Port and vessel insights from IoT edge vessel motion measurement devices

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Abstract
The advent of Internet if Things (IoT) infrastructure and advances in miniaturization of sensor technology allow the live delivery of vessel motion analysis to port users, where traditionally this has required laborious manual data collection and processing steps. This paper explores the broad range of opportunities this advance can provide port operations, from real-time movements monitoring for VTS (Vessel Transit Services) / marine coordinators to vessel-specific motion intelligence for load operators and pilots, and data-driven insights for ports and shipping companies.

To inform ship motion models used in port and vessel management systems, IoT edge devices stream data for immediate insights into port activities and vessel motion characteristics. These are used to refine vessel sailing advice in real-time, and to back-estimate the sea-state along the vessel's route. Indeed, these data can both inform modelling as historical datasets and in real-time for situational awareness, as a platform to accelerate developments in safety systems, remote pilotage and autonomous shipping in the context of port waterways (distinct from the open ocean).

The collection of vessel motion data on a larger scale can be used to better understand the operability and dynamics of the port and vessel movements. OMC's edge devices accurately measure vessel positions and dynamic roll, pitch and heave in a convenient package, allowing data collection to be integrated into business-as-usual for pilotage operations. This enables the collection of vessel intelligence to inform port management systems of specific ship-in-channel characteristics. These are aggregated and combined with predictions of meteorological conditions to achieve modelling excellence, to improve navigational safety and port throughput volumes on a ship-by-ship, movement-by-movement level.

Keywords: remote pilotage, measurements, modelling, autonomous shipping, insights.

1. Introduction

The collection of full-scale vessel motion data at commercial ports can be a logistically challenging exercise somewhat at odds with safe pilotage, frequently when vessel motions are of most concern and therefore of most value to observe (as noted in Hibbert & Lesser, 2013). This tends to limit the opportunity for data collection.

The advent of instrumented pilotage using dedicated PPU and FPU (portable pilot units, fixed pilot unit) devices would seem to provide the ideal opportunity to streamline and integrate the data collection process. However, there are limitations, largely around the accessibility and analysis of the measurements.

This is unfortunate, since vessel motion data can be of value for a variety of activities which may aid the safety and efficiency of operations, from real-time through to long-term strategic planning.

Recently, IoT (internet of things) devices have become available and promise to be near ubiquitous, provisioning sensor data easily and cost-effectively in all manner of industrial and operational settings. Accordingly, internet-connected vessel motion sensors have been developed (Hibbert & Curtis, 2022) to collect and deliver measurements in a port setting, making use of the cellular connectivity that is generally available.

This allows vessel motion data to be made available in near real-time in ideal circumstances, or automatically and rapidly as a cell-tower come into range. Were these sensors deployed as part of the business-as-usual pilotage, new data-based services can be offered to the port operators, users, and pilotage groups themselves.

2. Insights from motion measurements

The capability of measuring ship motions in full-scale has been used to provide data for the validation and calibration of models and simulations. Due to the difficulties in obtaining the data, this has typically been done in focussed campaigns and entails multi-stage collection and processing tasks.

The analysis of vessel movements can be useful for pilots on an individual and group level for achieving and improving best-practice for both horizontal movements e.g., to optimise seakeeping for pilot transfer risk mitigation, and to manage vertical under-keel clearance (UKC) factors such as squat and dynamic heel.

Vessel and movement specific behaviours can also be predicted with higher fidelity by incorporating observed characteristics such as the roll characteristics, squat behaviour, and ship-specific dynamics in all six degrees of freedom. An example of this is the characterisation of the roll coefficients from vessel response in random seas per Javanmardi et al. (2019).

The collection of such data can be aggregated and enhanced using value-adding analysis techniques. The aggregated data represents vessel motion intelligence (VMI), which can be used to drive knowledge and data informed services.

2.1 Connected sensors

The ubiquity of cellular data networking now provides the infrastructure for edge devices to deliver data cheaply and reliably to "cloud" internet-provisioned services for ingestion, processing, and analysis, illustrated in Figure 1. Being web-based, the scalability and future-proofing of the services can be addressed without the need for site investments beyond the edge devices themselves, so the focus can be placed on workflows instead.

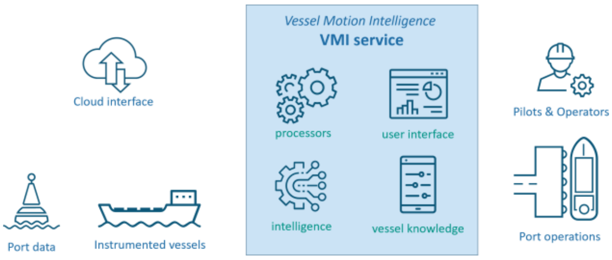

Figure 1 - Vessel Motion Intelligence service connects edge device data sources to the port users and pilots. The data connections enable the facilitation of the value-adding services, with little infrastructure investment by the port.

Bulk data transfer for high fidelity motion data presently can be achieved with land-based cellular IoT networks (such as LTE-M and NB-IoT), it is possible even now to transmit useful data via low-cost satellite data systems for continuous monitoring and pre-transit vessel model enhancement.

The IMUs (inertial motion units) contained in most modern smart devices may be sufficient to collect vessel motion data for limited uses such as roll measurements, though in practice such devices frequently can't be left undisturbed while collecting such measurements. As such, a dedicated device with known, calibrated accuracy and methods for alignment to the ship's frame of reference is preferable. This also frees up the smart device to collect additional information for data enhancement, such as vessel particulars and pilot card information.

Figure 2 – Map of observed vessel pitch response amplitudes. The ship range of motion can be overlayed onto the movements validated by AIS messages, and see in the context of other data such as wave grids and other traffic.

These data are enhanced with integration and assimilation with other vessel data sources, most notably the ship's AIS messages. These are particularly helpful to ensure data validity and to add context to the observed movements.

2.2 Streaming ahead

With the advent of streaming or rapidly available data, the development of automatic processing streams enables the analysis and provision of data via cloud infrastructure.

This immediacy and scalability of data collection provides the opportunity to use the data in new ways. When streaming data for pilotage underway, analysis of the ship's motions can be used to monitor the transit and to check against voyage modelling and stability information. In the event of a discrepancy, the VTSO and pilot may be alerted and potentially take corrective action where warranted, e.g. manoeuvres in response to parametric roll alerts.

On-the-fly data from instrumented vessels may also be used to augment vessel motion forecasts in near real-time. For example, the uncertainty envelope for a vessel's wave-induced motions may be reduced where the modelling is identified as being highly accurate, or increased if it is unexpectedly poor. The back-estimated sea state may also be used to inform the response model inputs for following vessels that will encounter persistent swell waves.

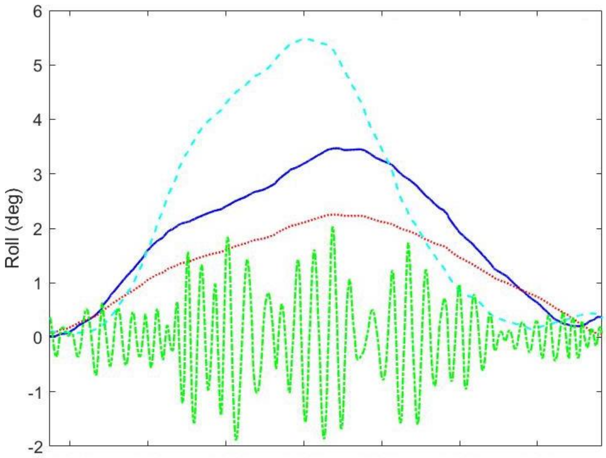

Figure 3 – Observed roll (green) versus three subtly different model's response envelopes. Vessel and wave model refinement can dramatically affect motion modelling.

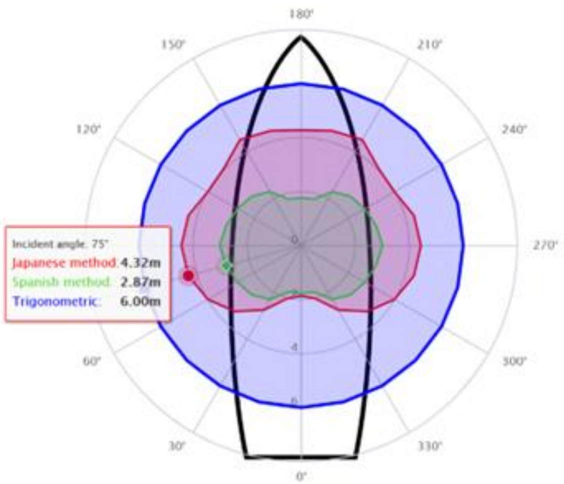

Figure 4 – Simple models for estimated ship sinkage due to wave action. The uncertainty envelope around response modelling, or it's inputs, may be refined on the fly where observations can validate individual model results.

2.3 Modelling excellence

In the first instance of a ship being observed, Bayesian techniques refine the baseline model assumptions to reduce the inherent uncertainties. However, as data is collected, return voyages (and/or observations from participating ports) will provide further augmentation through statistical and machine learning techniques.

As an example of this, observation-based vessel parameters will enhance the accuracy of seakeeping packages, in effect they being tailored to the hydrodynamic peculiarities of the waterway in a manner that would otherwise require expert model "tuning".

The next time the ship is seen, what was previously learned about the vessel is included in the modelling. This is further refined for additional returns to the same port of call for waterway-specific models (i.e., as affected by water depth per Mehr et al. 2022) as well as hull-specific variables. As the range of observational states increase, modelling certainty will likewise increase as the vessel motion intelligence is compiled. Consequently, uncertainty allowances are decreased, and the model accuracy is improved to the economic advantage of the port through improved cargo throughput and increased waterway access (accessibility periods) and utilisation (usable draft depth).

Vessel characterisation clustering, whether as sister vessels or simply those with related characteristics, will result in a "rising tide" of information upon which modelling excellence will rise.

3. Data horizon

The ubiquity of high quality, movement-by-movement data provides the basis on which layers of operational sophistication is built.

3.1 Big potential

With edge device streaming of data to cloud infrastructure, sophisticated analysis and decentralised vessel motion intelligence models will be available via networked infrastructure. In effect, apps and web portals can stream the information to users whether they are land-based or situated on-board.

As data is received by the processing platform, authentication, signal processing and cross-checks across sources are performed to ensure integrity. Where data quality is degraded in time e.g., due to transmission latencies or quality such as poor GNSS reception, it is tagged accordingly and it's uses will be managed, i.e., limited to display and post-evaluation rather than real-time processes. This mitigation protects the users and any dependant operational system whilst providing data availability.

With the developing global data accessibility via satellite, the ubiquity of such arrangements will allow services to extend to augmented reality (AR) enhanced situational awareness for pilots and operators (whether remote or ship based). Indeed, the value proposition will be to avoid overwhelming the users with extraneous information, as opposed to simply getting data to the users.

Further, the full gamut of vessel motion intelligence across all observed vessels, ports and transits will combine in the style of "big data" which may offer insights that cannot be presupposed. The application of deep learning and other techniques is anticipated to provide opportunities beyond day-to-day port operations, most likely for port and fleet planning and possibly even for ship design.

3.2 Autonomy enabled

Autonomous vessels will need to know themselves. Building upon the design parameters and hydrodynamically calculated constraints, vessels will need the capability to self-measure and self-calibrate in order to truly operate autonomously, particularly where vertical as well as horizontal constraints must be observed.

To achieve autonomous UKC management (AUKCM), real-time bathymetry and adaptive self-modelled responses & corrections will be required. Wide-scale data collection to support these developments for use on an industrial scale has necessarily begun.

4. Conclusions

It is a time of great potential in the realm of connected vessels and the confluence of live, big data with advances in machine learning.

While the path forward is inevitably hard to see clearly, we can see what lies directly before us and the horizon beckons. To lay the groundwork for the road ahead, foundational data collection and handling frameworks are the immediate challenge upon which to build the intelligent services of tomorrow.

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