Acoustic Transducer Calibration System

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Abstract

Multibeam sonars are being used increasingly to image fish. To realize their quantitative potential for measuring the numerical density of fish and other aquatic organisms, it is essential that they be calibrated. This can be done by the use of standard targets. The calibration of narrow beam acoustic arrays requires precise angular control of the transducer under test. Precision is defined as 0.1^{o}. This degree of control is achievable with a precision rotary table typically used in the CNC machining industry. This paper describes the system specifications and the development of the LabView interface that coordinates position and acoustic data acquisition. The initial evaluation of the rotary table for repeatability and possible backlash demonstrated that the system was within the required specifications. Finally, representative acoustic measurements made with a Kongsberg-Simrad SM 2000 and Reson SeaBat 8101 multi-beam sonars using the new system are presented.

I. Introduction

While the use of multibeam sonars is becoming increasingly more common for a range of applications, little work has been done on the absolute calibration of these systems. The goal of this ongoing project is to develop the capability of calibrating multibeam sonars using standard targets and reference hydrophones. Multibeam sonars are capable of broader area coverage, particularly when imaging targets in the water column such as fish (Mayer et al. 2002). The increased coverage without the compromise of spatial resolution is the promise of multi-beam sonar. However, to obtain real quantitative data, the sonar must be calibrated. The preferred method of calibration is to use a reference hydrophone, however this project also used a target with known backscatter properties for calibration.

This paper describes the efforts to date on developing this new acoustic calibration facility at the University of New Hampshire, Center for Ocean Engineering. There are three basic issues that are addressed here: 1) spatial positioning of the transducer in the test tank, 2) the

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angular position of the transducer during beam pattern measurements, and 3) the controller interface for positioning and data acquisition. The approaches to resolve each of these three issues are addressed in the remainder of this paper.

II. Approach

The fundamental concept behind the design was that the functioning of this calibration system could be viewed as components that had existing solutions, but were in need of system integration to perform the desired tasks. For instance, X-Y positioning systems are available from a variety of sources. The ability to control angular positioning is a common necessity for the CNC machining industry. The system integration could be accomplished using National Instruments (NI), LabView 6.1. The system requirements for moving in the X-Y plane, rotating about the Z-axis, and system integration are summarized in Table 1.

Table 1. System requirements

Lateral Positioning	Unimpeded motion across length and span of the tank
	Carriage to carry rotator & transducer
	2000# load, center span
	Simple control
Rotator	0.1° increment capability
	Zero backlash
	Hold a 200# transducer
	Simple control
System integration	Software & hardware intercommunication
	Control rotation
	Multi-channel digital and analog input and output
	Create a simple user interface

With these preliminary requirements defined the project moved towards the goal of designing a system for use in collecting acoustical source / system calibration data using either calibrated targets or a calibrated reference hydrophone in the acoustic field. The resulting system is shown in Figure 1. The remainder of this paper describes the path to this result.

Figure 1. The hardware for the positioning system: X-Y bridge-carriage, and the Yuasa rotation table and controller. The tank has a 40' span, the rails run along the 60' length, and the tank has 20' of water.

A. X-Y Positioning

There are a variety of sources for X-Y positioning systems. The goal was to find a cost effective system that would 'fit' the tank, without compromising structural integrity of the tank walls. The primary issue was moving the rotator and transducer to a given X-Y position. The precision of the X-Y position is a secondary issue in the design at this time.

The systems available ranged from industrial overhead cranes to antennae rotators to precision linear motion systems. The cost ranged from \$30K to \$250K respectively. The simplest solution was the industrial overhead crane sitting on the tank walls. This was cost effective and met the entire lateral positioning requirements presented in Table 1.

B. Rotator

The requirement of 0.1° increments are driven by the need to calibrate multibeam sonar systems, which have beam widths in the 0.5° to 3° ranges. Acquiring multiple measurements across individual beams requires this small angular increment. There are a variety of approaches to this rotation specification. Baldwin et al (1997) used stepper motors and custom made gears with a limited degree of success. There are many antenna rotators available, but most do not possess the increment control required or the zero backlash requirement. The machine tool industry is the one place where this small angular increment and the need for zero backlash thrive. Precision computer controlled (CNC) machining equipment manufacturers address these angular specifications. A Yuasa International, three-jaw chuck rotator (SUDX 320) with a programmable controller (UNDC 100) was selected. This device is shown in Figure 1 atop the carriage and in Figure 2 close-up. The rotator is a sealed unit designed for industrial environments; hence it should easily tolerate the humid environment over the tank when in use.

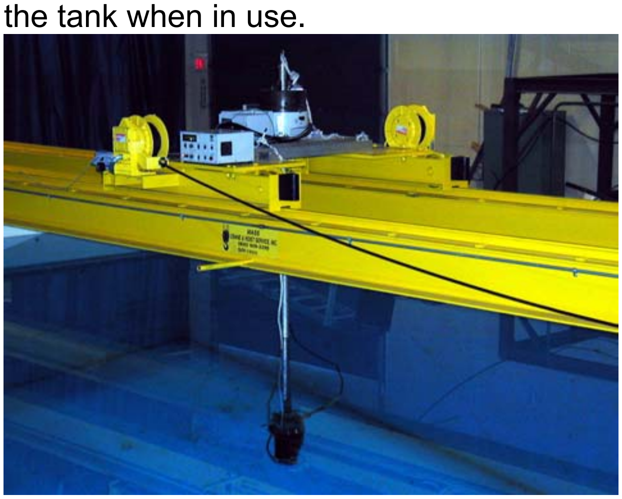

Figure 2. Yuasa rotation table with control box mounted on the carriage.

C. System Integration

This was the most challenging aspect of this system. The X-Y carriage system was left to be controlled using the manufacturer supplied radio link. The need to control angular position, know the absolute position, and coordinate this control with the acquisition of acoustic data was the essence of this task. National Instruments LabView© software was selected. Experience with this product for other data acquisition and system control tasks influenced the choice.

The first task was to establish a communication link between the rotator control box and the PC using National Instruments hardware and software. Bloomy Controls, Inc. has experience with this particular situation and was able to determine translation protocols for CNC to PC interfacing via the UDNC-100 control box. Establishing communication enabled control of absolute and relative positioning, rotation direction and rate, timing and incremental movement.

There are two acoustic calibration scenarios that need consideration. The first is the calibration of a sonar system with a known calibrated target in the acoustic field. The acoustic transmit and receive functions are contained in the sonar system. This testing requires a coordination of the angular indexing of the array(s) with the data acquisition in the sonar system. The second scenario is the calibration of an acoustic source with a reference hydrophone in the acoustic field. There are two configurations. The first is to use only the receive signal function and rotation control of the UNH calibration system, as the transmit signal is generated by the sonar system. The second configuration has the calibration system performing all the necessary functions such as generating the transmit signal, receive signal acquisition, initial processing of the received signal, and indexing the angular positioning.

In both scenarios a spatial definition of the system response, a 'beam pattern', is typically the required output. It is critical in both scenarios that the rotator control and position be indexed to the acoustic data.

The basic question is one of control. Does the acoustic event trigger the position control or does the position control trigger the acoustic event? Having a clear definition of position is paramount, so position was selected to control the acoustic event. The rotator is moved to a position, a pulse is transmitted and received, the waveform is written to a file, named by the rotator bearing, and after a prescribed time delay the rotator moves to a new position. A new pulse is transmitted and the process repeats. This provides a clear definition of the position in the database.

LabView provides a simple interface for use in either testing scenario. A list of basic inquiries is presented to configure the system for the particular test. The control and data acquisition is enabled through the serial port and the NI PCI-6110 high-speed data acquisition card. This card has A/D and analog output capabilities, and a total sampling rate of 5 MS/sec.

The system can generate the excitation pulse, capture and record the return signal to disk, while controlling the position in real time. The outgoing and incoming waveforms are presented on the PC monitor for viewing during the testing. The logical flow chart for the software is shown in Figure 3.

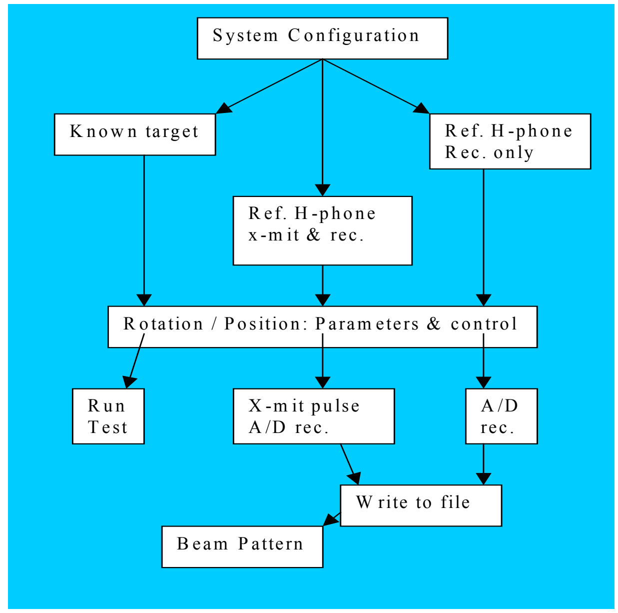

Figure 3. Logical flow chart for software.

III. Preliminary system evaluation and testing

This section describes initial system evaluation, preliminary acoustic results, and perturbations to the system to facilitate use. The first task after establishing communication with the rotator was to evaluate the incremental control and repeatability. Then the preliminary acoustic trials were performed with a multibeam sonar system using a calibrated target. A beam pattern was measured for a transducer with known characteristics utilizing a reference hydrophone. Finally changes, made to facilitate the logistics of installing and supporting a transducer during testing, are described.

A. Rotator

The fundamental concern in the rotator performance was the incremental control and backlash. Mounting an arm in the rotator chuck and specifying a radial distance at which displacement perpendicular to the arm was measured allowing the assessment of these parameters. The measurement was performed using a dial indicator with a 0.0001” resolution. Data were collected at randomly selected 2° intervals around the rotator. The 2° arcs were traversed in 0.1° increments in both clockwise and counter clockwise directions. The measurement scenario is shown in Figure 4.

The results were reviewed for linearity, repeatability, and backlash. The plot in Figure 5 shows the linearity and repeatability. There are three, 2° arc

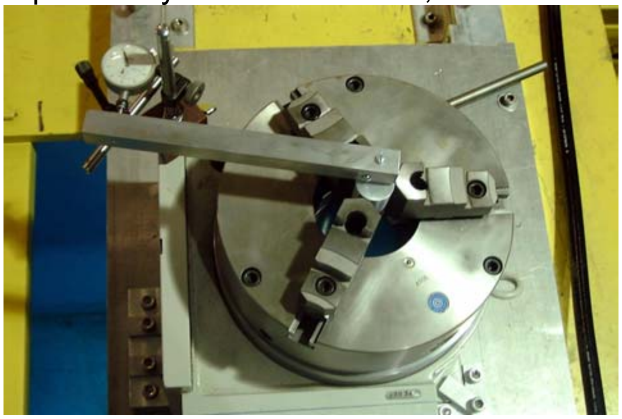

FIGURE 4. Yuasa turntable with arm and dial indicator used for verifying the incremental control and resolution.

sections shown in Figure 5. The difference plot is basically flat and horizontal indicating constant increment. The displacement for a 0.1° angle at a radial distance of 10” is 0.01745 “. For the three data sets shown in Figurer 4 the average distance for the 0.1° increments is 0.0174”. Furthermore, the RMS theta for these data is 0.023°. The Yuasa rotary table performs well for the task for which it was selected and is easily controlled with the LabView interface.

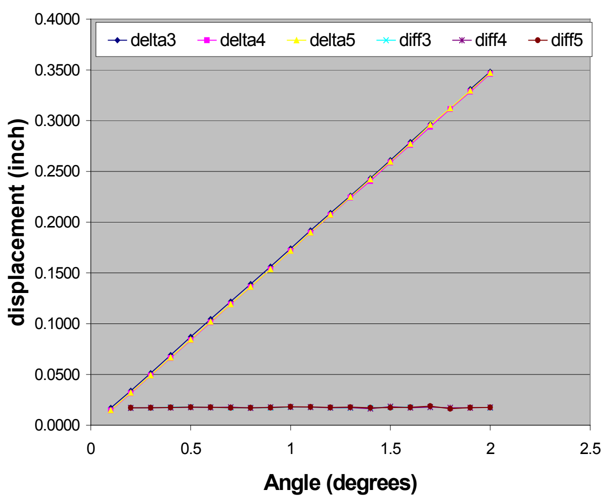

Figure 5. Displacement vs. angle in 0.1° increments.

B. Multibeam sonar testing

The initial testing with a multibeam sonar system and a known target occurred 14-16 January 2003. A Simrad SM 2000 operating at 200kHz was tested using a 60mm aluminum spherical target at 11.7 m range. This testing scenario was similar to a test performed earlier at the facility at Woods Hole Oceanographic Institution. During this testing data were acquired for ΔΘ = 0.2° over 30° sectors centered on the array axis and at a position 45° off axis. The target was suspended in the acoustic field using nylon monofilament. Its depth was precisely controlled and known. The depth of the sonar array was 2.45 meters.

The SM 2000 was altered to accept an external trigger from the PC used to control the rotation. Simrad established a 20 msec ttl pulse as the trigger pulse. The protocol was to rotate the sonar array a prescribed ΔΘ, then trigger the sonar to ping, acquire the data, wait a prescribed Δt, then rotate ΔΘ to the next position. As mentioned earlier this provides a clean indexing of the pings and positions.

The only problem encountered during this testing were occasional data drop-outs which were an artifact of the trigger pulse. It was discovered that shortening the pulse to 0.02 msec provided a data record with no dropouts, even with ΔΘ=0.1° over a 120° sector. Chu et al (2003) presents the specific results of this testing.

A second opportunity to test a multibeam sonar occurred in May 2003 (Weber 2003). A Reson SeaBat 8101 multibeam echo sounder was calibrated. Both transmit and receive array beam patterns were determined across and along track. The specific testing parameters for the calibration are shown in Table 2.

The transmit beam pattern testing used a Reson TC 4014 calibrated hydrophone suspended in the acoustic field. The hydrophone was connected to the receive function of the calibration system. The ping rate was set to two pings per second. Data were collected and a beam pattern was determined. In the receive mode a Reson 4034 was used as a source, and the Reson 4014 was used to listen. In this instance, the Reson 8101 collected data while the UNH system rotated on the acoustic trigger. Representative beam patterns for individual beams are shown in Figure 6.

Table 2. Testing parameters for calibrating the Reson 8101 multibeam sonar.

Mode	Across track	Along track
Transmit	+/- 90°	+/- 10°
	$\Delta\theta$ = 0.5°	$\Delta\theta$ = 0.1°
Receive	+/- 15°	+/- 30°
	$\Delta\theta$ = 0.1°	$\Delta\theta$ =1.0°

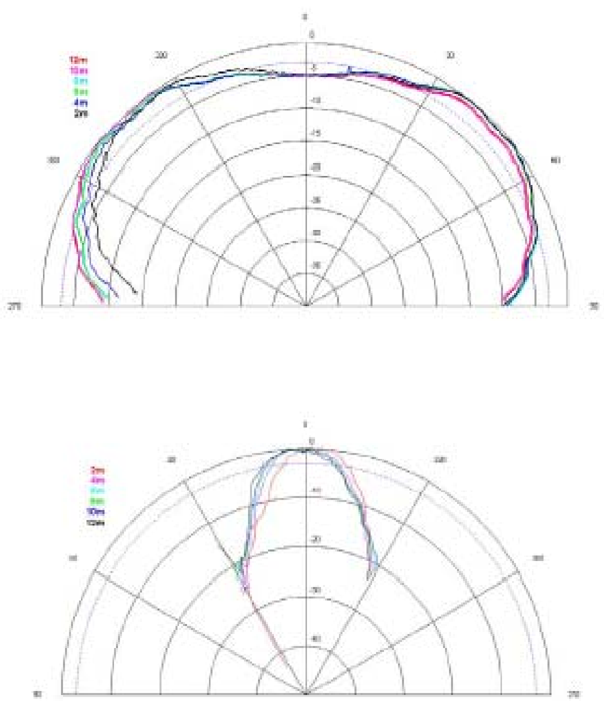

Figure 6. Polar plot beam patterns for ranges from 2 to 12 meters at 2 meter intervals. Top plots are across track transmit beam patterns and the bottom plots are along track receive array beam patterns.

Acquired waveform data are written to disk during incremental capture sequences. For each captured waveform, the rotational index reference is used to name that data file. Directory structure for data storage is an hierarchal design based upon user input, and is in the following structure: institution, transducer model name, mounting point orientation, range to target, incremental sequence. Matlab scripts originally created by Tom Weber at Pennsylvania State University were modified and were used to extract VRMS values from 12 cycles of the received pulse. These VRMS values were correlated with index bearings and written to a matrix from which a polar plot was generated (Fig 6).

IV. Adjustments

During the initial trials with this system some logistical and handling difficulties were encountered. These difficulties were basically associated with mounting transducers and moving them into place. The original mounting pole was stainless steel and hence was quite heavy and adjusting the vertical position was cumbersome. This pole was replaced with a larger diameter segmented carbon fiber pole, which weighs substantially less. This pole has internal couplings, which enable extending the length. There is a ‘universal' mounting plate for attaching any transducer array. A trolley was built to ride on the lower flange of the spanning I-beams of the X-Y positioning system. This trolley can readily hold two people and facilitates transducer array attachment. A lower lateral support bearing was added to stabilize oscillations in the pole during rotation and lateral motion. This bearing can be disengaged and rotated away from the pole during transducer array installation.

The communication with the Yuasa turntable was changed from radio controlled to direct wiring. This cable, along with other cables for future needs are now deployed over head in a conduit that removes them from harms way and the water during testing. These adjustments were made due to the early trials described earlier. All the adjustments are shown in Figure 7.

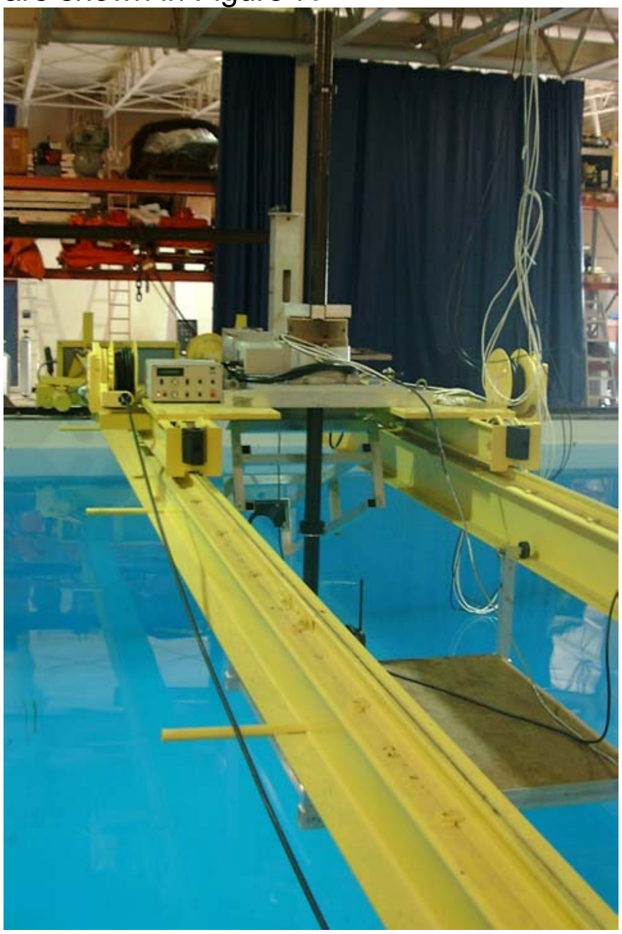

Figure 7. The tank and calibration hardware after the adjustments. The carbon fiber pole, trolley, and lower support bearing and bracket.

V. Summary

The Center for Ocean Engineering at the University of New Hampshire is in the process of developing a transducer calibration facility specifically designed for multibeam sonars. The key components of this system include the ability to position and stably hold relatively large transducers in a 60' x 40' x 20'deep tank, a computer controlled rotator capable of angular precision of less than 0.1° with no backlash, and system integration software that controls the hardware and acquires the appropriate data. A prototype system was developed and used to successfully calibrate both a Reson 8101 and Simrad SM 2000 multibeam sonar. These calibration results indicate that this system is functioning as intended but, as always, there are areas that can be improved. There are still some issues with indexing the angular position control with the acoustic data acquisition. In particular, whether the sonar system triggers the position is being reconsidered. The ability of the sonar systems to accept an external trigger also needs further exploration and work with the manufacturers to provide a pulse synchronized with the transducer ping. This would be useful to indexing the acoustic data and the position data in an absolute fashion.

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