Survey Operations and Results Using a Klein 5410 Bathymetric Sidescan Sonar

James M. Glynn, Jr., Christian de Moustier, Lloyd C. Huff

Center for Coastal and Ocean Mapping & NOAA-UNH Joint Hydrographic Center
University of New Hampshire, Durham, NH 03824, USA

Abstract - Since 2004, the Center for Coastal and Ocean Mapping (CCOM) at the University of New Hampshire (UNH) has conducted engineering tests and acoustic calibration of the Klein 5410 bathymetric sidescan sonar at the sensor, system, and survey levels. The survey capabilities of the system were tested at sea by rigidly attaching the towfish to the hull of a launch deployed from NOAA's ship Thomas Jefferson. Sonar data was recorded using Klein's *SonarPro* software. High resolution launch attitude data was recorded separately from an Applanix POS MV 320 V3 motion sensor. The attitude data was synchronized with the sonar data using commercially available timing hardware as well as software developed at CCOM. The data was processed using parameters from the acoustic calibration and a full vector processing algorithm which was specifically designed at CCOM for use with the Klein 5410 sonar. The algorithm writes processed data into GSF files which can be imported and processed with Caris HIPS. This paper describes the hardware configuration used to acquire the data and time synchronization methods for the sonar data and attitude data. Bathymetry obtained from a test survey conducted on October 6, 2006 in New York Harbor with the Klein 5410 sonar in 8-20 meter water depths over seven 50% overlapped 150 meter swaths matches results obtained with a Reson SeaBat 8125 multibeam sonar over twenty 120° swaths collected by surveyors from the NOAA ship Thomas Jefferson.

1. Introduction

In 1999, L-3 Communications Klein Associates began developing a bathymetric sidescan sonar designated the Klein 5410. In 2001, NOAA purchased a Klein 5410 sonar and used it to conduct several fisheries research surveys. While the backscatter imagery produced by the Klein 5410 has always been of high quality, the bathymetric function of the system produced unreliable results.

In 2004, CCOM began to conduct engineering tests and acoustic calibration of the sonar to determine what aspects of the system were responsible for the unreliability which was observed. It was found that phase distortions introduced by the transmit pulses, transducer elements, and electronic channels were causing the system to operate with a degraded level of performance. In 2006, Klein Associates made an upgrade to the system's firmware that provided a set of distortion free CW transmit pulses. Separately, we have taken measures to remove the phase distortions introduced by the transducers and receiver electronics in post-processing. Using a CW transmit pulse, a full vector bathymetric processing algorithm, and a high quality position and orientation sensor, we have conducted a hydrographic survey and processed the data to prove that the Klein 5410 sonar is capable of producing bathymetric results which are visually comparable to those produced by a Reson SeaBat 8125 multibeam sonar.

2. System Integration

Field testing of the Klein 5410 sonar was conducted aboard NOAA launch 3102 deployed from the Thomas Jefferson. The launch is a purpose-built 31-foot survey vessel with many built-in hydrographic systems including Hypack, an Applanix POS MV 320 V3, and a rigid hull mount for a Klein Series 5000 sidescan towfish. In addition to the standard hardware and software installed aboard the launch, we installed several components which are specific to conducting a hydrographic survey with a Klein 5410 sonar including a PC to run *SonarPro* [1] and perform time synchronization tasks, a Klein Series 5000 Transceiver Processor Unit (TPU) configured for raw data acquisition, and a Klein 5410 bathymetric sidescan towfish.

2.1 Mounting the Towfish

The Series 5000 towfish mount aboard the launch consists of an I-beam "sled" which is approximately the same length as the Series 5000 towfish and is welded to the bottom of the launch. At each end of the sled, an "omega" bracket with a rubber insert grips and secures the towfish. The coaxial cable which links the Klein towfish and TPU was routed into the cabin of the launch with a through hull fitting. Figure 1 illustrates the mechanical details of the towfish installation.

While the starboard transducer is clearly visible in Figure 1, the port transducer is facing the keel of the launch. The bathymetry arrays in the Klein 5410 transducers are located directly in the center of the window and span a distance of approximately 40 cm. It was critical that the center section of the port transducer clear the keel so that it would have an unobstructed view of the seabed. Figure 2 shows that there was sufficient clearance.

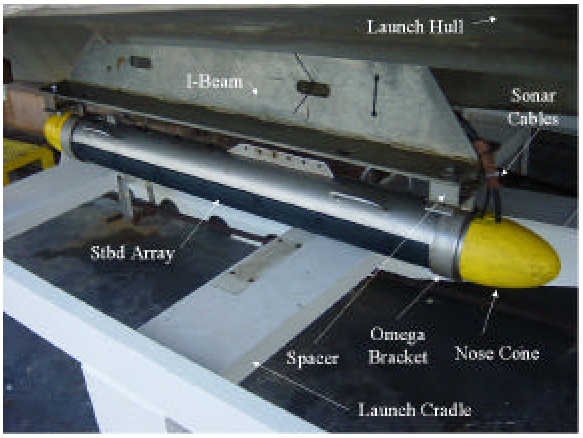

Figure 1: Photograph of the Klein 5410 towfish installed in the Series 5000 mount aboard NOAA Launch 3102.

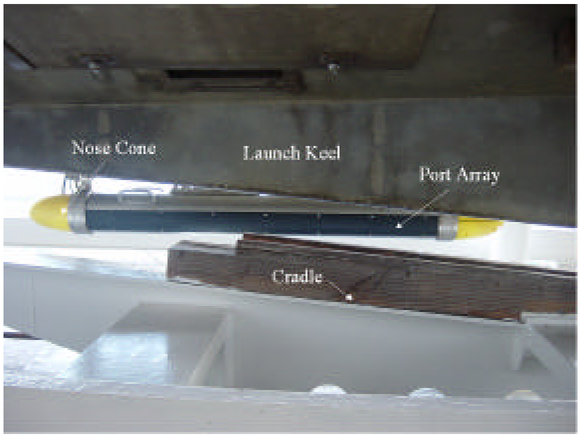

Figure 2: Photograph of the clearance observed between the top of the port Klein 5410 transducer and the bottom of the launch's keel.

Figure 3: Photograph of the mounted Klein 5410 towfish from the aft end of the survey vessel. The vertical grooves in the tail cone and omega bracket were used as visual references to remove as much of the roll bias as possible.

Once the Klein 5410 towfish was installed in the mount, the vertical grooves in the tail cone and omega bracket were used as visual references to align the orientations of the towfish and survey vessel. These visual references are shown in Figure 3. Despite our best efforts, post-processing of the data revealed that a 2.75° roll bias remained which was ultimately subtracted from the arrival angle estimates computed by the vector processing algorithm.

2.2 A Time Synchronization Problem

The Klein 5410 sonar's integrated position and attitude sensors do not provide data at a high enough rate or with enough accuracy to serve as the primary sensors in a seafloor mapping application. Instead, the POS MV aboard the launch was used as the primary source of position and attitude data during the Klein 5410 test survey. The major obstacle encountered in using the POS MV in this fashion was determining which position and attitude fixes in the data stream corresponded to each ping in the Klein 5410 sonar data records. The simplest way to integrate data streams from distributed sensors is to match their timestamps. However, if the clocks in the individual sensors are not precisely synchronized, merging their data streams becomes a difficult task. In order to ensure that the timing references for the Klein 5410 sonar and POS MV were synchronized, a National Instruments (NI) PCI-1588 [2] precision time protocol (PTP) synchronization device was used. The PCI-1588 was installed in the Klein PC which acquired the sonar data using *SonarPro*. The device operates based on the IEEE 1588-2002 standard [3], and provides sub-microsecond time synchronization between distributed clocks.

The hardware clock in the PCI-1588 was synchronized to the POS MV clock using specialty code developed at CCOM [4], and a serial NMEA ZDA string and 1 PPS TTL signal from the POS MV. The serial NMEA feed was required to contain only a ZDA string. Any other NMEA strings in the data stream caused a failure of the software. Since the POS MV 320 V3 only has one serial output port, and that output port was required to supply a ZDA string only, it was necessary to use a separate GPS receiver to supply the Klein 5410 sonar with position fixes to dynamically adjust the sonar's ping rate based on the launch's speed over ground. A Garmin GPS 76 handheld receiver was used for this purpose. Since the Garmin unit is less precise than the POS MV, the data it provided to the Klein sonar was eventually superseded by POS MV position data in post-processing.

2.3 Electronic Connections

Figure 4 shows a block diagram of the major electronic components which were used to conduct the hydrographic survey with the Klein 5410 sonar. Devices such as computer peripherals and monitors have been neglected from the diagram.

The launch Ethernet switch allowed the POS MV to stream data to the Hypack PC for both the vessel navigation displays and for storage so that it could later be used to post-process the Klein sonar data. The UNH Ethernet switch served as the communication hub for all of the Klein sonar electronics. The Klein 5410 towfish acquired sonar data and streamed it to the TPU over a coaxial telemetry link. The TPU accepted the sonar data as well as command and control data from the Klein PC and navigation data from the Garmin GPS 76 handheld receiver. The sonar data was then transferred over Ethernet from the TPU to the Klein PC.

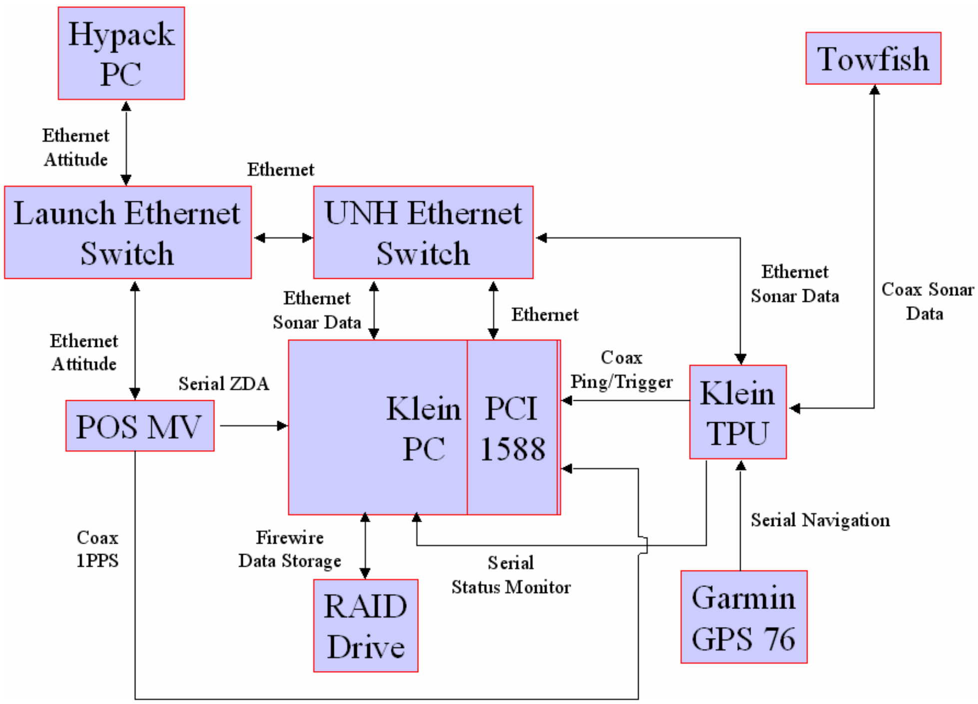

Figure 4: Block diagram which illustrates the electronic components which were used during the test survey and how they were interconnected.

The Klein PC served as the heart of this data acquisition system. It issued commands to the Klein TPU over Ethernet, monitored the TPU boot sequence and status over a serial link, and accepted and displayed sonar data streaming over Ethernet from the Klein TPU. The sonar data was routed by the PC through a FireWire (IEEE 1394) connection and stored on a 200 GB RAID drive. The Klein PC also housed the National Instruments PCI-1588 timing device and accepted a serial NMEA ZDA timing message to synchronize the PCI-1588 clock. The PCI-1588 card itself accepted two TTL logic signals including a 1PPS signal from the POS MV and a ping trigger from the Klein 5410 TPU. The TTL ping trigger forced the timing software to record the current time reported by the PCI-1588 PTP clock each time the sonar pinged.

The launch Ethernet switch and UNH Ethernet switch were connected to allow for data flow between the launch hydrographic systems and the Klein sonar systems. In this configuration, all relevant data from each sensor could be saved on the portable RAID drive, and ultimately taken off the launch when the survey was complete.

2.4 Survey Equipment Configuration

By default, the Garmin GPS 76 handheld receiver does not output serial NMEA messages. Through the user menus, the GPS 76 was configured to supply NMEA messages at 4800 baud, which was the data rate expected by the Klein Series 5000 TPU. The Klein 5410 sonar was configured to transmit with a 176 μs CW pulse, and was set to operate on the 75-m range scale. The Series 5000 TPU was configured to record the raw IQ data from each of the sonar's 28 hydrophones. The POS MV was configured to record latitude, longitude, pitch, roll, heading, and true heave at a rate of 50 Hz.

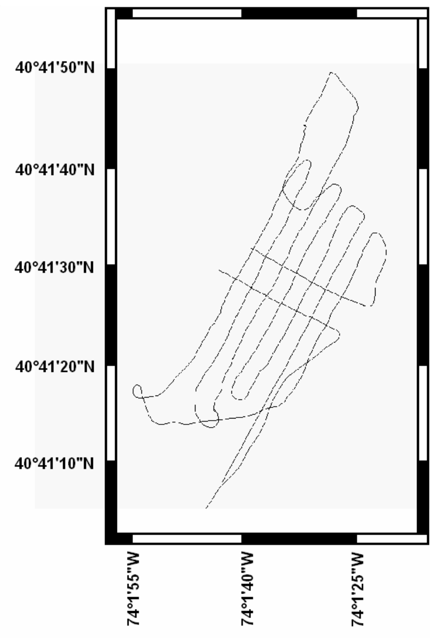

Figure 5: Track lines followed by the survey vessel during the Klein 5410 sonar test survey. Projection is NAD83 Zone 18, datum is GRS80.

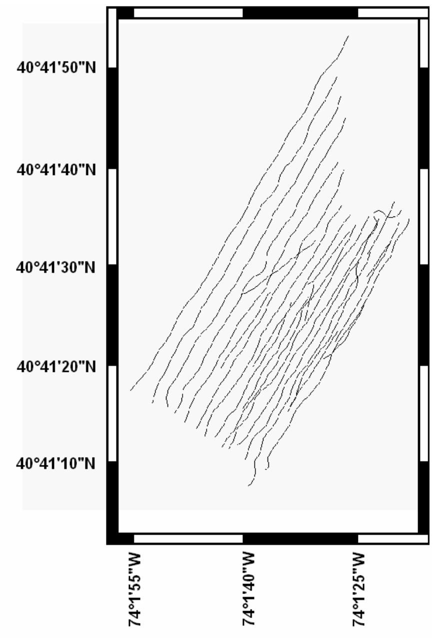

Figure 6: High density track lines followed by the survey vessel during the Reson 8125 multibeam sonar survey. No orthogonal tie lines were surveyed. Projection is NAD83 Zone 18, datum is GRS80.

3. Conducting the Surveys

The bathymetric performance of the Klein 5410 sonar was tested in New York Harbor, approximately 1.2 km southwest of the southern tip of Manhattan, and within 1 km of the western shore of Governors Island. This site features a large field of sand waves and a small shipwreck which were very distinct in the bathymetry produced by the Reson 8125 multibeam sonar. The water depth at this site is nominally between 8 m and 20 m. The nominal speed of the survey vessel during the Klein 5410 testing was 6 kn. Survey lines were spaced at intervals of approximately 50 m. The track followed by the survey vessel is shown in Figure 5. The total length of the survey lines shown in the figure is 5.07 nmi.

Figure 6 shows the survey tracks which were followed during the Reson 8125 survey of the test area. On average, the density of the survey lines which were necessary for full bottom coverage in the multibeam data is approximately twice the density of the lines required for full bottom coverage with the Klein 5410 sidescan sonar. In the shallow areas, the required density of the multibeam survey lines grows to approximately three times that of the Klein 5410 sidescan survey lines. The total length of the survey lines traversed during the Reson 8125 survey is 9.09 nmi. Note that if the multibeam survey contained two orthogonal survey lines such as those in the Klein 5410 sidescan survey, the distance traversed by the survey vessel would be increased to approximately 10.09 nmi. The speed of the survey vessel during the multibeam survey was between 5.5 and 8.5 kn. Despite the slightly higher speed of the survey vessel during portions of the multibeam survey, the multibeam survey took roughly twice as long as the Klein 5410 sidescan sonar survey.

Tide data for both the Klein 5410 and Reson 8125 surveys was recorded at NOAA tide station 8518750 located at The Battery, NY. Sound speed profiles were measured using an SBE 19*plus* SEACAT profiler. An Odom Hydrographic Digibar Pro was used to measure sound speed at the face of the Reson 8125 multibeam transducer.

4. Timestamp Matching

The NI PCI-1588 hardware clock was synchronized to the POS MV clock using specialty software. Each time the Klein 5410 sonar pinged, the software recorded the time of the ping in a text file.

The sonar was brought online and configured before the survey commenced. Even though the Klein 5410 sonar was pinging during this time, the sonar data was not being recorded. This resulted in a text file with more PTP timestamps than there were pings in the sonar records. It was necessary to determine in post-processing which of the timestamps in the text file corresponded to each ping in the sonar records. This was accomplished using the internal Klein 5410 timestamps as an aid.

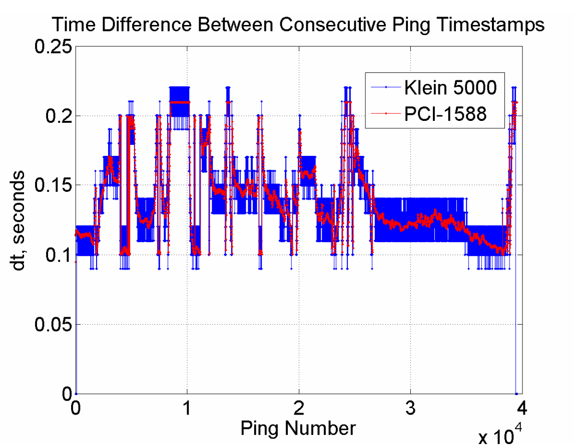

Figure 7: Time differences between consecutive ping timestamps logged by the Klein Series 5000 TPU clock and the NI PCI-1588 clock. The randomness of the time differences can be attributed to the variability of the speed of the survey vessel.

The time difference between each consecutive pair of timestamps logged by both the internal Klein 5410 electronics and the PCI-1588 clock was computed. Figure 7 shows the time differences between the ping timestamps.

Since the ping rate of the Klein 5410 sonar is dynamically adjusted based on the speed over ground of the survey vessel, the random nature of the time differences is attributable to the speed variations of the survey vessel. Since there are random variations in the timestamp differences, the cross-correlation of the two time difference sequences will result in a single distinct peak as illustrated in Figure 8.

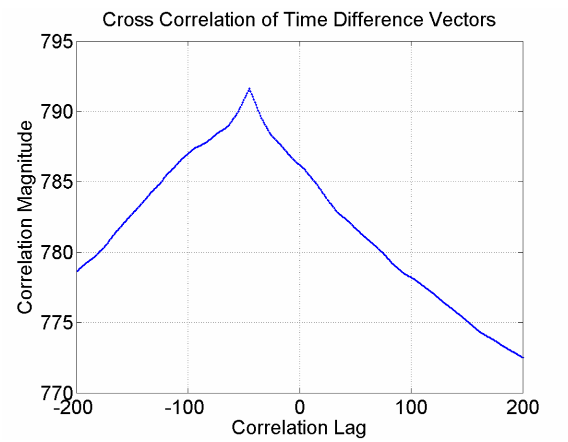

Figure 8: Cross-correlation of the Klein Series 5000 and NI PCI-1588 PTP time difference sequences shown in Figure 7. The peak occurs at a correlation lag of -45.

The cross-correlation peak in the figure occurred at a correlation lag of -45, and indicated the number of Klein 5410 pings that occurred before we began recording the sonar data. The timestamps for those pings were discarded from the text file of PCI-1588 PTP timestamps. The timestamps remaining in the file were the correct sequential timestamps for each of the Klein 5410 pings recorded in the sdf files. These timestamps were imported during processing of the data, and were ultimately written into the GSF (Generic Sensor Format) [5] files which were created and imported for processing in Caris HIPS [6].

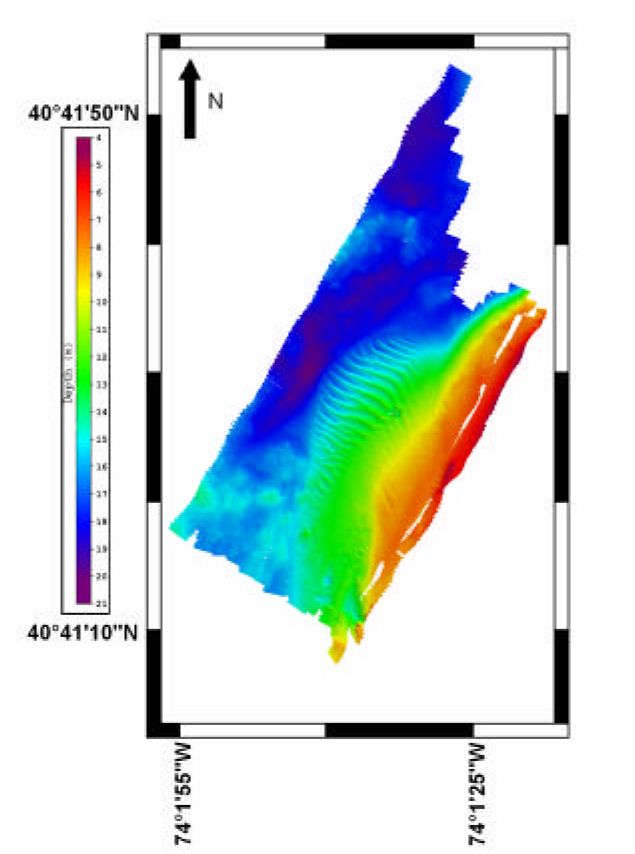

Figure 9: Color coded bathymetry near Governors Island, NY produced by a Reson SeaBat 8125 multibeam sonar. Projection: NAD83 Zone 18, Datum: GRS80, Tidal Reference: MLLW, Grid Size: 40 cm, Area Surveyed: ~ 0.75 km^2

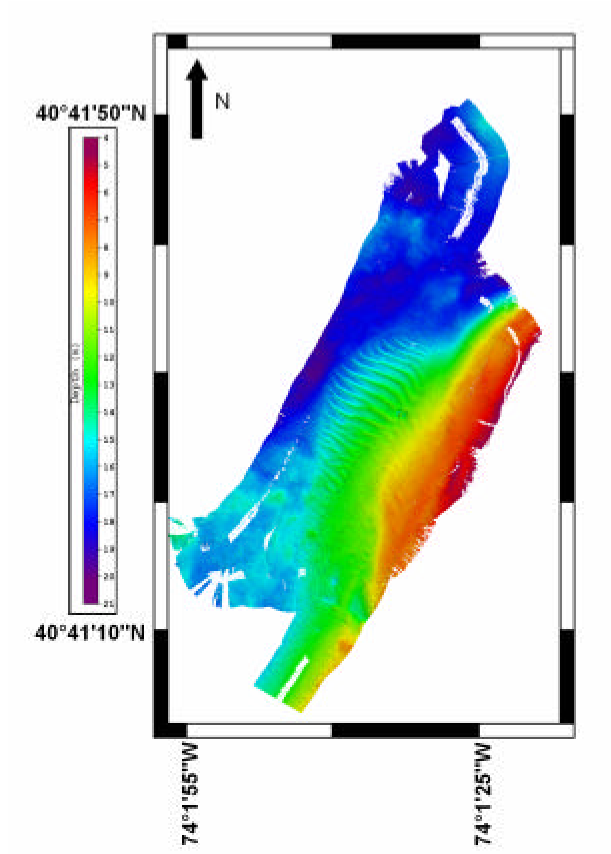

Figure 10: Color coded bathymetry near Governors Island, NY produced by a Klein 5410 bathymetric sidescan sonar. Projection: NAD83 Zone 18, Datum: GRS80, Tidal Reference: MLLW, Grid Size: 40 cm, Area Surveyed: ~ 0.75 km^2

5. Comparison of Bathymetry

The bathymetry in both Figure 9 and Figure 10 was processed using Caris HIPS tools. While the Reson data was processed through CUBE [7], the Klein 5410 data was processed manually since there are not yet any accurate statistical uncertainty models for data produced by the Klein 5410 sonar.

The major features shown in the bathymetry produced by the Reson 8125 have also been captured in the bathymetry measured by the Klein 5410 sonar, and they appear in the same geographical locations. Features as large as the sand wave field with a southwest to northeast length of approximately 500 m, and as small as a shipwreck of length 8 m, were observed by both sonar systems. However, some very fine details of the seabed which were detected by the Reson 8125 sonar are not apparent in the Klein 5410 bathymetry. It is not yet known whether these details were too fine for the Klein 5410 sonar to detect, or whether we have artificially removed them from the sonar data by using digital filters which are too aggressive. This will require further investigation.

The bathymetry measured by the Klein 5410 directly over the sonar track lines appears rougher than the surrounding bathymetry. The geometry of classic sidescan sonar results in serious problems in measuring and geo-referencing data in the near nadir zone. Therefore, the only reliable data that exists in the near nadir area of a track line is from the outer edges of adjacent swaths, where the data are progressively less reliable as off-nadir distance increases. However, the roughness along the sonar track lines could potentially be reduced if the acoustic arrays were tilted downward by 5-10°, and a more optimal digital filter were to be implemented to process the raw data.

Statistical comparison of the bathymetry produced by the Klein 5410 and Reson 8125 systems is beyond the scope of this paper.

6. Conclusions

Using a 176 µs CW transmit pulse, an NI PCI-1588 hardware clock, a POS MV 320 V3, a rigid hull mount for a Klein Series 5000 towfish, a Klein Series 5000 TPU configured for raw IQ data acquisition, and a full vector processing algorithm, we have produced realistic seafloor bathymetry from data recorded with a Klein 5410 bathymetric sidescan sonar system which matches the bathymetry obtained by NOAA over the same area with a Reson SeaBat 8125 multibeam echosounder.

A significant advantage of the Klein 5410 sonar over the Reson 8125 is its ability to cover 150-m swaths in shallow water while collecting high resolution sidescan imagery. The linear distance traversed in order to provide full bottom coverage with the Reson 8125 was nearly twice that of the Klein 5410 sonar. Full bottom coverage by the Klein 5410 sonar with its present transducer configuration mandates that swaths be overlapped by at least 50% in order to fill the data gaps near nadir. If that were not necessary, the time savings of operating the Klein 5410 sonar could be increased by an additional factor of two.

Acknowledgements

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