Wave Sensor on the Go

by Oliver S. Kirsebom, Sebastian Deggan

Figure 1: DataXplorer operating in beach surf near Tofino, BC, on west coast of Vancouver Island.

Field observations of ocean waves are used by researchers to improve models of wave dynamics, but such observations also have practical applications: real-time wave data informs navigation, ocean and weather forecasting, oil-spill response, and recreational ocean use. Various offshore industries rely on historical wave data to design and build structures that can withstand long-term wave energy, e.g., oil rigs, wind farms, fish farms, and bridges.

Uncrewed Surface Vehicles (USVs) are a relatively new but increasingly familiar presence on our ocean, offering a safe, affordable, and sustainable approach to ocean monitoring across a wide range of applications. To aid with navigation, USVs are typically equipped with an Inertial Navigation System (INS) providing measurements of the vehicle's rotational and translational motion at high sampling rate. From these data, it is possible to infer ocean wave properties, effectively turning USVs into mobile wave sensors. Rapidly deployable, mobile wave sensors offer significant value for transient oceanographic applications, such as interim replacements for decommissioned wave buoys or rapid oil spill response to help forecast the movement of the oil plume.

In this article, we discuss ongoing efforts at Open Ocean Robotics (OOR) to implement and validate algorithms for inferring wave properties from INS data collected on board a USV, utilizing open-source software and off-the-shelf hardware components.

OOR's DataXplorer(TM) (DX) is a solar-powered USV (Figure 1) with a wide range of applications such as monitoring of marine protected areas, bathymetric mapping, and data collection for ocean alkalinity enhancement studies. Its small size (3.7 m length, 0.9 m beam, 0.5 m draft) and modest weight (125-200 kg depending on battery and sensor payloads) simplifies deployment while its self-righting capability allows it to operate in all sea states, thus remaining at sea for weeks at a time.

DX is equipped with an IR-LOCK Cube Orange Pixhawk INS (CAD$350) reporting navigational telemetry, including GPS position, acceleration, and attitude. These data streams are processed by the onboard NVIDIA Jetson Xavier NX computer ($1,600), which acts as the USV's "brain," integrating and processing data from a range of sensors including cameras, a weather station, and a triducer for depth, water temperature, and speed-through-water. The Jetson typically consumes around 10 W, striking a good balance between computing performance and power consumption. It runs a Linux Ubuntu operating system, simplifying the process of writing and deploying software to it. DX can relay data back to shore in real time via cellular network and satellite (Iridium Certus).

Given accurate readings of the USV's vertical acceleration, one can obtain its vertical displacement – also known as heave – through straightforward numerical integration, in

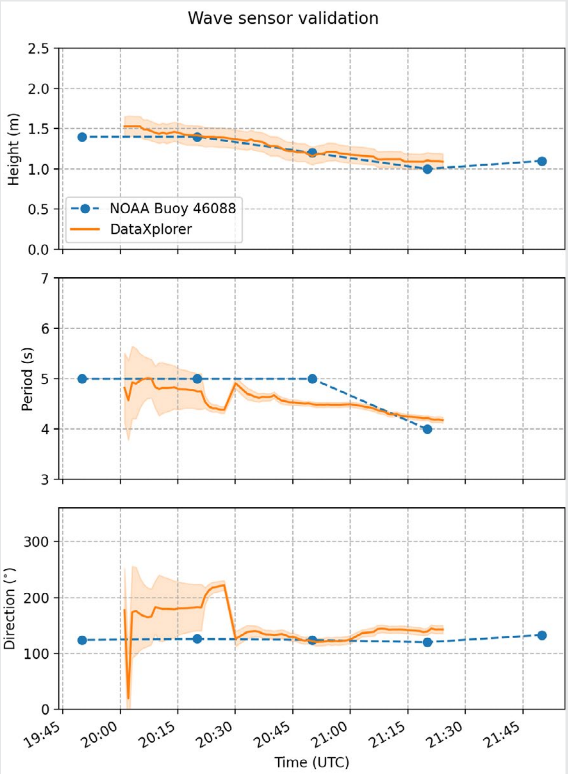

Figure 2: Comparison of wave parameters (height, period, direction) as determined by the DataXplorer (orange line) and the National Oceanic and Atmospheric Administration's National Data Buoy Center buoy (blue dots/line) over ~one hour period on March 19, 2025.

principle. However, in practice, sensor bias causes the heave to diverge while slow fluctuations (inaccuracies) in sensor readings contaminate the low frequency part of the wave spectrum.

There are several techniques for avoiding this divergence. Here, we use a simple, linear Kalman Filter to integrate the vertical acceleration and set the "observed" time integral of the heave to zero at all times. We implement this solution in Python using the open-source package SciPy.

As an initial validation of our solution, we sent a DX to an ocean observation buoy operated by the US National Oceanic and Atmospheric Administration's (NOAA) National Data Buoy Center. The buoy is situated in coastal waters (115 m depth) at the eastern entrance of the Strait of Juan de Fuca. At this location, it cannot easily be reached by long-period swells from the Pacific, but it often experiences large, local wind waves. On the day of our wave-data trial (March 19, 2025), the buoy was reporting wind speeds of 12 m/s from the east (110°) and waves with a period of 5 s and significant wave height of 1.4 m from the southeast (130°). Additionally, a fairly strong surface current was present east-to-west with a speed of 1.2 knots.

The DX orbited the buoy for about one hour, tracing a square-like pattern with sides of 400 m at speeds of 1 to 4 kts over the ground depending on its direction of travel relative to the ocean current. For each straight-line segment, the wave spectrum was computed with the aid of the Kalman Filter and integrated to determine significant wave height. Determination of the dominant wave period required special care as the motion of DX relative to the waves caused the observed period to be Doppler shifted. By combining data obtained from different speeds and directions of travel, it was possible not only to correct for the Doppler shift, but also to constrain the wave direction. As seen in Figure 2, the wave parameters estimated by DX are in satisfactory agreement with those reported by the NOAA buoy.

Below 0.1 Hz, the wave spectra were contaminated by low frequency noise. Thus, direct integration of the accelerometer data is unlikely to provide useful constraints on swells with periods of 10 s or above. While equipping DX with a more sophisticated (and expensive) INS may help address this problem, we are currently exploring an alternative solution for estimating swells based on the USV's pitch angle. Future development and testing will involve collecting long period swell data from an offshore location.

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