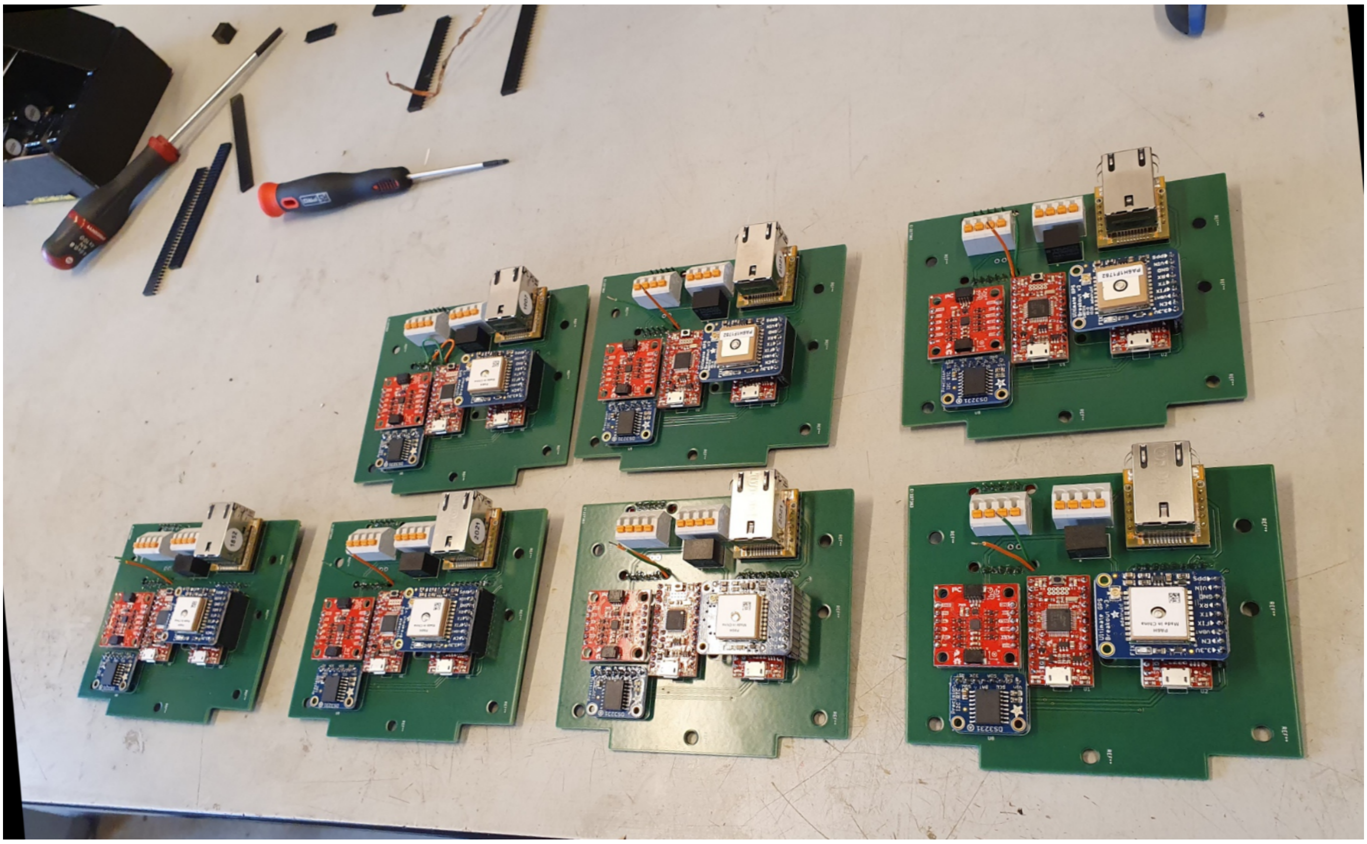

Figure 58 Distributed Collection motion loggers for Demonstrator test

Each local unit features a high stability battery powered real time clock with second resolution combined with a Mhz counter for microseconds resolution. The rated clock stability of 2 ppm for the RTC provides time already offers free running accuracy of better than 1 minute per year. The RTC clock is further adjusted or “disciplined“ to match the IRIG-B encoded time by fine adjustment to micro seconds using the starting edge of the IRIG frames

Each module further was outfitted with an Ethernet interface to enable communication during the tests, and facilitate forwarding of captured to a central logger for near real time evaluation. Because of practical constraints during the tests, the Ethernet interface could not be used however.

A total of 9 modules were configured and deployed on each floater in a test setup as indicated in Figure 59. The motions of the 9 floater and the loads in selected connectors were captured and stored to SD card in a compact test setup performed in MARIN’s Offshore Basin (OB) early August 2020.

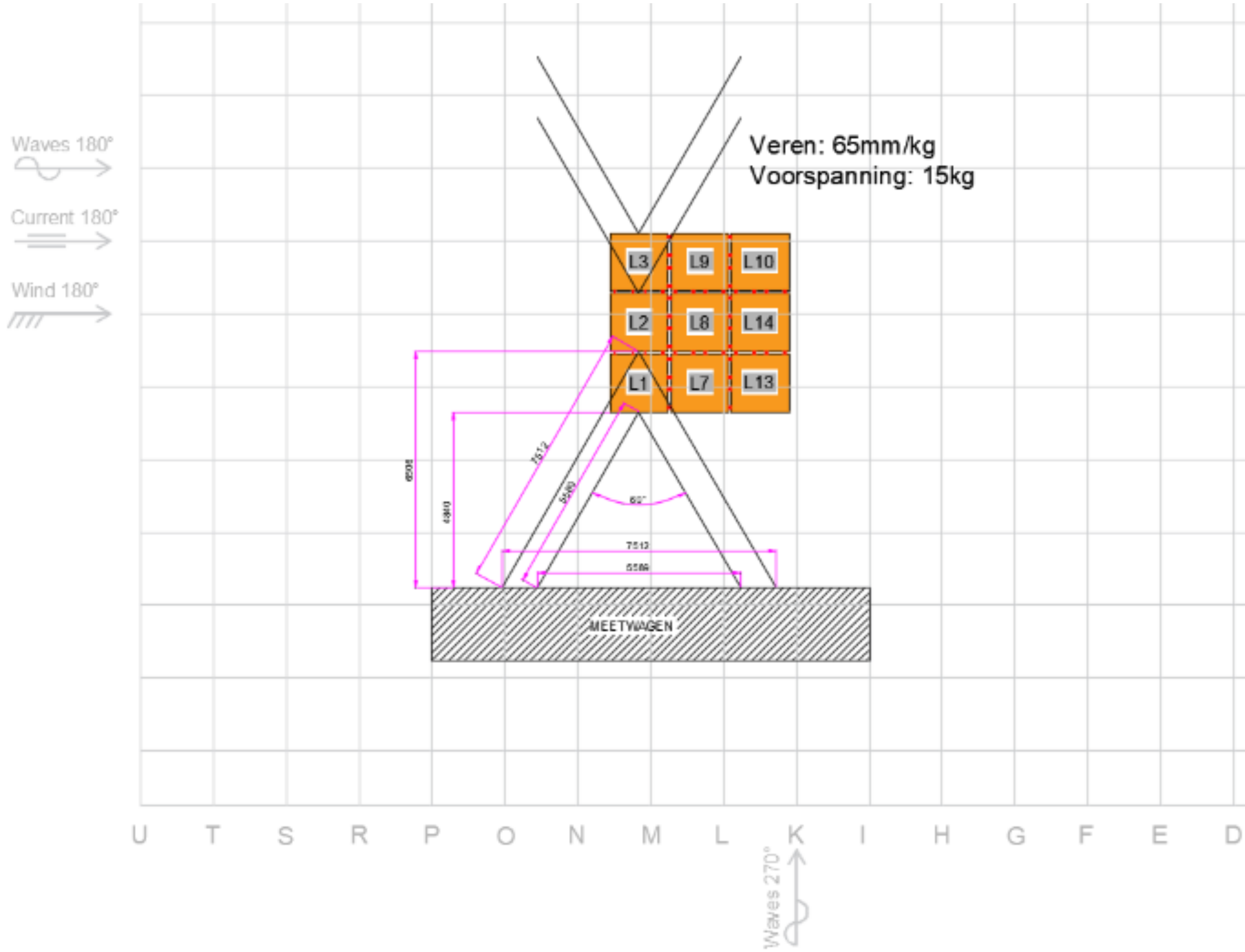

Figure 59 Model test configuration to demonstrate remote & distributed monitoring

The tests were conducted successfully. Cabling complications in the low freeboard, very wet test setup however prevented the hooking up of the data loggers in a joint network. During the tests it had to be relied on local storage on SD cards that could only be retrieved after the tests. The choice to rely on this data storage approach was configured at last moment and the setting was unfortunately not properly tested. The stored data was found to be corrupted on all 9 modules after the tests were completed. Although highly unfortunate it demonstrates the relevance of "live" data quality indicators as listed in the functional requirements to floating island DCS systems. If the network datalink could have been fitted then the problem could have been recognised in time.

7 Conclusions

The requirements and options for a remote monitoring system for a floating island configuration were reviewed. The focus was explicitly on the island infrastructure and not on the superstructure payload. The remote monitoring system should facilitate the needs for O&M operation as well as validation of underlying design models.

- O&M related operator needs were identified in relation to Endsley's model of situational awareness. The O&M of process characterised by a particular "state" is represented by stages of perception (measuring), comprehension (what does it mean), projection (what will happen in future), decision (choose best plan) and action (change controls).
- The requirement for design model validation was identified as a subset of O&M functionality as in the ability to store relevant parameters for offline retrieval and post processing.

It was shown that keeping track of the status and condition of a floating island comprising of many modules includes a large number of aspects that each rely on inputs from a variety of locations.

The importance of quantifiable parameters was highlighted via a reference to an ISO standard for metrology.

Current practice technology from the Process Control and Automation world was discussed. The merits of DCS, SCADA, CAMS, and ESD systems were outlined and explained metaphorically to bio-mimic the sensory system along with its local control and processing, the conscious control (open) loop, subconscious control (closed) loop, and reflex type of pre-programmed response.

The versatility of DCS systems allows to acquire / collect inputs and perform processing into quantity type of parameters which can be forwarded to SCADA, CAMS and ESD layers.

To prevent extensive cabling and avoid complex control interfaces a systems architecture for a floating island configuration is anticipated with separated local DCS systems per floater, that each handle local floater data collection, storage, alarms and simple processing and are interfaced with a central controller location sharing central time reference and providing access to data.

This introduces differences of floating island monitoring solutions in comparison to monolithic single site solutions:

- The interconnection of multiple DCS systems instead of a single DCS system. Combining multiple floaters from different manufacturers calls for an open standard framework to allow the DCS layers to work together and exchange information.
- A data processing layer in between the multiple floater DCS systems and a top level SCADA system that combines the multitude of local sensors into quantitative representations for relevant operator comprehensible parameters. This is referred as the digital twin model. The digital twin model provides the state representation of the floating island. The state is matched with inputs from the lower level DCS systems. The digital twin could have in theory the functionality to indicate if it "feels well" based on all connected sensors instead of a SCADA system merely showing values of all individual sensor points with respect to acceptable ranges.

The central SCADA, CAMS, and ESD systems should have access to both the individual DCS subsystems, as the digital twin model. The central controller location could in theory be located on the island, or on shore. SCADA operation relies on an active and reliable data link. Downtime of the data link will interrupt controller situation awareness, decision and actions which seems undesirable. Locating the SCADA control server on the island thus seems to be preferred. Shore operators could then work through a remote connection sharing workload between on site and on shore.

Interfacing of sensors to the DCS system, and cross connecting the DCS systems to each other may involve direct wiring, Wi-Fi, cellular networks, or satellite telemetry. Sensor-DCS communication is expected to include both direct wiring (Ethernet, can/mod/profi bus etc.) and radio telemetry as (RF, Wi-Fi, 3/4/5G). DCS - (local)SCADA communication is expected to be hard wired across various floaters. Remote shore operated SCADA is anticipated to be remote connected to a local server on one of the floaters. This will minimise data flow and could be via Satellite or hardwired shore link.

With respect to operator functionality, specific floating island O&M needs were identified. It was highlighted to keep track of and anticipate

- external loads onto the island,
- present stationary loads and ballast condition,
- dynamic response,
- structural health, and
- impact on environment.

A limited set of control actions were identified for operators with respect to the island infrastructure:

- Draught control and ballast arrangement
- Maintaining power grid and shared resources, water, waste, data
- Scheduling inspection and maintenance efforts
- Dealing with traffic of incoming ships, rovs, helicopters
- Monitoring regular alarm status and emergency control

Direct sensors and methods to acquire information on above were identified. Specific sensors and subsystems are available for the majority of parameters, providing direct quantitative readings for many phenomena.

Some aspects of floating island operation however were noted to rely on behaviour that cannot be directly measured and quantified. Examples of these are

- Phenomena relying on combinations of sensors that are measured at different floaters (DCS systems) and that cannot be combined straight forward. For instance global deflections and combined mooring forces.
- Correlating mooring loads, connectors loads and stresses in the local structures, and the accumulated effects of these on remaining service life, or time to scheduled preventive maintenance.
- Phenomena that are observed in non-quantitative ways. For instance video footage on the impact of the island on the environment and the marine growth on structure and moorings.

Digital twin algorithms and approaches to determine relevant quantitative parameters from data inputs that can be fitted to DCS systems were found and discussed. These algorithms should be part of the digital twin model and might use inputs that can be obtained from DCS connected sensors and camera footage to determine operator feedback. These models however are still quite academic and not fully validated. With respect to motions and loads they appear to be constrained to the linear regime.

Condition monitoring systems (CMS) as in use for merchant shipping, offshore oil and gas structures, and offshore wind, may be implemented in local floater DCS systems, or included at higher level in the digital twin. Since loads in the mooring lines and the connectors are a function of the global response it would seem that the digital twin model is the best candidate to handle mooring and connector condition while floater structure may be part of the floater DCS as it relies also on the local structure details.

It is noted that the comprehension and projection of global behaviour from combinations of local motions is challenging. In particular for structures that have degrees of freedom with large differences in rigidity and where friction and non-linearity plays a part. Having proper models to match global behaviour with local measured data and vice versa is essential to comprehend overall response, and recognise a structural anomaly from a sensor malfunction. Representing global motions from combined local behaviour requires further attention.

8 Recommendations

The Space@Sea project evaluated a floating island concept using 2020 type of technology. It was concluded that a "monitoring" system for O&M purposes can be drawn up under that technology without principal envisaged problems. Challenges though were anticipated in the interfacing of the many inputs from various floaters to a central SCADA layer, and deriving comprehensive information from it as needed for proper future projection and decisions.

The main recommendations as such are thus to do

1. Data fusion algorithms to match detailed global level digital twin models on various aspects with readings from scares and distributed local sensor readings.
2. Further developments in multi body dynamics. This field of technology overlaps with for instance dynamics of high stacked container cargo that can exhibit extreme response in case of unfavourable excitation by wave slamming or short wave encounter periods. Practical (linearised) models are needed to assist in on site and design stages where full blown two way CFD-structural codes are too CPU intensive.
3. Strive for open standards to enable a flexible triangle DCS-SCADA-DIGITAL TWIN for floating islands where third parties outside classic Process Control and Automation industry can contribute with the digital twin functionality. This would enable inclusion of hydro mechanic, and data science fields of expertise into the optimisation of floating island O&M.

References

[Ref. 1] Featherstone, R. (2014). Rigid body dynamics algorithms. Springer.

[Ref. 2] Linder, J., Enqvist, M., Gustafsson, F., & Sjöberg, J. (2014). Identifiability of physical parameters in systems with limited sensors. IFAC Proceedings Volumes, 47(3), 6454-6459.

[Ref. 3] Zhu, J. and Collette, M. (2017), A Bayesian approach for shipboard lifetime wave load spectrum updating, Structure and Infrastructure Engineering, 13(2), 298–312.

[Ref. 4] Mondoro, A., Soliman, M., and Frangopol, D. M. (2016), Prediction of structural response of naval vessels based on available structural health monitoring data, Ocean Engineering, 125, 295–307.

[Ref. 5] Lau, K. K. (2018). Online structural health monitoring using Kalman-filter-based methods (Doctoral dissertation).

[Ref. 6] Martí, L., Sanchez-Pi, N., Molina, J. M., & Garcia, A. C. B. (2015). Anomaly detection based on sensor data in petroleum industry applications. Sensors, 15(2), 2774-2797.

[Ref. 7] Buhmann, M.D. Radial Basis Functions: Theory and Implementations; Cambridge University Press: Cambridge, UK, 2003; Volume 5.

[Ref. 8] Rüping, S. SVM Kernels for Time Series Analysis. Technical Report, SFB 475: Komplexitätsreduktion in Multivariaten Datenstrukturen; Universität Dortmund: Dortmund, Germany, 2001.

[Ref. 9] Ranganath Kothamasu, Samuel Huang, and William VerDuin. System health monitoring and prognostics — a review of current paradigms and practices. The International Journal of Advanced Manufacturing Technology, 28(9):1012–1024, July 2006.

Annex 1: Contribution to the Knowledge Portfolio

This report is intended to provide an overview of requirements to monitoring systems for future floating islands, and how these relate to existing methodologies in monitoring and control solutions today. The work described gives an overview of existing methodologies as collected by the authors from experience, and from public and scientific publication domains.

It is attempted to include references to knowledge holders of used documentations where possible.

The work is intended to be informative. The authors do not claim explicit ownership of methodologies, algorithms or solutions as described in the report.