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Coda Octopus[1] ECHOSCOPE PIPE® IHO[2] REPORT[3]

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2 International Hydrographic Organization

Table of Contents

1. Overview

We have now evaluated our latest Echoscope PIPE® Sonar series to establish its performance against the IHO S44 6th Edition standard for hydrographic surveys. A series of surveys was conducted using our state-of-the-art survey setup, including an Echoscope PIPE® XL mounted on an Integrated Pan-and-Tilt (IPT) unit (port-side mount), in combination with a Coda Octopus F280® motion and positioning system with RTK data. This configuration was pole-mounted from the side of our survey vessel, as shown in Figure 1 below.

Figure 1: Survey Vessel Configuration

The surveys were conducted in the Firth of Forth, Edinburgh, at the location shown in Figure 2(a) below. This area has a smooth bottom with a gradual slope, typical of a large estuary, and the water depth at the time of the survey was around 20m. The resulting depth map is also shown in Figure 2(b) below for the 375kHz survey, together with the overlaid survey track lines.

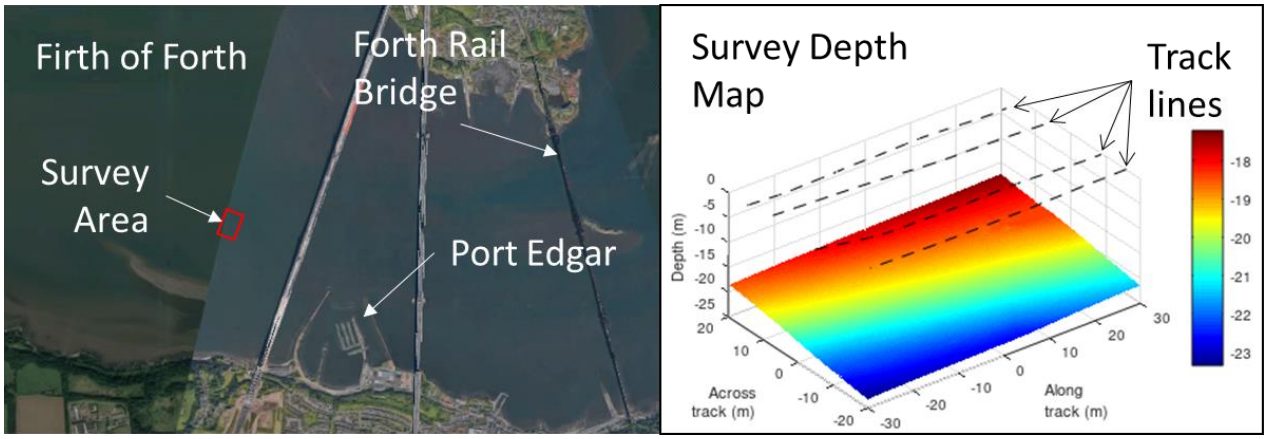

Figure 2: a) Survey Location; b) Echoscope PIPE® Data 375kHz Depth Map

The data from each survey are processed into 10cm square bins (processing consisted of patch testing and then binning the data – no data cleaning was performed), and the statistics computed for the collection of points in each bin. These statistics are compared against the IHO S44 order classification criteria, allowing the precision of the Echoscope PIPE® data to be evaluated.

2. IHO S44 Requirements

The latest IHO S44 standard includes a new Exclusive Order Classification (the strictest classification), which specifies strict limits for Total Vertical Uncertainty (TVU), Bathymetric Coverage, and Feature

Detection, and this is the order against which the Echoscope PIPE® has been evaluated for this report. For the minimum water depth of 17m in these surveys (minimum depth gives the strictest TVU), this gives the following requirements:

Maximum Total Vertical Uncertainty	= 0.20m (for worst case @ 17m)
Minimum Bathymetric Coverage	= 200 %
Feature Detection	= Cubic features > 0.5m

The Echoscope PIPE® can be operated in multiple different orientations, and over a wide range of frequencies.

Two different configurations that are recommended for survey operations are presented here, and these are:

- 375kHz with a 50° x 50° field of view (FoV), and
- 630kHz with a 24° x 24° FoV.

In both cases the Echoscope PIPE® sonar was angled using the IPT to be pointing directly down at the seabed, and the resulting ping shapes are shown schematically in Figure 3 below for each of the two cases. For each case, a 60m x 40m area was surveyed, with approximately 50% overlap between each of the lines.

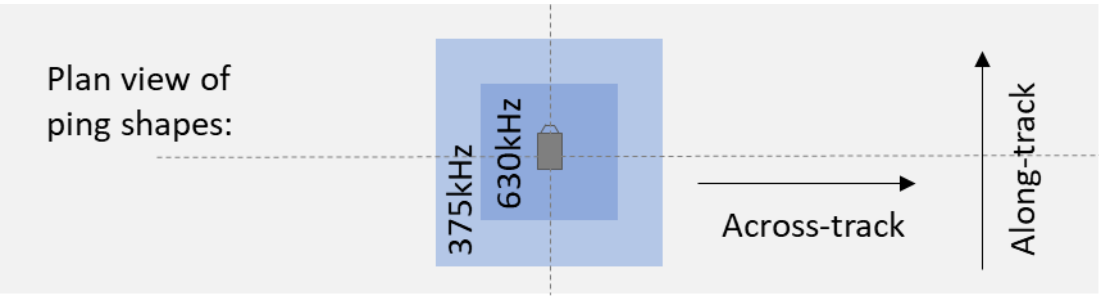

Figure 3: Ping coverage shapes for 375kHz and 630kHz

Note that all the results presented in this report are for MAX beam detection, which returns the range to the point with the maximum intensity on each beam.

3. Total Vertical Uncertainty

The Total Vertical Uncertainty (TVU) is computed using the a posteriori approach as defined in the IHO S44 standard and is given by 1.96 times the vertical standard deviation of the points in each 10cm x 10cm bin. Data for the two surveys are shown in Figure 4 and Figure 5 below:

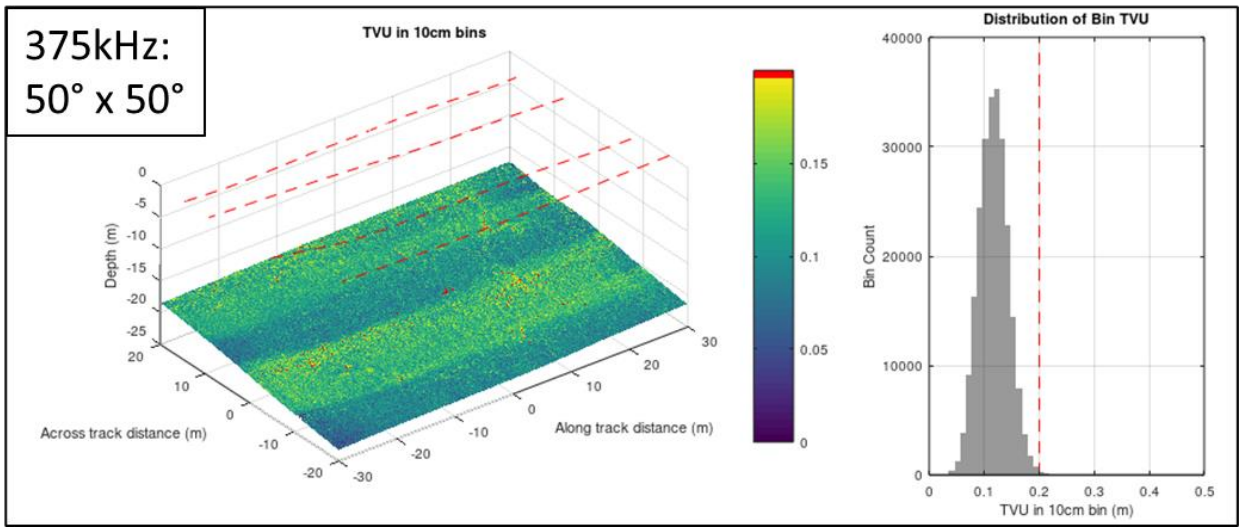

Figure 4: 375kHz TVU Data

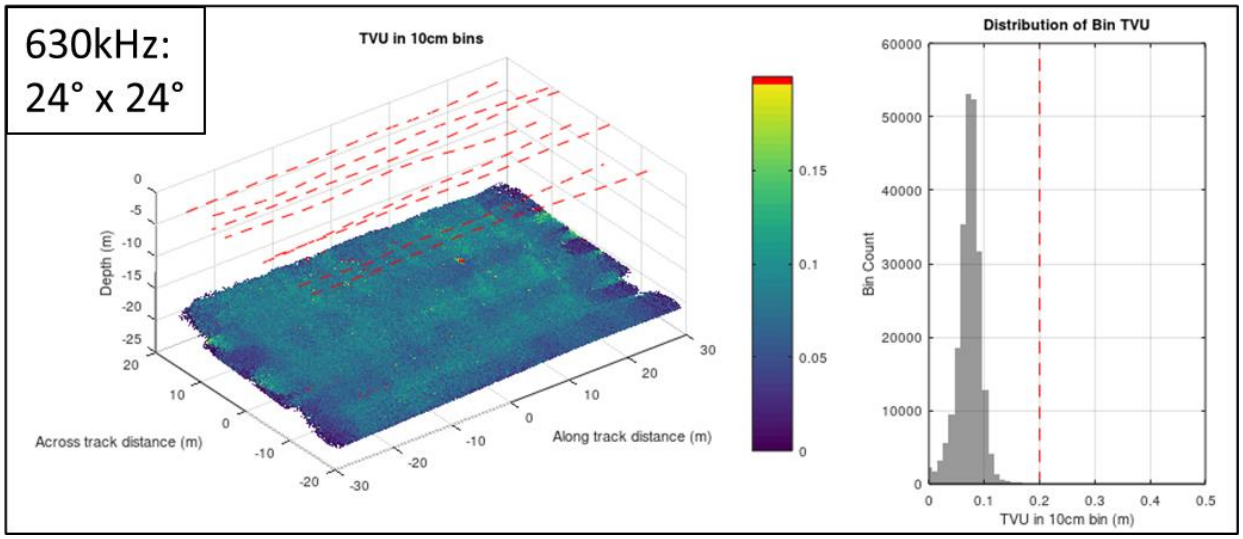

Figure 5: 630kHz TVU Data

In Figure 4 and Figure 5 shown above the left-hand plots show the variation of the TVU in the 10cm bins over the seabed, where the colour scale is set to range from zero to the upper limit for Exclusive Order TVU at 17m depth of 0.20m. The survey track lines are shown by the red-dashed lines in these figures. The right-hand plots show the distribution of the TVU values across all the bins and the vertical dashed-red line again indicates the Exclusive Order TVU limit of 0.20m.

The table below presents a summary of the data shown in the plots above:

Freq. (kHz)	Field of View (deg)	Points (millions)	Mean Points per bin	Mean TVU @95% (m)	Order Classification
375	50 x 50	5.11	21.4	0.117	Exclusive
630	24 x 24	5.88	25.2	0.073	Exclusive

The plots and the summary data clearly demonstrate that the Echoscope PIPE® survey setup comfortably meets the IHO S44 Exclusive Order classification at both frequencies. In fact, at 630kHz the precision of the Echoscope PIPE® sonar is twice as good as is required for Exclusive Order TVU limit.

At both frequencies the plots of the TVU distributions show that there is a slight increase in the TVU where two lines overlap, but that these regions are still well below the limit for Exclusive Order.

4. Bathymetric Coverage

The 3D nature of Echoscope PIPE® output means that a single ping has a much larger extent in the along-track direction than an MBES[4] system and generates multiple points in this direction. By way of illustration, the 630kHz setup has an along-track field-of-view of 24°, meaning that for a water depth of 20m, a vessel speed of 6kts and a ping rate of 10Hz each section of seabed is still hit by three pings, as shown in the schematic below (Figure 6):

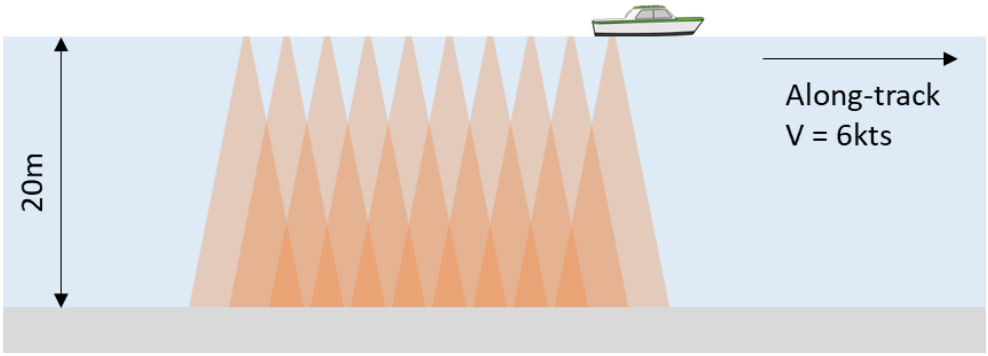

Figure 6: Along-Track Ping Overlap for 630kHz Coverage

In the example shown in Figure 6, the coverage is 300% for a single pass of the vessel, and this value will be much higher for configurations with greater FoV in the along-track direction. This means that it is never necessary to overlap lines to meet the coverage requirement. It may also mean that higher vessel speeds are possible while still meeting the bathymetric coverage requirement.

It is worth noting at this point that the IHO S44 standard is written for MBES systems and does not always recognise the advantage of the fully 3D beamformed output from the Echoscope PIPE® systems. This is highlighted by the discussion of coverage percentages, presented above.

5. Feature Detection

The extremely large number of beams generated by the Echoscope PIPE® makes feature detection one of its biggest strengths. The fact that the fore and aft beams are angled away from the vertical also means that the system can resolve one or more vertical surfaces better than a standard MBES system. This further enhances its ability to unambiguously detect objects on the seabed.

In the lower resolution mode, operating at 375kHz, the Echoscope PIPE® has a beamwidth of less than 1.2°, meaning that in 20m water depth it could easily resolve a 0.4m cubic feature. At 630kHz the beamwidth is 0.7°, allowing the system to resolve cubic features as small as 0.25m in this water depth. In both cases, the system comfortably exceeds the IHO S44 Exclusive Order requirement.

This excellent feature detection capability of the Echoscope PIPE® system is clearly demonstrated in the data from recent 375kHz surveys shown in Figure 7 below. The images present two surveys with a view looking straight down onto of rock jetty and seabed with debris and tires, with the images coloured to show the depth of the objects. The other images show both horizontal feature detection on the

[4] Multibeam Echosounder System

seabed with excellent vertical surface detection of the complex pile structure and ladder in the background. All images show feature detection of objects from 8cm upwards. Each of the detected targets have 10's to 100's of beams on the surface which demonstrates the exceptional capability of the Echoscope PIPE® volumetric imaging capability.

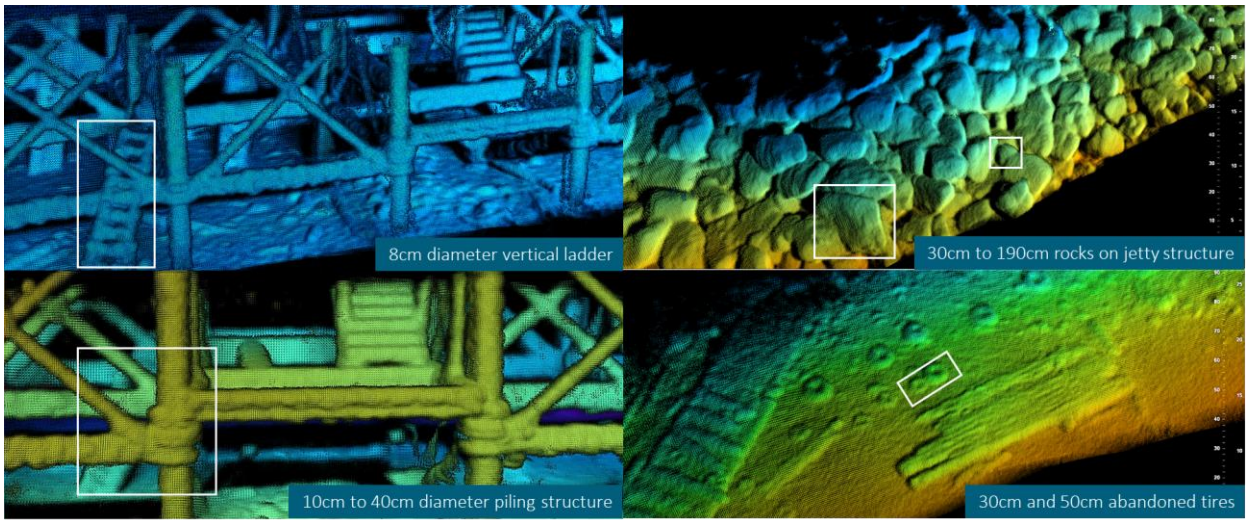

Figure 7: Examples of Feature Detection in Echoscope PIPE® data

6. Conclusion

For both frequencies evaluated in this report, the Echoscope PIPE® system easily satisfies the IHO S44 Exclusive Order requirements under what can be regarded as typical survey conditions. The mean Total Vertical Uncertainty falls well below the required threshold in both cases, and at 630kHz the TVU precision is more than twice as good as the required standard. Bathymetric coverage and feature detection are where the Echoscope PIPE® is most capable, and it easily meets the IHO S44 Exclusive Order standard, even in the lower resolution, 375kHz configuration.