Hydrographic Multibeam Processing System (HMPS) Swath Alignment Tool

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Abstract

The Mapping, Charting, and Geodesy Branch of the Naval Research Laboratory has developed software for the determination of system alignment errors and the verification of system performance for fixed-mount multibeam swath sonar systems. The HMPS Swath Alignment Tool is designed to work with Generic Sensor Format (GSF) data files now in use by the U.S. Naval Oceanographic Office for the processing of hydrographic sonar data. The use of GSF allows the software to be used for the identification of alignment errors on various swath sonar systems without modification. The software has been used successfully with USNS Pathfinder (T-AGS 60) Simrad EM-121A data, Oceanographic Remotely Controlled Automaton (ORCA) Simrad EM-1000 data, and with Reson Seabat 9001 data collected during the 1996 United States/Canada Hydrographic Commission Coastal Multibeam Training Course.

The alignment software has been designed in a modular fashion using standard programming languages and techniques. It has been tested on several computer systems, including Silicon Graphics, Hewlett-Packard, DEC Alpha, and Sun workstations. It has also been ported to a Pentium PC computer system running Linux. It can be used at sea for the determination of system alignment errors before beginning a survey, during a survey as a means of quality control, and ashore during post processing to verify proper system performance.

Résumé

La section Mapping, Charting and Geodesy du Naval Research Laboratory a développé un logiciel pour la détermination des erreurs d'alignement et pour la vérification de performance de systèmes échosondeurs multifaisceaux montés rigidement. Le HMPS Swath Alignment Tool a été conçu pour fonctionner avec des fichiers en format Generic Sensor Format (GSF), actuellement en usage par le U.S. Naval Oceanographic Office pour le traitement de données hydrographiques sonar. L'utilisation du GSF permet au logiciel d'être un moyen d'identification d'erreurs d'alignement sur divers systèmes sonar sans modification préalable. Le logiciel a fonctionné avec succès sur des données provenant des systèmes USNSPathfinder (T-AGS 60), Simrad EM121A, Oceanographic Remotely Controlled Automaton (ORCA), Simrad EM1000 et Reson Seabat 9001, données acquises lors du Multibeam Training Course de la comission hydrographique États-Unis/Canada en 1996.

Le logiciel d'alignement a été conçu de façon modulaire utilisant des langages et techniques de programmation standards. Il a été testé sur différents systèmes informatiques, incluant Silicon Graphics, Hewlett-Packard, DEC Alpha et des stations de travail SUN. Il a été également exporté sur Pentium PC doté du système LINUX. Il peut être utilisé en mer pour la détermination des erreurs du système avant le début d'une mission, durant une mission en tant qu'outil de contrôle de qualité, et à terre lors de traitement en temps différé pour la vérification des performances du système.

Introduction

In order to accurately position multibeam sonar soundings on the ocean floor, it is necessary to precisely know each of the following:

- horizontal position of the transducer
- attitude of the transducer (roll, pitch and heading)
- elevation of the transducer (heave and tide)
- speed of sound through the water column

Traditional single-beam surveys normally include corrections to sonar beam positioning due to tide and heave, but sometimes ignore the effects of vessel attitude. As both horizontal and vertical positioning become increasingly more accurate (differential and kinematic GPS), knowledge of the vessel's attitude becomes critical for accurate positioning of sonar beams on the ocean floor. The increased path lengths of the outer beams in a multibeam system result in greater errors due to ray bending and require a more detailed knowledge of sound speed through the water column.

The multibeam sonar system alignment software described here is intended to aid the hydrographer in determining sensor misalignments and timing errors and assumes that factors such as tide, heave, and the speed of sound are accurately known.

Horizontal Positioning Errors

With a narrow beam sonar such as the Reson Seabat or Simrad EM-series, it is possible to resolve features as small as 5m on the seafloor [Hughes Clarke, 1996]. In order to take full advantage of this capability, it is necessary to accurately position the survey vessel to within a few meters. In very shallow water, even differential GPS will not provide sufficient positioning accuracy for offset determination, and kinematic GPS is required. An accurate determination of antenna and transducer offsets from the reference position is assumed in the following discussion.

Timing Errors

Proper horizontal positioning of the transducer is dependent on accurate measurement of sensor offsets and on proper synchronization of the positioning and sonar clocks. In addition, computational delays within the sonar processing software may produce errors even if both clocks are well synchronized. A timing offset of 0.5 seconds between the positioning system and the sonar processing system will produce an error of about 2.5m at typical ORCA survey speeds (about 12 knots). This error increases with survey vessel speed and will exceed 5m at typical surface vessel speeds (about 20 knots). Timing errors produce a positioning error, which is independent of water depth, but directly related to vessel speed.

Attitude Errors

Errors in alignment between the sonar transducer and the inertial measuring unit. will result in positioning errors and depth measurement errors. Errors in alignment between the transducer and the gyrocompass will result in incorrectly positioned beams.

Pitch misalignments introduce errors in both the measured depth and in the positioning of the sounding. This error is usually the same within a ping or swath (depending on sonar transducer geometry) and increases with water depth. Pitch alignment errors can be difficult to distinguish from timing errors, but tend to dominate in deep water.

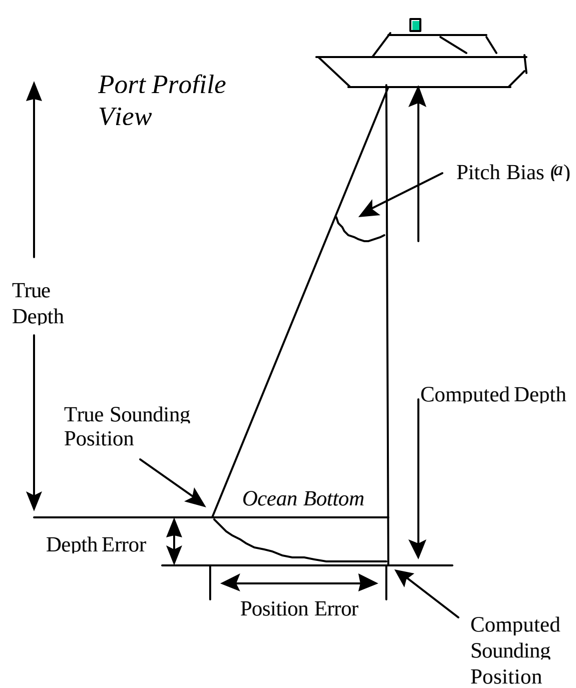

Figure 1. *Error induced by pitch misalignments. Note that this type of error will increase as the water depth increases.*

A roll misalignment introduces both an error in depth measurement and an error in positioning. The error induced by a roll misalignment, or "roll bias," is greater in the outer beams and also increases with water depth.

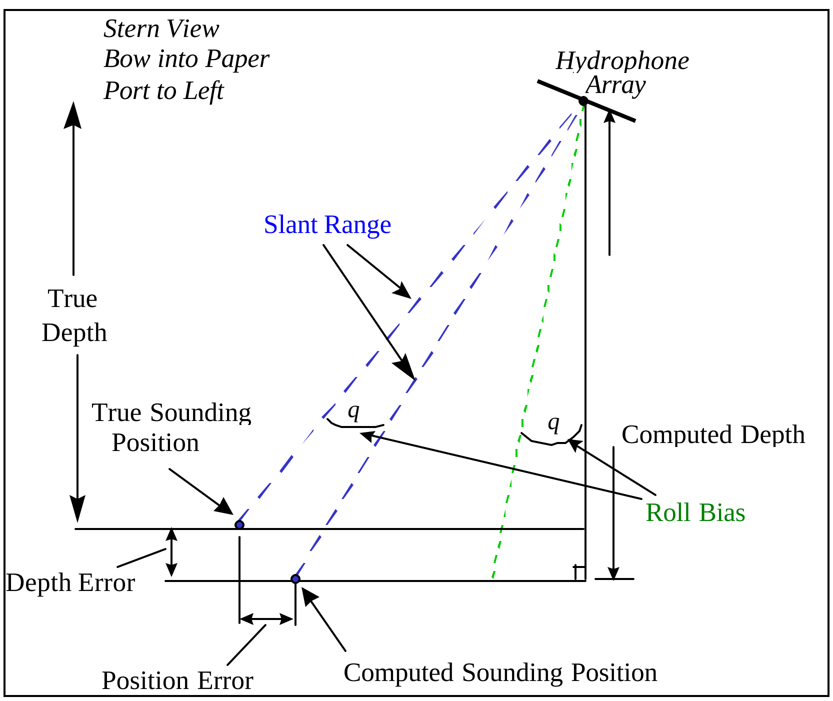

Figure 2. *The error induced by a roll misalignment.*

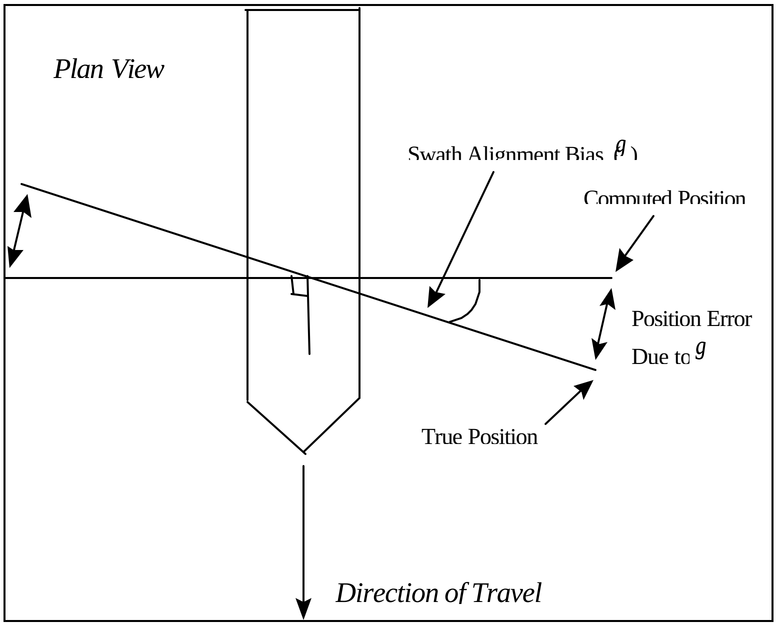

Figure 3. *Horizontal positioning error induced by a gyrocompass or transducer heading alignment error.*

A misalignment between the gyrocompass and the sonar transducer produces a horizontal positioning error but does not affect the measured depth. Errors in misalignment of the pitch and roll sensor (Vertical Reference Unit, VRU) induce cross talk errors which affect pitch and roll measurements. This discussion assumes that VRU alignment errors are negligible.

Vertical Positioning Errors

Vertical positioning errors, or elevation errors, are those caused by incorrect application of tide or vessel draft and heave. Factors such as the location of the tide station and changes in the survey vessel's trim while underway (lift and squat) are as important here as in single-beam surveys. However, it is easier to detect such errors during a multibeam survey with overlapping swaths. The alignment procedures described in this report assume that these corrections have been properly applied.

Sound Speed Errors

The propagation of sound in the ocean is distorted as a result of spatial and temporal variations in water column characteristics. It is important to have accurate knowledge of the water column in the area of the survey and at the time of the survey. The alignment procedures described in this report assume that accurate, timely sound speed information has been used in sonar computations.

Operation of the Swath Alignment Tool

The algorithms developed for the HMPS Swath Alignment Tool assume a single sonar transducer is in use. The determination of alignment errors for dual-transducer systems, such as the Honeywell ELAC or Hydrochart II systems, would require each transducer (port and starboard) to be treated separately.

Each test requires a specific set of lines to be run under different conditions. The accuracy of the alignment error estimates is directly related to the quality of the survey lines. It is important to follow standard survey procedures very carefully. Vessel turns must be made early, allowing time for inertial systems to settle. Vessel heading and vessel speed must be held constant. Finally, accurate sensor offsets (antenna, transducer, inertial measuring unit, and draft) must be applied, and accurate and timely sound speed profiles must be used in processing the acoustic data.

The Swath Alignment Tool uses two windows; the first window displays a geographical display of color-coded depth data (Figure 5), while the second window displays an X-Y plot of depth versus distance (Figure 6). After using a standard file selection box to choose the appropriate two lines to be analyzed, color-coded depth data is displayed in the first window. A "slice" of data is chosen by clicking and dragging a line through the color-coded swaths and the corresponding depth profiles are then plotted in the second window. (If necessary, the plot scales may be adjusted using the buttons provided.) Adjusting the timing, pitch, roll or gyro sliders (Figure 4) causes a recomputation of the depth profiles, which are automatically replotted. The sliders are adjusted until the two depth profiles exactly coincide. At this point the alignment error value may be read directly from the slider.

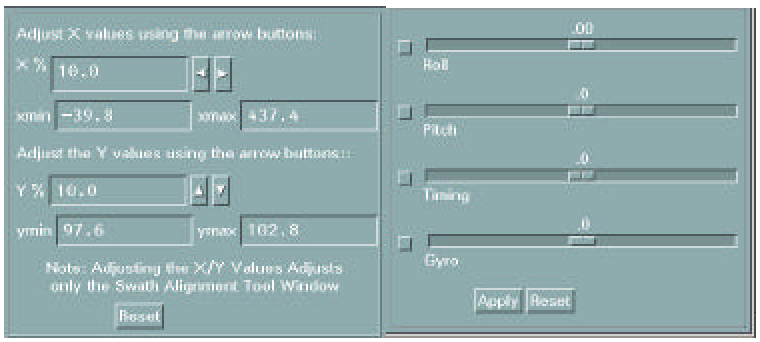

Figure 4. *"Sliders" are used to adjust vessel attitude offset values.*

It is important to perform the alignment tests in the proper order. Pitch and timing errors are closely related, making distinguishing between the two difficult. Timing offsets cause an error in depth measurement that is independent of water depth and can also *seem* to introduce a positioning error. For this reason, it is sometimes difficult to distinguish a timing error from a pitch alignment error. The timing alignment test should be performed first, followed by the pitch alignment test, the roll bias estimation and the heading (gyro) error estimation.

Timing Offset

Measurement errors in the along-ship direction due to timing errors or processing delays are determined by comparing coincident or reciprocal lines run at different speeds. These lines must be run over a significant feature or over a sloped bottom. An apparent shift in the position of the feature or slope indicates a timing offset, which is then estimated using the difference in geographical position and difference in vessel speed.

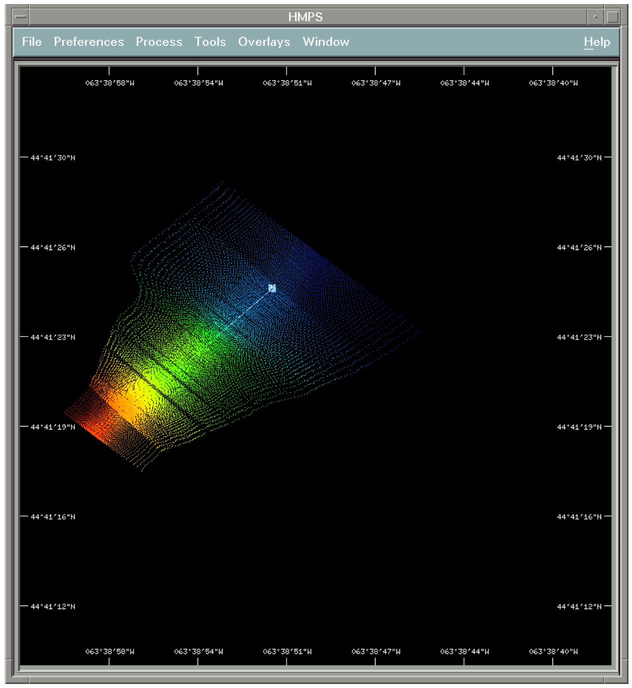

Figure 5. *Survey lines used for timing offset estimation should be run perpendicular to a steep slope or over a significant feature. Lines should be run in opposite directions in order to maximize timing differences. Alternatively, lines may be run in the same direction but at very different speeds. These lines are from the CSS Frederick G. Creed using a Simrad EM-1000 sonar.*

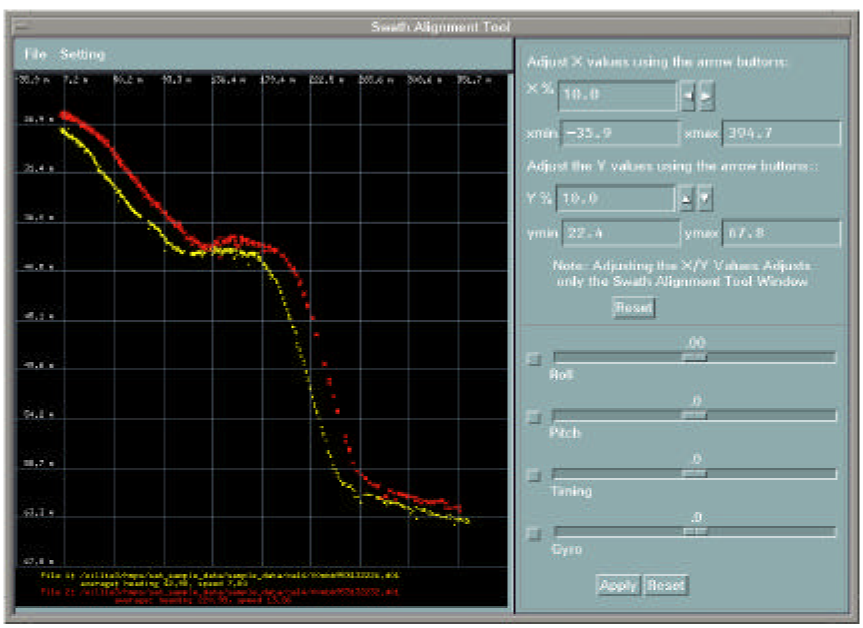

Figure 6. *Depth profiles from reciprocal lines run over a sloped area. These profiles indicate a timing error in the data.*

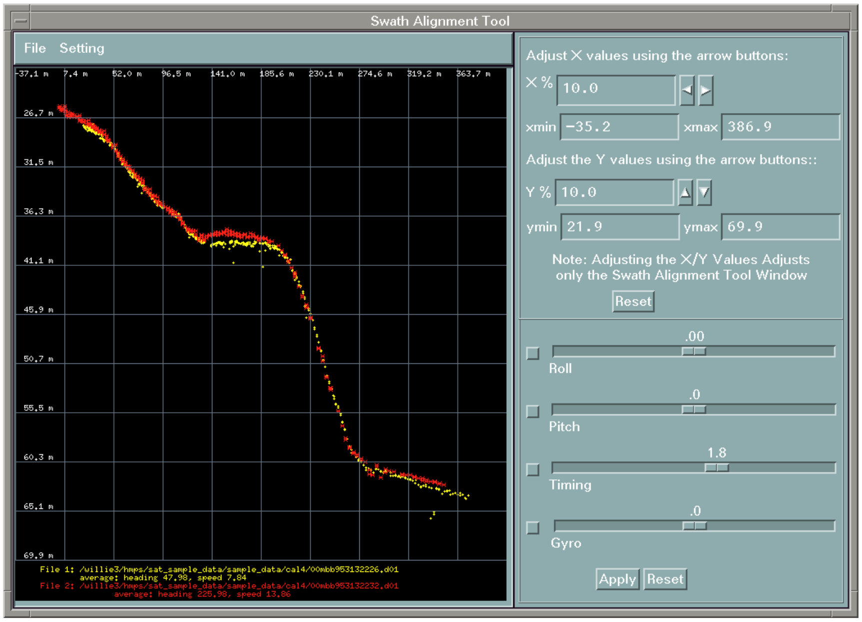

Figure 7. *A timing correction of 1.8 seconds is applied using the "Timing" slider.*

Pitch Alignment

Measurement errors in the along-ship direction due to pitch angle misalignment are determined using a method derived from the National Oceanic and Atmospheric Administration (NOAA) "patch test" [Herlihy, 1989]. This method requires that a set of parallel lines is run in opposite directions over a uniform slope. The horizontal distance between points of corresponding depth and that depth itself are then used to estimate the alignment error in pitch angle. Figure 8 illustrates this method.

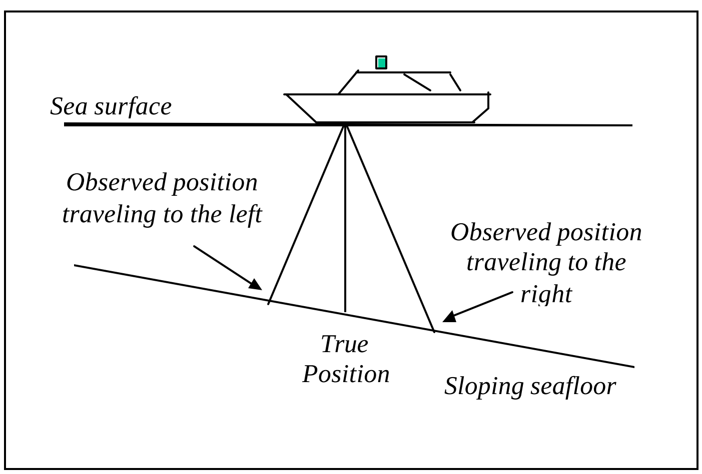

Figure 8. *A vessel with its bow pitched up will observe a given depth ahead of its true position as indicated here (vessel moving to the left). Here the measured depth would be less than the true depth, and there would be a horizontal positioning error. If the vessel reverses course, the measured depth would be greater than the true depth, and the positioning error would be in the opposite direction.*

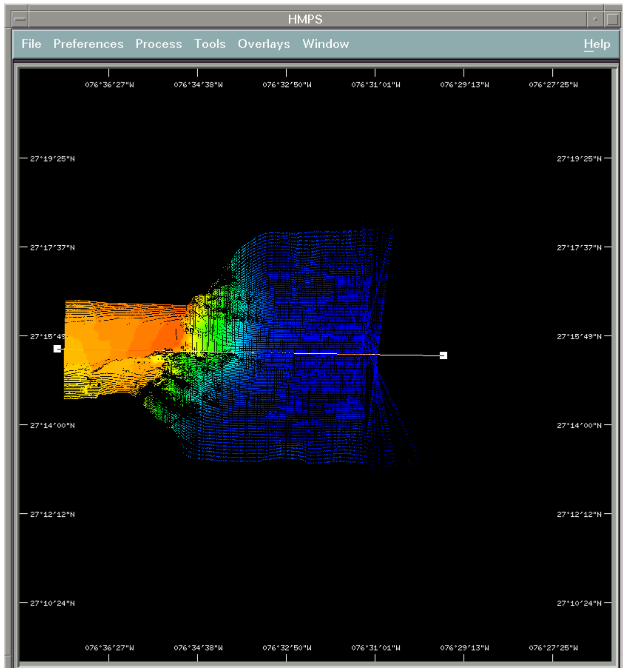

Figure 9. *The survey lines used for timing error estimation may also used to estimate the pitch angle offset. Since pitch and timing errors are difficult to distinguish and pitch errors dominate over timing errors in deep water, the lines used for pitch misalignment estimation should be run in the deepest water possible. These lines are from the USNS Pathfinder in about 4000 meters of water using a Simrad EM-121A.*

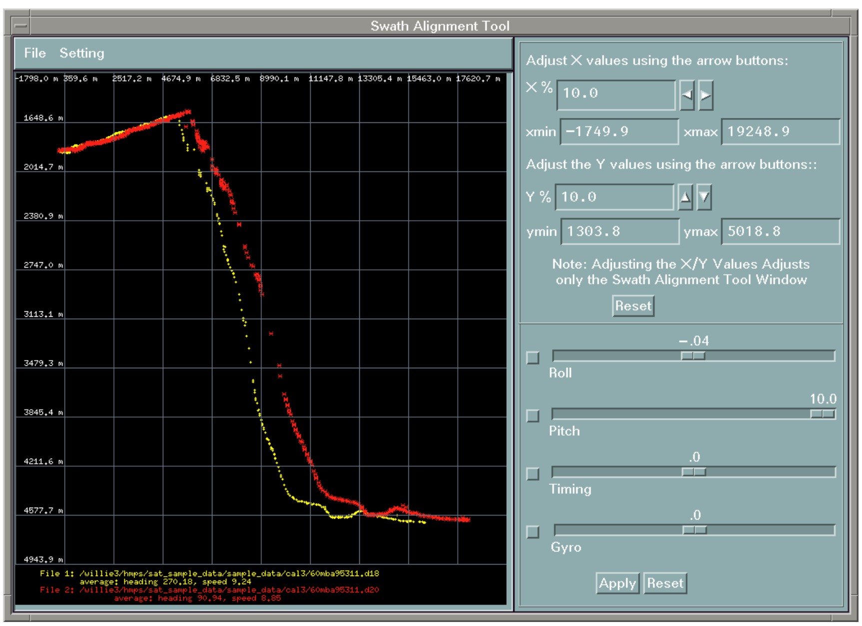

Figure 10. *These depth profiles indicate an artificially induced pitch error of 10 degrees. Note that the error increases with water depth.*

Roll Alignment

Errors in roll alignment, or "roll bias," are determined using reciprocal survey lines run over a flat area. The roll bias is estimated by comparing the port and starboard depth values for a series of overlapping sonar pings, as illustrated in Figure 11.

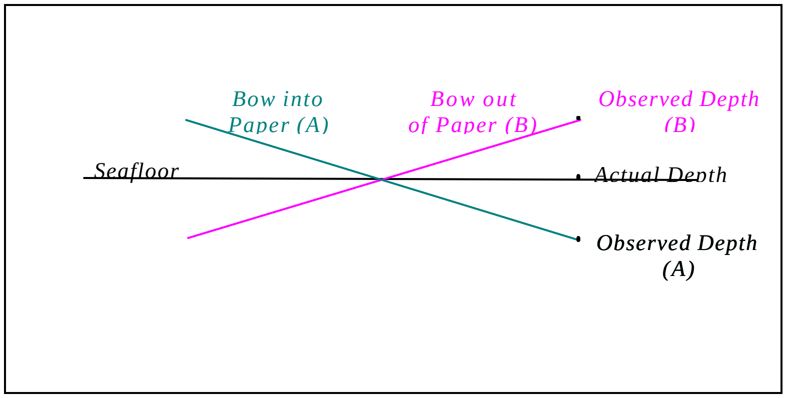

Figure 11. *Swath orientation for a vessel with a roll offset to starboard. When traveling with the bow into the paper, depths on the starboard side are measured greater than their actual values, while depths of the port side are less than actual values. When the vessel reverses course, an "X" is formed by the overlap of the two swaths. When the offset is zero, this "X" becomes a straight line.*

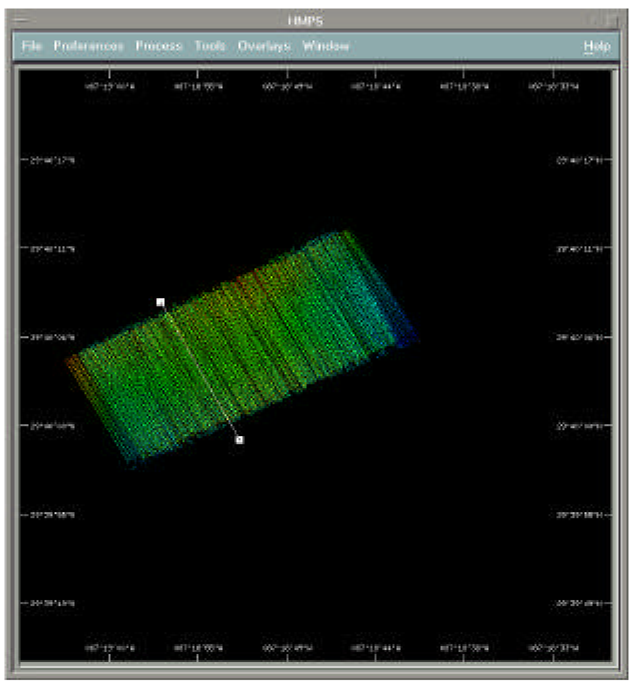

Figure 12. *The roll bias is estimated using lines that overlay and are run in reciprocal directions over a flat bottom. A short along-track distance is selected to be used for computation. These lines are from the NRL Oceanographic Remotely Controlled Automaton (ORCA) using a Simrad EM-950 sonar.*

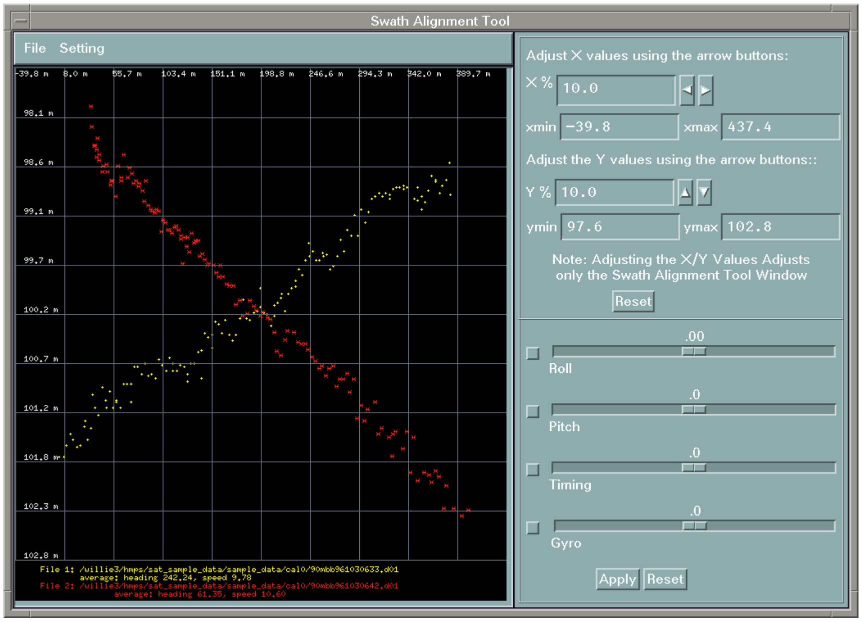

__Figure 13.__ These profiles indicate a roll alignment error.

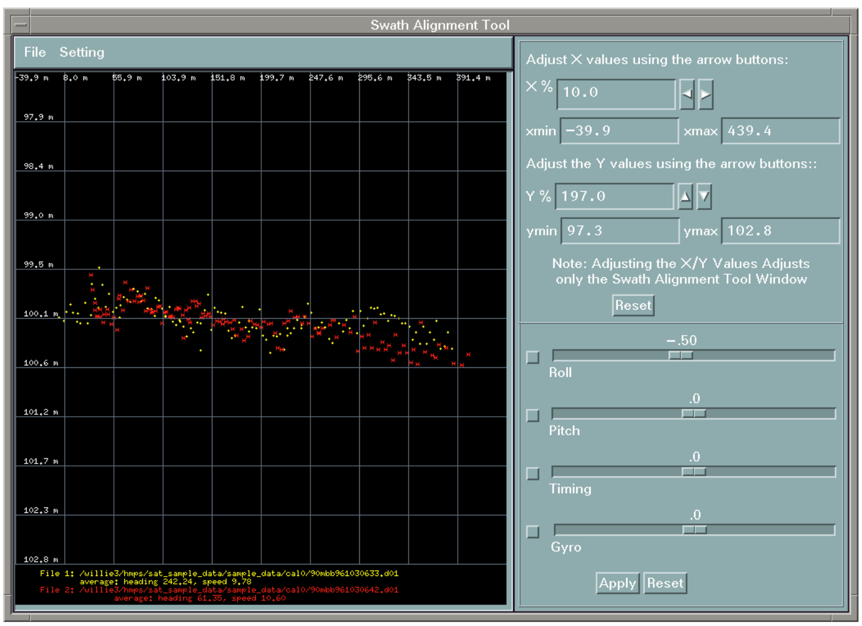

__Figure 14.__ The roll alignment error is corrected by introducing a –0.5 degree offset.

Heading (Gyro) Alignment

Misalignment between the transducer and gyrocompass is determined using a set of parallel lines run over a significant feature. The lines are run such that there is a 50% overlap between swaths (that is, the port swath of one line overlays the starboard swath of the other). The feature should be centered between the two survey tracks. Using the observed horizontal distances from each survey line to the feature and the computed horizontal distance between the two tracks, the error in heading alignment can be estimated as illustrated in Figure 15.

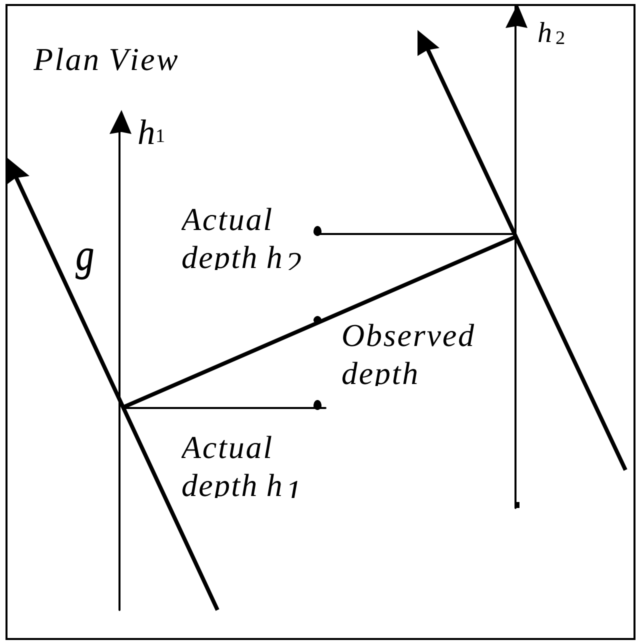

Figure 15. *Errors in heading induce positioning errors as indicated here. The heading error, L, causes observed depths to be located aft of their real position on the port side of the vessel, and forward of their real position on the starboard side of the vessel. A single feature will appear as two separate features under these conditions.*

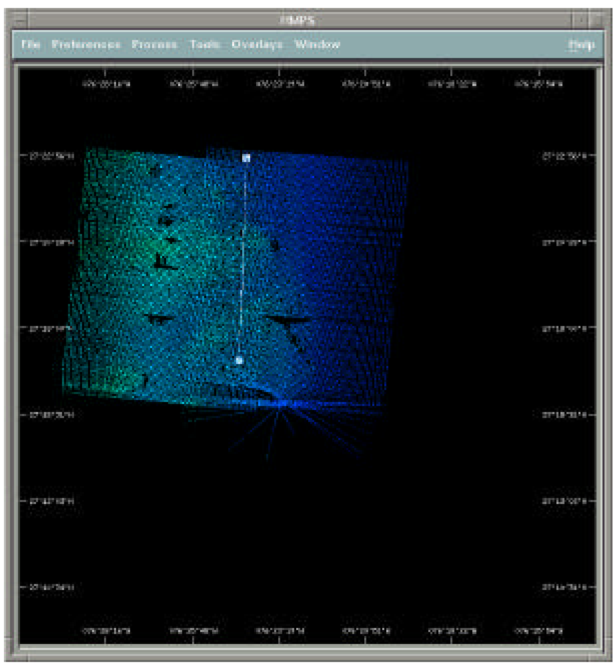

Figure 16. *Parallel lines run near a significant feature are used for the estimation of heading, or gyro, alignment error. These lines are from the USNS Pathfinder using a Simrad EM-121A sonar.*

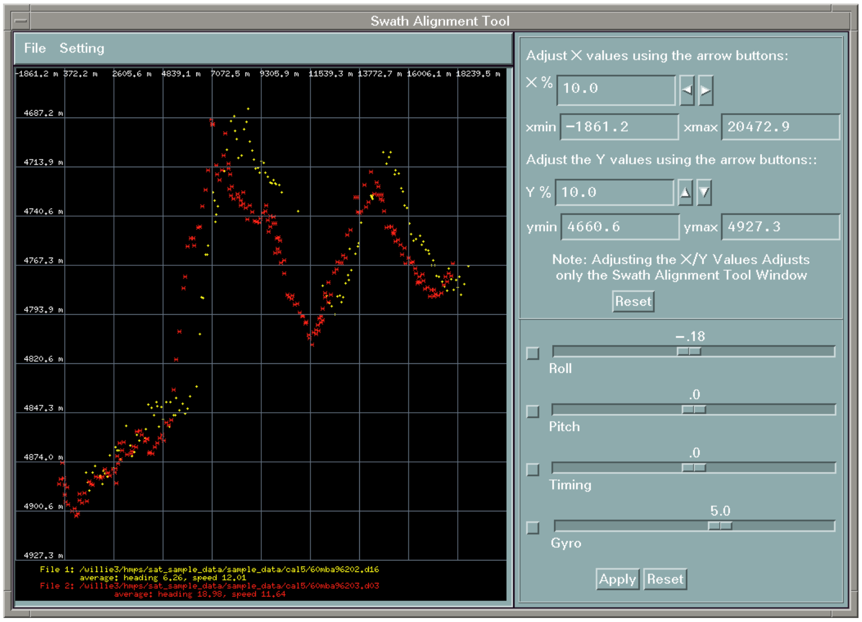

Figure 17. *These depth profiles include an artificially induced heading error of 5 degrees. This causes a difference in positioning for the two features.*

Summary

A simple interactive method of determining swath bathymetry system alignment errors has been demonstrated. The system has been tested with several types of fixed-mount sonar systems and with several survey vessels. It has been proven to be a useful tool for the determination of alignment errors before conducting a survey and may also be used for quality control and verification of system performance during and after a survey.

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Hughes Clarke, John, 1996. Swath Bathymetry System Alignment and Calibration. *U.S. Canada Hydrographic Commission Coastal Bathymetry Working Group Shallow Water Multibeam Training Course, Lecture 23.*