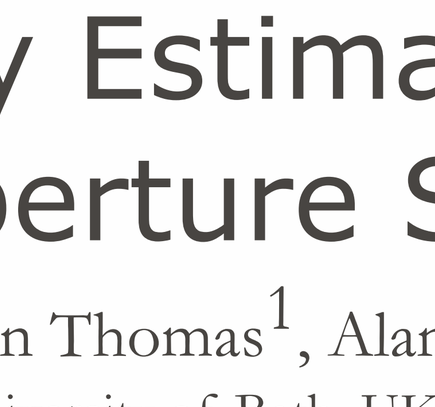
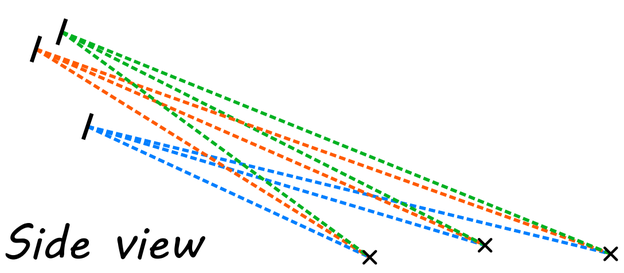
Time Delay Estimation for Repeat-pass Synthetic Aperture Sonar Micro-navigation

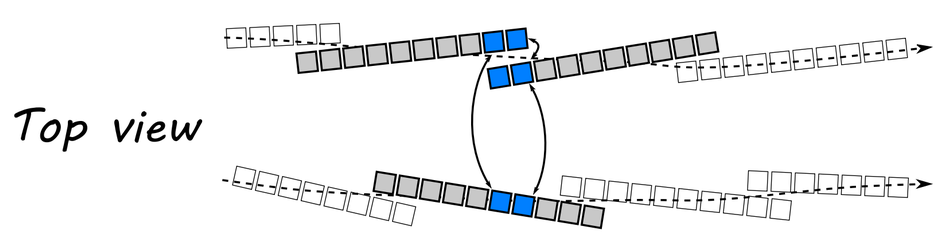
Benjamin Thomas[1], Alan Hunter[1], Samantha Dugelay[2]
1 - University of Bath, UK 2 - NATO-STO CMRE, IT

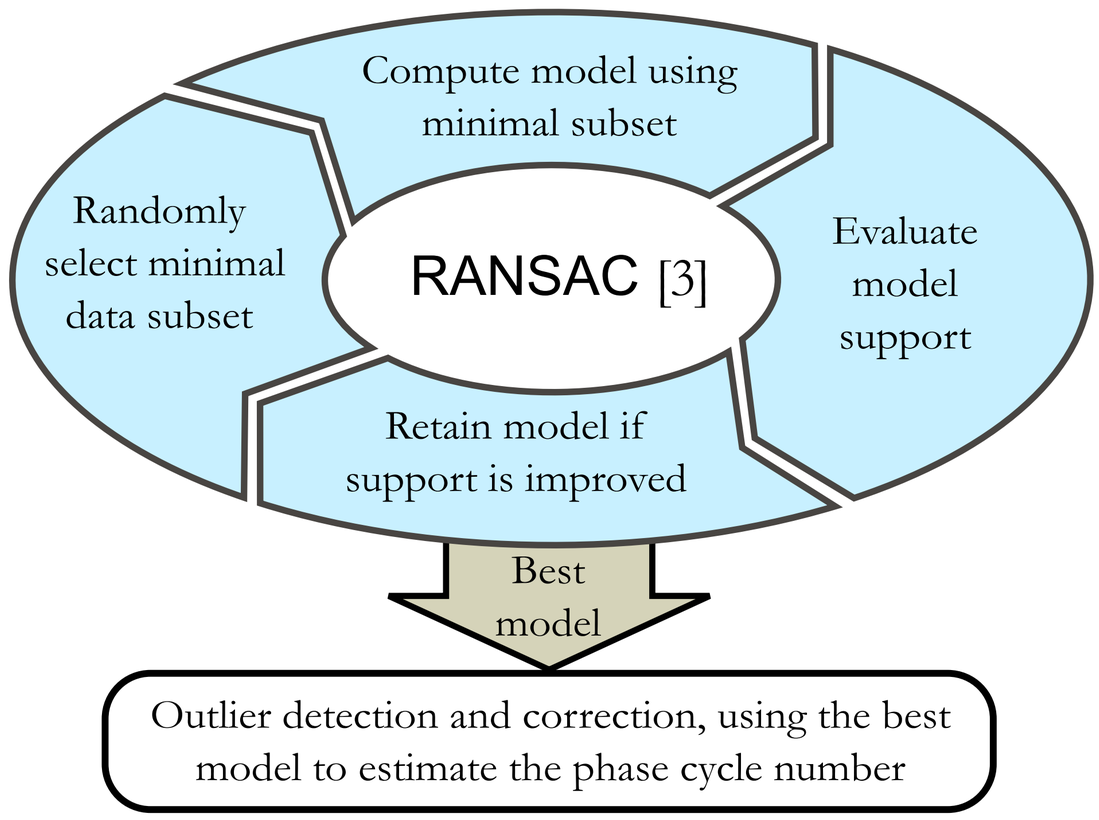
Repeat-pass micro-navigation

- Sub-wavelength precision through the sensor navigation estimation
- Simultaneous estimation of navigation and bathymetry [1]
- Exploits time delays between signals measured at overlapping arrays within and between passes
- Time delay is a function of navigation, bathymetry and medium propagation speed







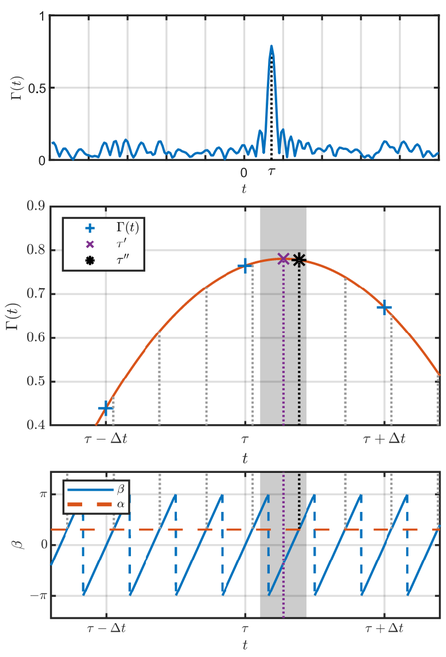


Outlier detection and correction, using the best model to estimate the phase cycle number

Time delay estimation

Cross-correlate signals → Get peak phase and position

Parabolic peak interpolation → Refine estimate using phase



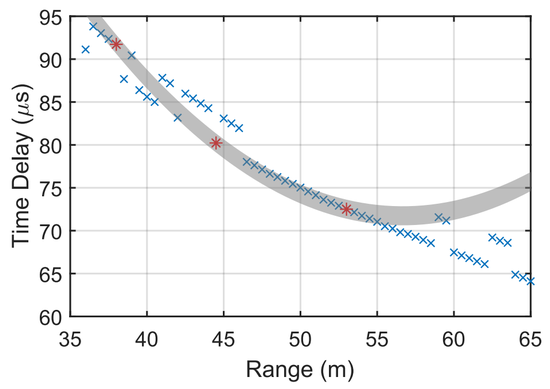
$$\tau_f = \left(-\frac{\alpha}{2\pi} + M\right)\frac{1}{f_c} \quad [2]$$

Sub-wavelength delay

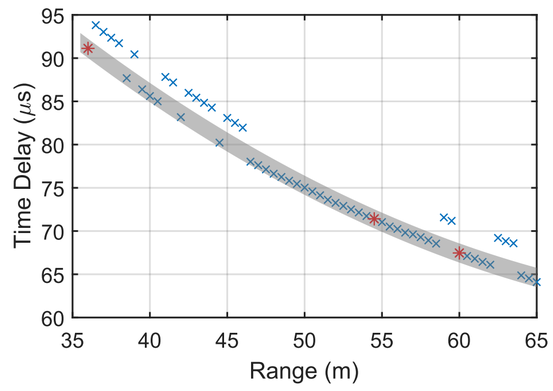
Integer phase cycle number

- Noise causes errors in the integer phase cycle number estimate
- Time delay estimates are made at many range windows
- Time delays vary smoothly in along- and across-track directions
- Phase cycle number errors are detected by fitting a model using RANSAC
- The outlier phase cycle numbers are re-estimated using the model

Example RANSAC iterations

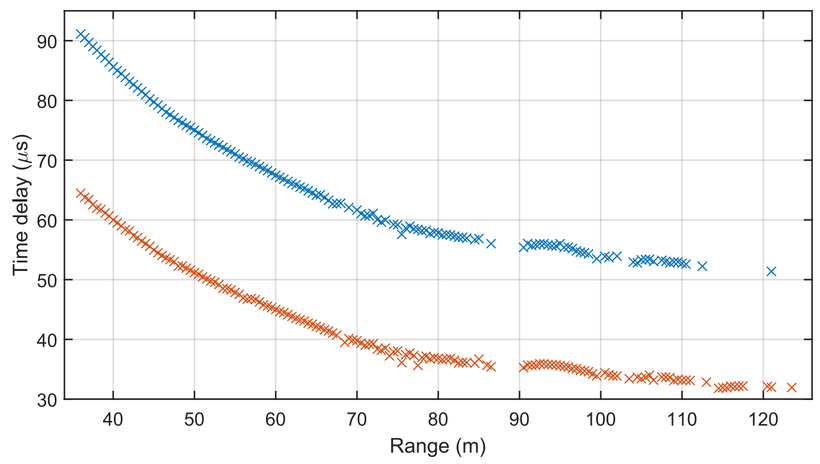


- Minimal subset includes an outlier
- Resulting model has poor support



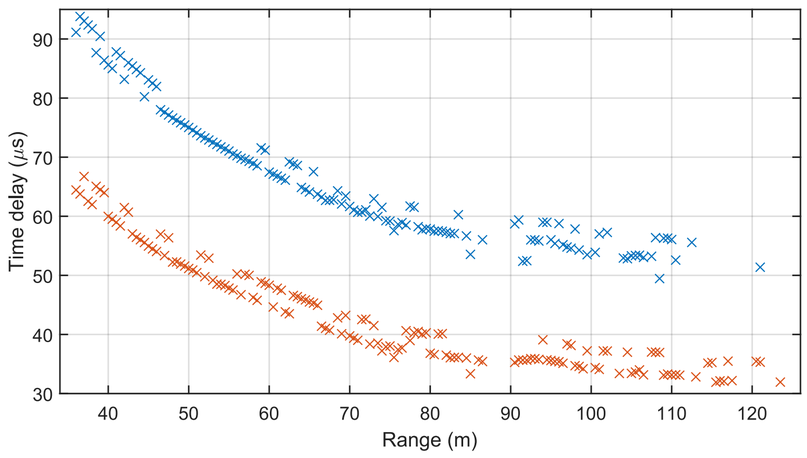
- Minimal subset includes only inliers
- Resulting model has good support

Resulting time delay estimates



- The phase cycle numbers of outliers have been adjusted to fit the majority
- The resulting time delays can be used for repeat-pass micro-navigation
- 2D models can be used to additionally exploit the smoothness of the time delay estimates along the track

Inter-pass time delay measurements



- Each ping forms at least two inter-pass redundant phase centre arrays.
- Example of repeat-pass time delays from the 270-330 kHz SAS of the CMRE MUSCLE AUV. Smoothly varying time delays are expected.
- Phase cycle number errors corrupt time delay estimates.

References

[1] B. Thomas, A. J. Hunter, and S. Dugelay, "Repeat-pass micro-navigation and bathymetry estimation using interferometric synthetic aperture sonar," in IOA Synthetic Aperture Sonar and Synthetic Aperture Radar, Italy, 2018.

[2] D. A. Cook, "Synthetic Aperture Sonar Motion Estimation and Compensation," Georgia Institute of Technology, 2007.

[3] M. A. Fischler and R. C. Bolles, "Random sample consensus: a paradigm for model fitting with applications to image analysis and automated cartography," Commun. ACM, vol. 24, no. 6, pp. 381–395, 1981.

Acknowledgement

The authors would like to thank the Centre for Maritime Research and Experimentation for the MANEX'14 data and the Autonomous Mine Countermeasures team scientists, engineers and the crew of NRV Alliance for their support in collecting the data. The trial and CMRE's work are funded by the NATO Allied Command Transformation.