Towards a next generation Ocean Bottom Node: Incorporating a 6C motion sensor

Introduction

Acquiring marine seismic data often means having to compromise between good quality data and acquisition costs. Rotational measurements, in addition to translational measurements, could help mitigate self-imposed aliasing problems and suppress low velocity surface wave noise.

For ocean bottom seismic (OBS) successful implementation of such technology has obvious business potential. Efficiency gains in acquisition can be achieved by using fewer nodes to cover the same area and positioning requirements in time lapse (4D) surveys could be relaxed - both without compromising on data quality. Another objective for adding rotational measurements is to enable separation of the wavefield into P- and S-waves. Such measurements may therefore also be helpful in elastic full waveform inversion (FWI). Rotational measurements contribute to the spatial gradients at the seafloor in the sense that the horizontal components of rotation correspond to the horizontal derivatives of the vertical component of the wavefield in the perpendicular direction. Also, rotational measurements combined with collocated translational measurements yield the local S-wave apparent velocity without the need for a seismic array.

Additional measurements previously proposed for seabed seismic recording have typically involved different forms of spatial gradient sensors at the node. This could be measuring pressure gradients in the water column (spaced hydrophones or water-borne accelerometers) and/or spatial gradients of the vertical component - which can be exploited in source and/or receiver side interpolation. Equinor has previously developed and tested a gradient measurement acquisition technology coined '6C' (Amundsen, Westerdahl and Thompson 2010). Benefits of combined recordings of translational and rotational motion for land applications have been discussed earlier (Schmelzbach et al. 2018, Muyzert et al. 2019, Robertsson and Curtis 2002).

In this paper we present results from a collaborative effort to field test a recently developed single station rotational sensor (Faber et al 2020). The main goals have been to (1) demonstrate that the sensor can be deployed and used in an offshore setting and (2) to assess the potential of this single sensor prototype unit to directly measure translational and rotational components, verified by reference data measured by nearby conventional nodes. Early results and data examples from a field trial acquiring ocean bottom multi-component data with this new motion sensor are presented as a first step in a wider scope effort to develop acquisition technology that could enable cost-efficient full wavefield reconstruction capabilities.

A new 6DOF motion sensor

A translational sensor measures the linear motion of a particle in a direction along an axis and a rotational sensor measures the angular motion of a particle about an axis. When translational and rotational sensing is accomplished simultaneously in three orthogonal axes, a 6 degree-of-freedom (6DOF) sensor is realized representing 6 component (or 6C) measurements.

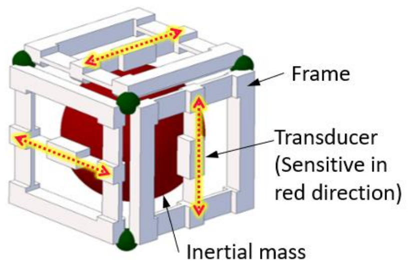

Figure 1: *The new 'Ksphere' sensor*

The new 6DOF sensor (called '*Ksphere*') is comprised of a single sphere serving as an inertial mass surrounded by a stiff cubic frame. A shear sensitive transducer is "sandwiched" between the frame and the sphere on each face of the cube (Figure 1). These transducers respond electrically to stress in only one direction while remaining insensitive to stress in the perpendicular directions. Opposite face transducers are sensitive to stress in the same direction with the three face pairs arranged to measure stress in the three orthogonal axes. The motion sensed by the shear sensitive transducers is proportional to acceleration. The summation of output from opposing face transducers yields acceleration along their sensitive axis while the differencing of output yields rotational acceleration around an axis perpendicular to the plane defined by the sensitive axis of the opposing face transducers. The outputs of the six transducers are pre-amplified and simultaneously digitized resulting in self-consistent broadband translational and rotational acceleration measurements.

Field Trial and Data Acquisition

The new *Ksphere* sensor was recently tested in a field trial carried out offshore at a field in the North Sea.

A limited number of *Ksphere* sensors were used, each fitted into the modified housing of a conventional ZXPLR node.

For reference and comparison purposes, the nodes were deployed in a fixed pattern configurated in groups of five (Figure 2). Each group had a *Ksphere* node at the center, distanced approximately one meter from the other four reference nodes which contained standard 3C geophones.

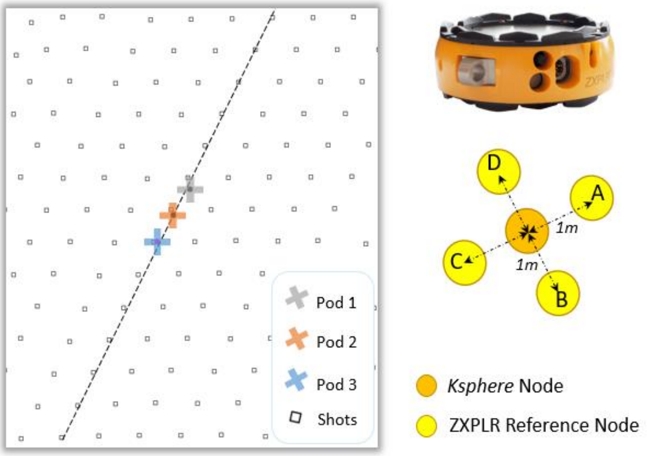

Figure 2: *Source grid and sensor stations deployment details. The Ksphere node was placed at the center of a group of four reference nodes. Difference data from reference nodes* C *and* A *deployed in 'Pod 1' are shown in Fig. 3c. A photo of the ZXPLR node is also shown.*

The field trial was timed to coincide with the acquisition of a commercial seismic survey, with standard air-gun sources fired on pre-plot positions in dual mode (flip-flop) on a 50x50 meter grid over the nodes in the trial area, providing offsets and azimuths suitable for subsequent analysis of the data acquired by the Ksphere and reference nodes.

Observations and Early Analysis Results

In this first section we present preliminary analysis and some key findings from comparing data from one *Ksphere* sensor to data obtained by the reference nodes in the same group.

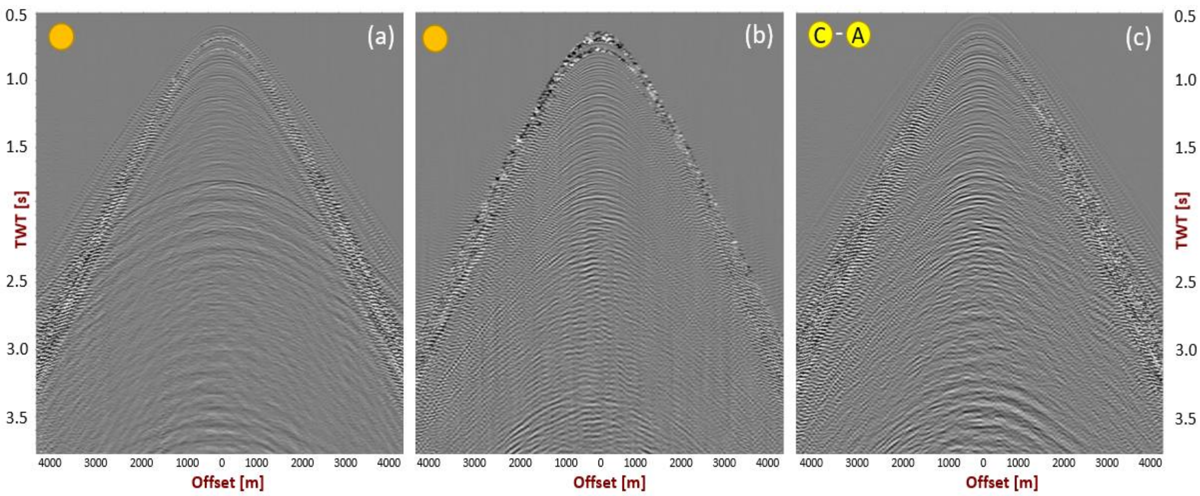

Figure 3: *Data from Ksphere (orange) and reference (yellow) nodes: Ksphere vertical translational component (a) and horizontal rotational component (b). A vertical acceleration (Az) difference section from two reference nodes* C*-*A *is shown in (c). The Ksphere rotational axis in (b) is perpendicular to the axis between the two reference nodes.*

Data from the *Ksphere* sensor and reference data from two of the four reference nodes grouped together in 'Pod 1' is shown in Figure 3. The left section (a) shows the *Ksphere* vertical translational component, while the middle section (b) shows the same *Ksphere* sensor's horizontal rotational component. Of note in (b) is some short duration overscaling around the first arrivals induced by an issue with the prototype sensor electronics.

One key objective of the trial was to demonstrate the *Ksphere* sensor's ability to match rotational measurements derived from closely spaced reference sensors. The right section (c) shows the difference of vertical acceleration (Az) components (time differentiated vertical geophone measurements) of two diametrically opposite reference nodes. We observe that the horizontal rotational component from the *Ksphere* sensor in the direction perpendicular to the axis between the two reference nodes in (b) and the derived rotational measurement from the conventional nodes in (c) are quite similar. There are remnants of P-reflections in (c), so this reference node difference section is, as expected, not fully representative of a point-measured spatial derivative. We observe similar encouraging results when comparing the difference between the other two diametrically opposite reference nodes to the corresponding single reading from the *Ksphere* sensor.

Ksphere rotational measurements made at the ocean bottom represent the horizontal spatial derivatives of the vertical component. Due to the construction of *Ksphere* these derivatives are self-consistent with the corresponding translational measurements requiring no additional conversions when the two types of measurement are to be used in combination.

To further test the validity of the rotational measurements we applied wavefield matching filters using spatial derivatives measured by the *Ksphere* to study and separate the rotational and translational wavefields [Amundsen et al. (2000), Robertsson and Curtis (2002)]. Figure 4 shows results from the chosen approach, used to attenuate shear wave energy on the vertical component: The left section (a) shows the *Ksphere* vertical translational component; the right section (c) shows rotational data matched and subtracted from (a). The middle section (b) shows the result of subtracting the matched rotational data (c) from the vertical component (a).

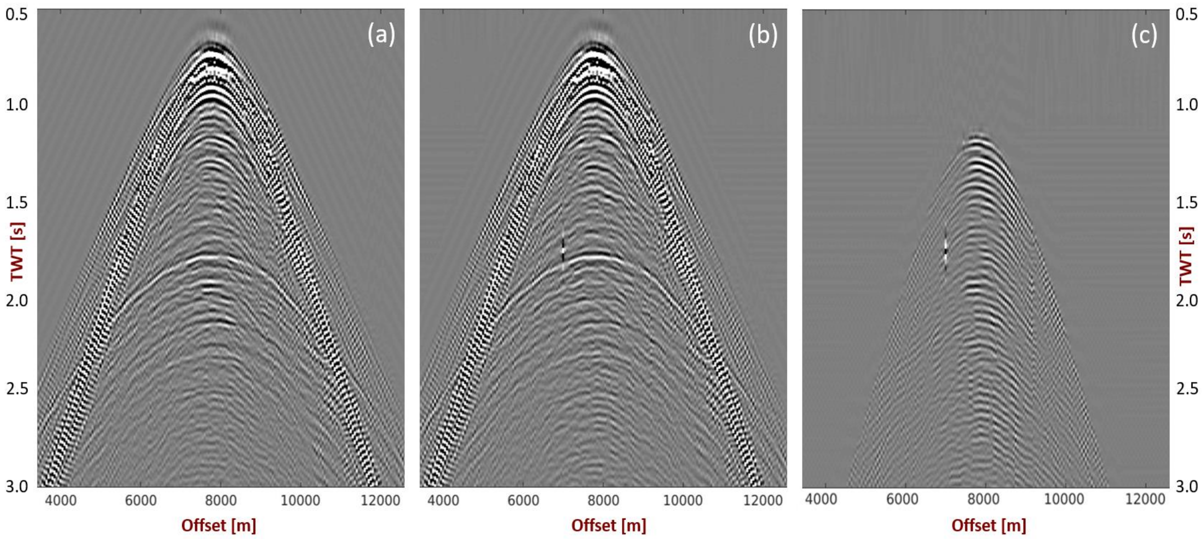

Figure 4: *Vertical component displays from Ksphere sensor: Vertical translational component (a), same after applying adaptive filter to rotational data and subtraction (b), and rotational data matched and subtracted from the vertical gather (c).*

The filters used in this exercise clearly help to remove rotational data from the vertical record and do not alter the main primary energy of non-rotational origin. This example can be considered as a test of *Ksphere* capabilities to record the rotational data on both translational and rotational records.

The spatial filters can be re-designed to remove surface waves and any type of noise with rotational behaviour. Optimal filter design should focus on the selected type of seismic noise to suppress where specific wavenumbers and frequencies of interest can be estimated or are known.

Conclusions

Based on the results of this trial we found that the 6C *Ksphere* sensor is fully deployable in a working ocean bottom seismic node, provides direct measurements of translational and rotational components from a single sensor and delivers results according to expectations when compared to equivalent measurements synthesized from the data recorded by the adjacent reference nodes.

Further analysis and processing will be carried out to verify these initial findings. The next step will be to build a larger number of *Ksphere* sensors and identify potential test areas for a mini-3D.

More testing and development will be required to provide a fully commercial implementation, but the early results are encouraging, and clearly indicate that the 6C *Ksphere* sensor could be a fit-for-purpose and cost-effective alternative to existing ocean bottom node sensors.

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