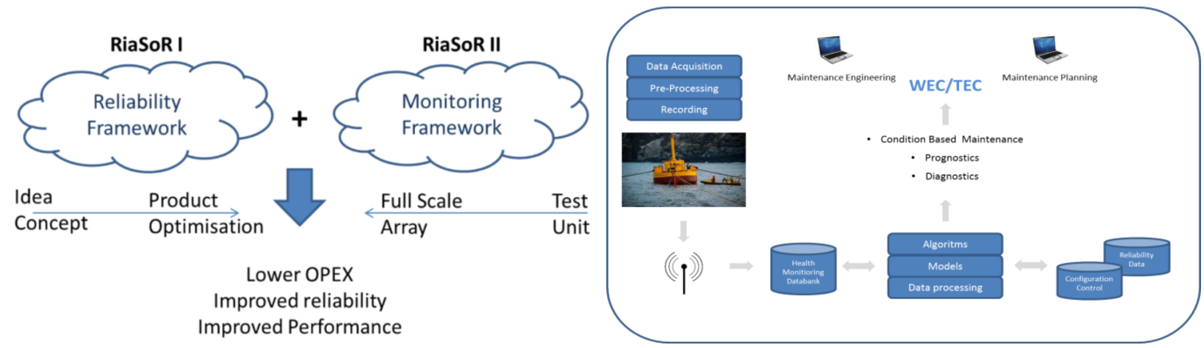


Figure 1 RiaSoR 1 & RiaSoR 2 overview

The RiaSoR 1 reliability guideline built upon established practices from the automotive industry where a monitoring framework is applied to a fleet of test-vehicles. Through design iterations, the reliability is improved and a final reduced set of sensors are deployed in the commercial vehicle.

For RiaSoR 2, the chosen components for monitoring are equipped with several sensors to collect the required data, which will then be fed into the reliability process to reduce uncertainties. Sea tests act as case studies to feed the methodologies and training into the guideline. The findings from this will then be trialled with the other developers.

The key objective of the RiaSoR 2 project is to offer a comprehensive suite of testing methodologies to wave and tidal developers that will enable a systematic approach to achieve optimal reliability and performance, while minimising cost and time-to-market.

## 1.2 Work package 2 aim and scope

In WP 2, a condition monitoring framework architecture will be designed which can be applied to the wave testing centres to support how to gather and handle big data from WEC operations to support reliability and survivability assessment of single devices and arrays.

## 1.3 Deliverable description

This document is intended to capture the requirements and needs for data capture and processing for condition monitoring systems in marine (wave energy) applications.

## 1.4 Methodology

The methodology employed has been to investigate current approaches for data collection, in particular from the Corpower half-scale prototype and Waves4Power's planned prototype WEC, combined with literature studies and experiences from condition monitoring in other application areas, including offshore wind and automotive.

## 1.5 Limitations

The study focuses on the wave converter types that are represented in the project. Certain parts described might therefore only be applicable to these and cannot be generalised.

# 2 Condition Monitoring Architecture

This section describes high level architectural design considerations for Condition Monitoring systems (CMS) targeting marine applications, in particular wave energy converters (WECs).

At a high level, a CMS for wave energy applications, as targeted by the RiaSoR 2 project, is composed of the following main components:

- Onboard (in-WEC) data capture units,
- Communication and telematics infrastructure,
- Back-end server infrastructure,
- Front-end user interface and presentation system

A schematic picture of a RiaSoR 2 CMS is shown in Figure 2 below.

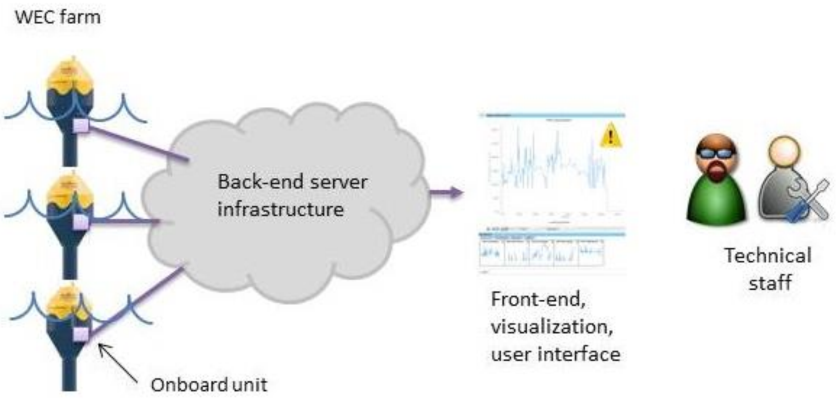


Figure 2 RiaSoR 2 High level Condition Monitoring architecture

## 2.1 Aims of Condition Monitoring

The aims of condition monitoring of relevance in RiaSoR 2 include:

- Diagnosis of potential anomalies within the WECs
- Avoidance of unplanned production downtimes.
- Reduce the need for repairs and optimise planned maintenance
- Increased availability
- Planning of repair
- WEC/system protection
- Reduction of maintenance costs
- Preventive and predictive maintenance
- Knowledge-driven product development

## 2.2 Target system integration

A condition monitoring system for the kind of applications considered in RiaSoR 2 can be designed either as a **stand-alone system** with external sensor systems or as a component closely **integrated** with the target system (i.e. the WEC control system). With a stand-alone approach, the sensor system is specifically designed for condition monitoring (CM) purposes, whereas an integrated system approach reuses the sensors already available for the operation of the WEC. In the integrated approach, the CMS could be realized as a software hosted on same hardware as the WEC control system, whereas the stand-alone approach requires dedicated hardware. There are benefits and drawbacks of both approaches, with the stand-alone approach typically resulting in a more generalized solution and the integrated a more application specific solution.

The pros and cons of these two fundamentally different approaches are listed in the table below.

| Approach | Pros | Cons |
|---|---|---|
| Stand alone | • Minimal influence on target system operation<br>• Simpler integration<br>• WEC supplier independent<br>• Resiliency to WEC system failures | • Requires more space in WEC<br>• Higher power consumption<br>• Costly |
| Integrated | • Better use of available resources<br>• Less space and power requirements<br>• Better adapted to application specific needs | • CM operation could negatively affect operation of WEC<br>• WEC supplier specific |

Table 1 Pros and cons of approaches

## 2.3 Distributed vs. Centralized (cloud) approach

Another high-level design option for a CMS is whether to place the computational complexity needed for the operation of the condition monitoring close to the data sources (i.e. in the WECs) or in a centralized (possibly cloud-based) back-end server infrastructure. The two approaches are illustrated in Figure 3.

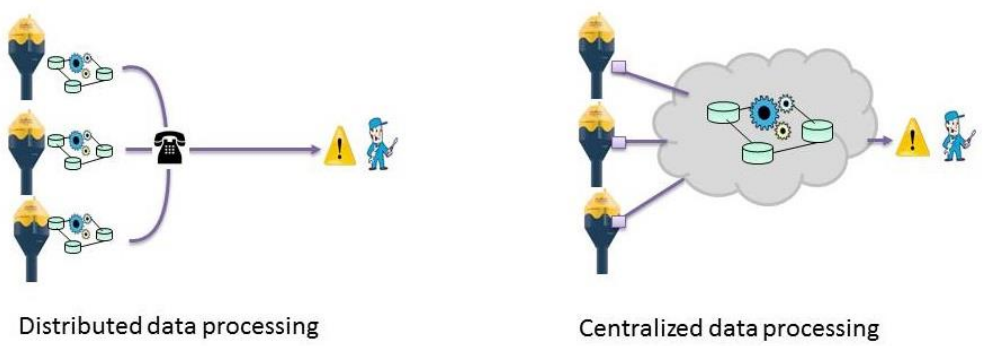


Figure 3 Distributed vs. centralized CM architecture

In the distributed processing approach, the onboard (in-WEC) parts of the CMS processes captured data locally, triggering alerts to remote service management personnel whenever the performance of the monitored systems is not according to plan. In the centralized processing approach, captured sensor data is transmitted to a back-end server infrastructure where it is processed to detect deviations from normal operation. Both approaches have benefits and drawbacks. Hybrids of the two can also be envisioned, where some (pre-) processing is performed onboard and the remaining (post-)processing is performed in the back-end architecture.

The distributed data processing approach requires less communication bandwidth and simpler back-end service infrastructure, while requiring more on-board computational capacity. The reverse is true for the centralized (cloud) processing approach. The distributed approach can be considered a more "traditional" architecture for industrial condition monitoring systems, whereas the centralized processing is more in line with emerging Internet-of-Things architectures, which emphasizes simple edge devices and extensive cloud-based processing. (Note that the use of the term "centralized" in this context does not prevent the processing architecture to use distributed computing mechanisms such as cluster computing.)

The pros and cons of the two approaches are given in the table below.

| Approach | Pros | Cons |
|---|---|---|
| Distributed | • Less communication bandwidth required<br>• Fault tolerance (less dependent on communication links)<br>• Simpler back-end architecture | • Higher on-board CPU requirements<br>• More onboard storage required<br>• Higher cost per unit |
| Centralized, IoT | • Lower on-board CPU and storage requirements<br>• Enables outlier detection<br>• Simples onboard devices<br>• Improved scalability | • Higher communication bandwidth<br>• Sensitive to failure of back-end infrastructure components |

**Table 2 Pros and cons of approaches**

# 3 Requirements and needs

The overarching need is to be able to collect measurement data from WECs in operation for condition monitoring purposes. This includes the following basic steps:

- Sampling of sensor data at prescribed sampling rates
- Collection of other operational data (except sensor data) from the WEC control system
- Communication of data from WEC to onshore back-end server infrastructure
- Storage of collected data sets in a structured way (e.g. database, data warehouse, data lake)
- Feeding data into automated data processing for fault prediction
- Making data available for other analytical processing
- Presentation of data analyses (e.g. visualization)

The monitoring framework which is the scope of WP2 is concerned mainly with the first three steps above.

## 3.1 Need for sensors

The approach of the monitoring framework in the RiaSoR2 project is to use sensors available already in WECs and used by the WEC control system. With this approach no new sensors will be required solely for the condition monitoring, and hence the cost of the system will be less than if new sensor systems need to be added. Although this is the initial approach, it is not clear from the onset if enough sensors are available in WECs for the condition monitoring needs, detecting the critical failure modes. Corpower's half-scale prototype WEC, used as a reference design in the RiaSoR2 project, is equipped with many sensors (see Appendix A), but it is not known whether all of those sensors will be available in the final production-level system. Indeed, input from the RiaSoR2 project regarding which of the sensors in the prototype are valuable for condition monitoring purposes could inform the decision of whether to include a particular set of sensors in the final product. Generally speaking, as many installed sensors as possible should be used by the CMS to maximise the ability to predict need for service to avoid unplanned service operations to the highest possible degree.

## 3.2 Sensor data capture needs

Many general requirements of the data capture system can be identified, relevant regardless of the type of sensor or signal.

- Data capture should be configurable in terms of which sensors to include in a particular measurement set-up and the sampling rate of each sensor.
- The data upload interval should be configurable and possible to set to capture data frequently enough for effective condition monitoring
- Data transmission should be protected by encryption.

## 3.3 Other data capture needs

Except for sensor data the unit should (at least optionally) be able to capture the following data:

- Control system logs
- Crash core dumps and catastrophic failure freeze-frames
- Snapshot images or videos recorded by cameras in the WEC

Some WEC customers will demand protection measures against theft of equipment. This is an important factor to be considered also in the context of a CMS. If a sensor is stolen that collects key data for condition monitoring, the CMS does not work as intended. Recording of video or photos triggered by external events such as motion of objects (people) onboard or in close vicinity of the floating structure could be important to secure the integrity of the CMS and the PTO functionality.

## 3.4 Types of data capture methods

Data can be captured using different mechanisms, including:

- Polling, i.e. data is read through passive reading from a communication bus or similar
- Request/response, i.e. actively requesting a signal value though e.g. a diagnostic command
- Calculated signals, i.e. through averaging of sensor data or similar

A data capture system for condition monitoring for marine applications should be able to capture data both using polling and request/response mechanisms.

## 3.5 Data capture unit requirements

The data capture unit is a piece of hardware installed in a WEC that captures data from onboard sensors and possibly other data sources. The data capture process is implemented in software running on the data capture unit. The data capture unit can be the same physical hardware as the control unit of the WEC. In this case the data capture system is a piece of software running on the control unit hardware.

The following operating requirements can be identified for onboard data capture units.

**Form factor:** Unit should be small enough to be easy to integrate into the WEC. This means that it should be less than about 20 cm x 20 cm x 10 cm.

**Dust and liquid ingress protection:** The unit should be dust protected and insensitive to splashing of water, consistent with at least class IP54 of ISO 20653 [4].

**Temperature range**: The unit should be able to operate in the temperature range -40°C to 80° C, i.e. Class F of ISO 16750-4 [5].

**Power consumption:** Power consumption should be below 50W.

**Vibration tolerance:** The unit and required cabling should be insensitive to vibrations.

**Communication Interfaces:** The unit should be equipped with the kind of communication interfaces needed to access sensor data, i.e. Fieldbus interfaces such as EtherCAT, CAN, etc or serial interfaces such as USB or LIN. The data capture unit should furthermore support Ethernet and optionally WiFi and mobile data communication (e.g. 3G, 4G).

**Storage:** The unit should be capable of storing captured data at least for the time intervals between uploads to the back-end server infrastructure.

**Processing power:** The CPU of the onboard unit should be powerful enough to execute the data capture software at the highest configurable sampling rate for the maximum number of sensors supported. It should simultaneously be able to communicate with the back-end server architecture.

## 3.6 Communication and telematic services requirements

The data captured by in-WEC data capture units should be communicated at regular intervals to the back-end server infrastructure for processing. Depending on whether a highly distributed processing architecture or a more central processing approach is chosen (as discussed in section 2.2), the upload interval and the volume of data uploaded will be different. There are also other needs for communication with in-WEC units, such as the possibility to log on to the unit for fault tracing and similar, remote software update, remote configuration, etc. These communication needs should be reflected in the design of the telematics service architecture.

The general mechanisms required by the communication infrastructure and telematics services are:

- Periodic uploading up sensor data and other data from in-WEC units to back-end server infrastructure
- Downloading of software updated and configuration data from back-end server infrastructure to in-WEC units
- Remote log-on capability, optionally using remote desktop (graphical user interface)

Basic requirements for the communication infrastructure are as follows:

- Bandwidth must be adequate for communication of data for the above services
- Latency must be low enough to allow reasonable response times for remote log-on
- Fault tolerant to transient connectivity problems, e.g. in mobile data communication
- Encryption of all communicated data using strong encryption
- Access control for log-in

Conceptually, sensor data communication can be supported in two main modes: **Store-and-forward** and **capture-and-transmit.** In store-and-forward mode, captured data are stored to local persistent storage and uploaded at regular intervals (configurable). In capture-and-transmit mode, each captured data sample is immediately transmitted to the back-end server infrastructure. The main benefit of the store-and-forward approach is that data is not lost when the communication uplink is unavailable. The main benefit of capture-and-transmit is low latency and reduced local storage need on the onboard units. For the RiaSoR 2 application, a store-and-forward approach is preferable (mainly due to the fault tolerance requirement), but there is nothing preventing that both mechanisms are implemented in parallel. The capture-and-transmit mechanism could for instance be transmitting data at a lower rate, to be used mainly for quick manual state of health inspections, whereas the store-and-forward mode is used for the automated data processing performed in the back-end infrastructure.

## 3.7 Back-end server architecture requirements

The back-end server infrastructure composes the main off-board parts of the system. The data sets uploaded from onboard units using telematic services are received, stored, processed and presented to users by means of components in the back-end infrastructure.

Since the processing of data that is needed for CM is highly dependent on the target system (i.e. WEC) design and on operating conditions, the processing framework needs to be customizable to execute any type of computational task. In the RiaSoR2 approach, a Variation Mode and Effect Analysis (VMEA) is performed to identify failure modes and root causes based on which the processing of data to detect deviations from normal operation and predict failures are derived.

When the number of WECs to monitor increases, the data processing to predict failures must be realized with a high level of automation. The ultimate goal is to have a completely automated system that monitors the performance of the complete systems and automatically generates warnings when prognostics show that the availability of a WEC will be compromised in the near future, so that maintenance actions can be planned. To accomplish this is a considerable challenge, however, and until such a system is feasible, human intervention will be required. Support functions to simplify analysis of data, e.g. through visualizations of data, trend analyses, statistical processing, etc, will be core elements in decision-making for predictive/preventive maintenance. This functionality will to a great extent be realized in the back-end server architecture of the system, including a front-end (typically web-based) visualization and user interface.

By building the back-end server infrastructure on standardized commodity software components, such as database management systems, web servers, back-up systems, virtualization platforms and similar, the back-end server infrastructure can be deployed as a cloud service, taking advantage of state-of-the-art execution and hosting platforms.

The basic requirements on the back-end server architecture are:

- Always up (24/7 operation of servers)
- Firewalled, access controlled, secure computing platform
- Large volume data storage. Must be able to store all data uploaded from all WECs in a structure, searchable way.
- Back-up of data
- Management interface, preferably web-based
- Sufficient processing power for automated condition monitoring processing operations

- Horizontally scalable architecture, i.e. more CPU and storage resources can be deployed as needed
- Front-end user interface with customizable data presentation primitives, preferably web-based
- Configurable alerting mechanism, generating e.g. e-mails or text messages at specific conditions
- Application Programming Interfaces (API) for accessing data in a well-defined way for custom processing

## 3.8 SCADA based condition monitoring

Supervisory control and data acquisition (SCADA) is a concept for high-level process supervisory management, including data collection, for industrial applications. In for example wind turbines, SCADA based systems typically record data in 10-minute intervals [6] and these data set can be used as the basis for condition monitoring.

## 3.9 Data fusion and signal processing approaches

Since many types of sensor data are available for Condition Monitoring purposes, from the target system's control system, from SCADA systems and other data sources, sensor fusion, i.e. that ability to aggregate and combine sensory data from disparate sources is important. How this sensor fusion is done depends on the type of signal processing or analytics approach. Some approaches are described below.

**Signal trending**

The Signal Trending approach relies on comparing corresponding signals from different systems (i.e. WECs), or with signals collected previously from the same system. It is hence an approach based on deviation detection.

**Artificial Neural Networks**

Artificial Neural Networks (ANN) is a Machine Learning approach whereby patterns can be detected. For the purpose of Condition Monitoring, an ANN must be trained with data sets collected during normal operation, so that a deviation detection metric can be calculated based on collected data.

**Physical models**

Mathematical or statistical models based on knowledge of the underlying principles fall under the category of "Physical models". Condition Monitoring algorithms can be developed using regression models based on time series data from training periods of normal operation.

# 4 Conclusions

The design of a CMS for wave energy converters is a complex task. In this document we have identified and analyzed requirements on the constituent parts of a CMS: data capture system, communication and telematics infrastructure, back-end server processing infrastructure and front-end presentation interfaces. A number of high-level architectural design alternatives have also been identified and discussed, including onboard/offboard processing alternatives and target system integration levels.

# 5 Recommendations

The recommendations of this study are to carefully consider how a scale-up to many connected WECs will affect the design and cost of condition monitoring. This includes a careful analysis of where to put the complexity of data processing: onboard or offboard, or (perhaps most likely) a hybrid approach. Consideration of how tightly to integrate the CMS with the target system are also important. Finally, the business aspects, including cost of ownership, service level agreements, risk sharing between stakeholders, etc, should also be investigated.

# 6 Abbreviations and definitions

| Abbreviation | Definition |
|---|---|
| **CAN** | Controller Area Network |
| **CM** | Condition Monitoring |
| **CMS** | Condition Monitoring System |
| **CPU** | Central Processing Unit |
| **LIN** | Local Interconnect Network |
| **MTBF** | Mean Time Between Failures |
| **MTTF** | Mean Time To Failure |
| **MTTR** | Mean Time To Repair |
| **OPEX** | Operational Expenditures |
| **RiaSoR** | Reliability in a Sea of Risk, finalized project |
| **RiaSoR 2** | Reliability in a Sea of Risk, this project |
| **SCADA** | Supervisory control and data acquisition |
| **TEC** | Tidal Energy Converter |
| **TRL** | Technological Readiness Level |
| **USB** | Universal Serial Bus |
| **VMEA** | Variation Mode and Effect Analysis |
| **WEC** | Wave Energy Converter |

**Table 3 Abbreviations and definitions**

# 7 Definition of terms

**Reliability** is defined as the ability of a system or system element performing its intended function under stated conditions without failure for a given period of time. A precise definition must include a detailed description of the function, the environment, the time scale, and what constitutes a failure. Typical quantitative measures are Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR).

**Maintainability** is defined as the ability of a system or system element to be repaired in a defined environment within a specified period of time. Increased maintainability implies shorter repair times.

**Availability** is defined as the ability of a repairable system or system element to be operational at a given point in time under a given set of environmental conditions. Availability depends on reliability and maintainability.

# 8 References

[1] Othmane El Mountassir, "Condition Monitoring Systems of Wave Energy Converters", RiaSoR WP5 Report, December 2017.

[2] Kenny, C. J., Findlay, D., Lazakis, I., Shek, J., & Thies, P. R. "Development of a Condition Monitoring System for an Articulated Wave Energy Converter", *European Safety and Reliability Conference* , (ss. 1-6). Glasgow, 2016.

[3] M. Johanson, L. Karlsson, "Service Architectures for Product and Production Availability: A System of Systems Approach", System of Systems Engineering 2016 (SoSE2016), Kongsberg, Norway, June 2016.

[4] ISO 20653:2013, "Road vehicles -- Degrees of protection (IP code) -- Protection of electrical equipment against foreign objects, water and access"

[5] ISO 16750-4:2010, "Road vehicles — Environmental conditions and testing for electrical and electronic equipment — Part 4: Climatic loads"

[6] Fraunhofer IWES, “Condition Monitoring of Wind Turbines: State of the Art, User Experience and recommendations”, January 2015.

RiaSoR 2 project partners

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