Qualifying Interferometric Swath Bathymetry Data for Charting

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Principles of Interferometry

- Transmits short acoustic pulse in beam:
  - narrow along track
  - wide across track
- Receives backscattered signal
- Measurement of range and angle:
  - Range from timing
  - Angle by comparing phases at vertically-spaced transducer staves
- Depth calculated from range, angle and transducer motion
- Similar range coverage and data density to a sidescan sonar system
- Amplitude image is equal to that of a sidescan-only sonar system
Benefits of Interferometry

• Wide swath width in shallow water or low altitude:
  USGS: “Operating Swath of the bathymetric system ranged from 15 to 20 times water depth in depths less than 15m.”

• Co-registered, high quality bathymetry and seafloor imagery
• High data count gives high spatial resolution up to the swath edge
• Low cost of ownership compared with most beamforming multibeams
• Lightweight, compact, lower power requirement and highly portable - facilitates simple and rapid deployment
• Reduced survey effort and data turn-around times
• Data exportable to industry-standard applications, such as CARIS
• Meets international data standards, such as IHO survey requirements
Very Small Platforms

- Variants designed and built for specific applications:
  - Hydroid REMUS 100 AUV
  - Hafmynd Gavia AUV
  - JetSWATH: Jetski
  - Inspection-class ROVs
  - Watertight system for small open vessels (“SWATHplus-SPLASH”)
JetSWATH

- Developed together with ITER, France
- Modified Bombardier jet ski (personal watercraft)
- Integrated SWATHplus swath bathymetry system
- Full range of position, motion, navigation and speed of sound sensors
- Aluminium hull designed for shallow surveys in tough environments
- Waterproof console situated at the craft’s steering column
- Compact and portable: easy, rapid deployment
Shallow survey with small AUVs

- Rapid setting to work: AUV is a self-contained unit
- Can reach places where surface vessels cannot go: e.g. close to platforms and underwater structures
- Surface vessel can continue its survey work whilst AUV is operating: cost-effective
- Can optimise altitude and stand-off
- Can track pipelines and similar features
- Fine track control and short turns
- More stable than surface ships in poor weather
RS100-REMUS Data

- North Sea platform surveyed with RS100 on REMUS

Acknowledgement and thanks to Hydroid and NAM – no product approval implied
Data Quality Analysis

- Interferometric swath bathymetry systems give many data points per side (2000 to 8000)
- Uncertainty of raw data points usually greater than that of beam-forming multibeams (100 to 200 points per side)
- Software filtering reduces uncertainty to internationally acceptable survey limits,
  - at the expense of survey resolution

Cross-profile depth plot

spread of raw data

white = filtered

red = rejected

nadir

transducers
1. Establish the statistical data quality requirement (IHO S44):
   • Accuracy: Total Propagated Uncertainty (TPU)
   • Resolution (detection of small objects)
   • Data coverage (accepted points per metre)
   • The first parameter can be traded off against the other two, using statistical processing
2. Analyse real data to see whether it can fall within stated limits for these two parameters, with suitable processing
3. Create an error model, and validate it against the real data
4. Use the error model to explore the limits of conformity with accuracy requirements
Data Sets Analysed

- From SWATHplus “Shallow Survey 08” Common Data Set
- Published on the internet by the Shallow Survey conference team
- Collected by USGS, using their own SWATHplus systems, and using normal operational survey procedures (speed, line spacing, etc.)
- All three SWATHplus frequencies used: 468kHz, 234kHz & 117kHz
- Most common commercially-available swath bathymetry systems, MBES and interferometers, were used over the same data area, in similar survey conditions
Typical “Ping”: 234kHz

- Plot of depth vs. horizontal range
- Blue: raw data
- Red: smoothed to IHO S44 resolution requirement
Raw Data Estimated Error, 234kHz

- Plot of depth error in raw data vs. horizontal range
- Vertical uncertainty (error) in raw data estimated using depth variance from highly smoothed profile
Filtered Data Uncertainty, 234kHz

- Plot of depth uncertainty of **filtered** data vs. horizontal range
- Data smoothed at a level to maintain IHO points-per-m² criterion
- Represented as 95% uncertainty, in line with IHO S44 specification, over a second sliding window

nadir

“sweet spot”
Error Model Validation, 234 kHz

- 95% uncertainty averaged over many “pings” and compared with model, 234kHz
- Blue: model
- Red: average uncertainty of real data
Error Model Validation, 468kHz

- The same as the previous slide, for 468kHz data
Range vs. Depth for Special Order

- Range at which IHO S44 Special Order is just met plotted against range
- Computed from validated model
- Marked points derived from real data
Error Analysis Summary

- Statistical variance of raw, un-processed interferometric data is in excess of IHO S44 requirements
- However, spatial resolution of interferometric data is far in excess of that called for in S44
- Simple statistical processing, as provided by SWATHplus and third-party software, brings interferometric data within S44 accuracy and resolution envelopes at good swath widths
- So:
  - **Interferometric swath bathymetry sonars can meet IHO S44 accuracy requirements**
Qualifying Data for Charting

• When collecting data for type-approved charts,
  • the approval authority checks that data collected meets data quality requirements:
  • must agree methods for surveying and data processing to support those checks
• Concepts designed in discussion with the United Kingdom Hydrographic Office (UKHO) and Maritime and Coastguard Agency (MCA), with Fathoms Ltd.
• No automatic approval of these or any other approval authority can be assumed; discussions may be required with the approval authority for each new case
Data Quality is defined by IHO S44. This defines:
- Total propagated uncertainty (TPU),
- Resolution (detection of small objects),
- Data coverage (accepted soundings per metre)

The TPU is reduced using filters,
- but these filters will also reduce effective resolution and data coverage statistics

SWATHplus software filter settings
IHO S44 refers to “soundings” to mean individual depth measurements. I propose that raw interferometric data samples are not “soundings” in this sense:

- any more than the raw electronic data recorded by other sonars, for example before beam-forming.

Rather, a “sounding” is a depth measurement after all statistical filtering and combination, as delivered to the authority for approval.
Requirements for Approval

• To achieve approval of data for charting, the following need to be ensured:
  1) The filters are set so that the statistical variation (TPU) of the data is constrained:
     • this is also a factor of the sonar range
  2) The filter settings are not so wide that the resolution and data coverage criteria are no longer met
  3) It can be shown that filter settings used for a particular data set were appropriate for the above
Qualifying Uncertainty

- Checked in delivered data by the approval authority using data quality tools in charting software
- In real time and immediate processing, use data quality displays

SWATHplus software views
Qualifying Resolution

- Compare spatial properties of filters with resolution requirements of the survey standards
- E.g., need 9 samples per square metre,
  - Nominal 3 pings per metre along-track
  - No less than 3 samples per metre across-track
Validating the Settings

• “Black box” approach:
  • settings of the sonar and filters locked into one “approved” state and never changed
  • … **but** this is likely to reduce survey efficiency and accuracy
• Modified version:
  1. surveyor selects the best settings for the sonar and filters
  2. “lock” these settings in software
     • settings are written to a log file
     • all changes must be approved
  3. settings log files are time-stamped
     • can easily be compared with delivered data sets

*SWATHplus software*

/settings lock
Conclusions

- Interferometry gives significant advantages, particularly in shallow water and on small survey platforms
- Order of magnitude more data points are provided, but statistical variation of the points is similarly greater
- Suitable data processing can reduce this statistical variation to within internationally accepted limits, whilst retaining the required spatial resolution
- A method for demonstrating that resolution and accuracy criteria are met in data provided for charting purposes has been agreed with UK charting authorities
Questions?
Annex

• Further slides for information and discussion
Principles of Interferometry

The returning acoustic wave reaches each receive element fractions of a second apart measured as a phase difference.
Qualifying Uncertainty

- Post processing, data quality displays
Qualifying Coverage: nadir

- Data density at nadir is lower than elsewhere

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- Can add to nadir by using a third, forward-looking transducer

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Cross-profile depth plot

nadir: lower data density

>5m range: high data density

Real-time survey coverage plot
Qualifying Coverage: nadir

- Data density plots
- Note that there are very few empty 1-metre bins with the two-transducer system

Two-transducer data density plot: 
samples per 1-metre bin

Three-transducer data density plot. Colour scale same as two-transducer plot