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AN APPROACH TOWARDS SOLVING REFRACTION PROBLEMS
IN EM1002 MULTI-BEAM ECHO-SOUNDER SYSTEM

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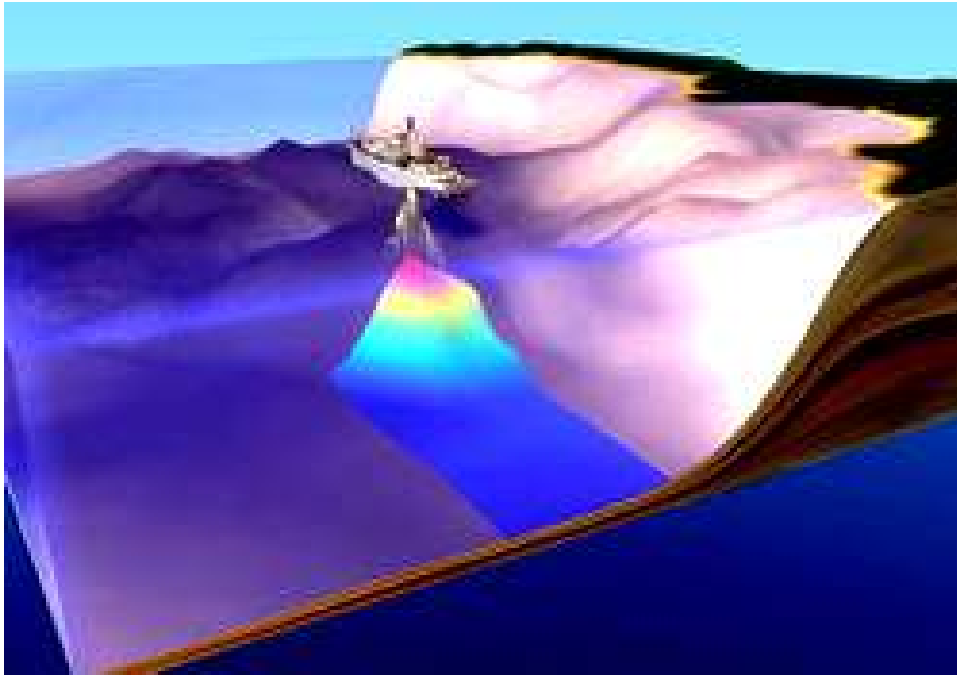


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**AN APPROACH TOWARDS SOLVING REFRACTION
PROBLEMS IN EM-1002
MULTI-BEAM ECHO-SOUNDER SYSTEM**

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ABSTRACT

Multi-beam echo-sounding is the technique in which multiple beams of acoustic in nature are sent down to seabed and upon reflection, they are received back and processed to give depths values. The report is focused to give a brief idea about EM1002 multi-beam echo-sounder system's components, calibration and data analysis with corrections. The topics such as "problem identification" and "the exercise conducted to solve the refraction problems online" were discussed to give the ideas about methods utilized to correct for refraction problems during data analysis. A 3D view of recently acquired data in Mandovi river is also shown as an example of using sound velocity profiler in data collection.

The report is also stressed upon the operator level maintenance and debugging of the EM1002 multi-beam echo-sounder system. This report will be very useful for the multi-beam system operators as it is focused on multi-beam operation, data-processing and maintenance.

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1. INTRODUCTION

Echo sounding is a technique for measuring water depths by transmitting acoustic pulses from the ocean surface and listening for their reflection (or echo) from the sea floor. This technique has been used since the early twentieth century to carry out traditional hydrographic surveys using single beam echo-sounders, which relied on a grid of tracks, between which data was interpolated to produce a map of certain parts of the seafloor in geographic reference frame. The echo-sounders used were of broad and narrow beam width types. These types of echo-sounders could provide only a profile along a track and hence to map certain area requires tremendous amount of time. In coastal areas it is very much required to have a 100% information about the topography of the seabed and it is difficult to achieve this by using single beam echo-sounders as they are time consuming and proved to be very expensive. To overcome this problem the advanced method of multi-beam mapping (swath mapping) been introduced, which has been one of the most significant technological advance for marine geologists. Multi-beam echo-sounder systems replaced the single beam transducers with 60 – 120 beams, simultaneously collecting data from a broad swath, allowing digital terrain models of the seafloor to be produced, equivalent to photographic and satellite imagery on land. Multi-beam echo-sounder systems has provided the vital depth input to charts that now map most of the world's water-covered areas. These charts have permitted ships to navigate safely through the world's oceans. In addition, information derived, has aided in laying trans-oceanic telephone cables, exploring and drilling for off-shore oil, locating important underwater mineral deposits, and improving our understanding of the Earth's geological processes.

Just after December 2005 trial, the ship sailed out for its first multi-beam mapping operation in exclusive economic zone of INDIA, which failed due to malfunctioning of the system. In May 2005, on visit of OEM engineer, the problem was identified and reported to change the underwater multi-beam transducer. The system was made operational after re-fitment of new underwater unit. And later from October 2006, the hydrographic surveys had been started off Goa. The hydrographic chart produced by system will be of good help to the port / river navigation authorities, geologists exploring the seas and oceans etc.

This report is stressed on the operational aspects, problems encountered in the acquired data, exercise conducted to solve the sound velocity problems and the debugging/ maintenance of the multi-beam echo-sounder system.

2. SYSTEM DESCRIPTION:

The EM1002 multi-beam echo-sounder system is based on the principle of sonar and echo processor with hydro-acoustical transmission fan, which divides into three separate sectors when the angular coverage is larger than 100° approximately. It has a swath coverage of 150 ° equal to 7.4 times the depth. The system provides the phase and amplitude detection methods for outer and inner beams respectively. System effectively operates for variety of depths from shallow water to 1000 meters and hence depending on the depth range, the system automatically selects one of the transmission modes (shallow, medium, deep).

2.1. EM1002 system's Technical specifications:

Operating frequency	95 KHz
Maximum ping rate.....	>10Hz
Number of beams per ping.....	111
Beam-width.....	2x2 °
Beam spacing.....	equi-distant and equi-angle
Coverage sector.....	up to 150°
Depth range from transducers.....	2 to 1000m
Depth resolution.....	8cm
Pulse lengths.....	0.2, 0.7 and 2ms
Range sampling rate.....	9 KHz (8cm)
Beam-forming method.....	phase interpolated
Economic survey speed.....	7 knots
Working sea state.....	3

The EM1002 multi-beam echo-sounder system consists of several units out of which some important units are listed below.

- A. Transducer array.
- B. Transceiver unit.
- C. Operator station.
- D. Raw data logger.
- E. Motion sensor.
- F. Positioning sensor.
- G. Sound velocity sensor.

2.2. TRANSDUCER ARRAY:

The transducer array is made up of poly-urethane material and is sealed for under water use. The array is used both for transmit and receive purpose. It is semicircular with a radius of 45 cm and 160° angular extent. Its weight in water is 90Kgs approximately. This transducer is fixed to the hull of the ship which is protected from strong longitudinal underwater currents by the dome called blister. The blister helps to eliminate bubble formation and improves acoustic measurements from the ship speed of 2 to 7 knots. The transducer consists of 8 Arrays and each array consists of 16 elements comprising of total 128 elements. Eight 12.5m long underwater cables connect the transducer to the junction box. The cables are fitted with connectors on the dry end. The cables from the transducer junction box to the transceiver unit are 5 m long. The function of transducer is to execute the command given by TRB-32, which is to transmit and receive the beams.

2.3. TRANSCEIVER UNIT (TRU):

The EM1002 transceiver unit contains the transmit and receive electronics and processors for beam forming, bottom detection and control of all parameters with respect to gain, ping rate and transmit angles. The EM1002 transceiver unit performs the data acquisition, received signal processing, transmission and reception for the multi-beam echo-sounder system. The cabinet holds two wired racks containing the system circuit boards.

- ✚ The top processing rack holds the complete processing unit with its own power supply. The unit provides data acquisition, signal processing and function control.
- ✚ The bottom receiver rack holds the receiver and transmitter boards, a controller, two power supplies and a large capacitor bank.

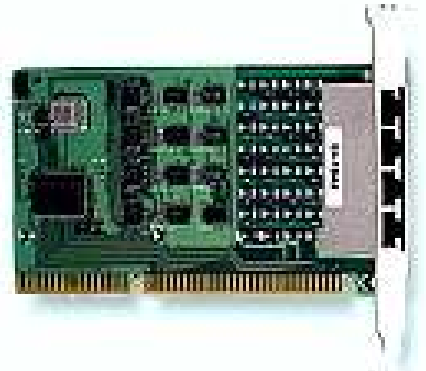
The processing rack contains 4-port serial line board, beam-former and signal processing (BSPs), diskonflash module, control processing unit (CPU) board, power supply and motherboard.

The receiver rack holds the transmitter/Receiver (TRB32) board, low voltage power supply, high voltage power supply, signal processor board RX (SPRX) and capacitor bank.

The total process of transmission occurs in TRU. The purpose of each module is described.

2.3.1. 4 – port serial line board:

The board is located in the processing unit. The serial line board is well equipped with surge protection and ISA bus. Surge protection is provided to prevent the board from damage caused by lightning and high potential voltage, hence transient voltage surge suppressor technology is introduced to protect the board. The board is basically used as serial interface between system and the peripheral instruments like GPS, motion sensor etc, which introduces corrections and fixes in the sounding data of multi-beam echo-sounder.



2.3.2. Control processing unit:

This board is the main controlling board for the multi-beam echo-sounder system. The board consists of DOF (DiskOnFlash) module, which contains the software needed for the CPU and BSP cards to work. The Ethernet port of this card is directly connected to the operator station. Optional interfaces like VGA



port, mouse and keyboard ports are also available on this board for debugging.

2.3.3. Beam-former and signal processing:



The beam-forming and signal processing (BSP) board (single slot standard ISA format circuit board) is a multi digital signal processor board, which perform the beam-forming and signal processing in sonars and multi-beam echo-sounders. The full process is controlled from a host processor.

The processing power in the BSP board is based on the 8- texas fixed point digital signal processors working in parallel while beam-forming data. There are additional 4- texas floating point digital signal processors interconnected to use both parallel and sequential processing of the beam formed data from the fixed point processors. In turn the BSP boards contain 4 main sections.

- ✓ Sonar input Data
- ✓ Beam-forming
- ✓ Signal processing
- ✓ Host interface

2.3.3.1. Sonar input Data:

The Sonar Input Data interfaces 18 bit wide and 1K deep input FIFO register. Input FIFO holds the data received from he transducer array through the receiver processing circuitry. A dedicated digital signal processor reads the input FIFO.

2.3.3.2. Beam-forming:

Two identical beam forming digital signal processing consisting of 4 digital signal processors each and a 16 bit wide ad 8K deep dual port memory (DPRAM), which helps in data exchange.

2.3.3.3 Signal Processing:

This section contains three digital signal processors dedicated to do further processing of the beam formed data.

2.3.3.4. Host Interface:

The host interface function is maintained by the master processor on the beam-forming and signal processing (BSP) board. It exchanges data with the host processor via a 16 bit wide and 8 K deep dual port memory (DPRAM) on the ISA bus.

2.3.4. Transmitter / Receiver board (TRB-32):

The purpose of TRB is to transmit and receive to and from 32 individual channels. It also contains a control interface that controls the 32 transmitters on the board.

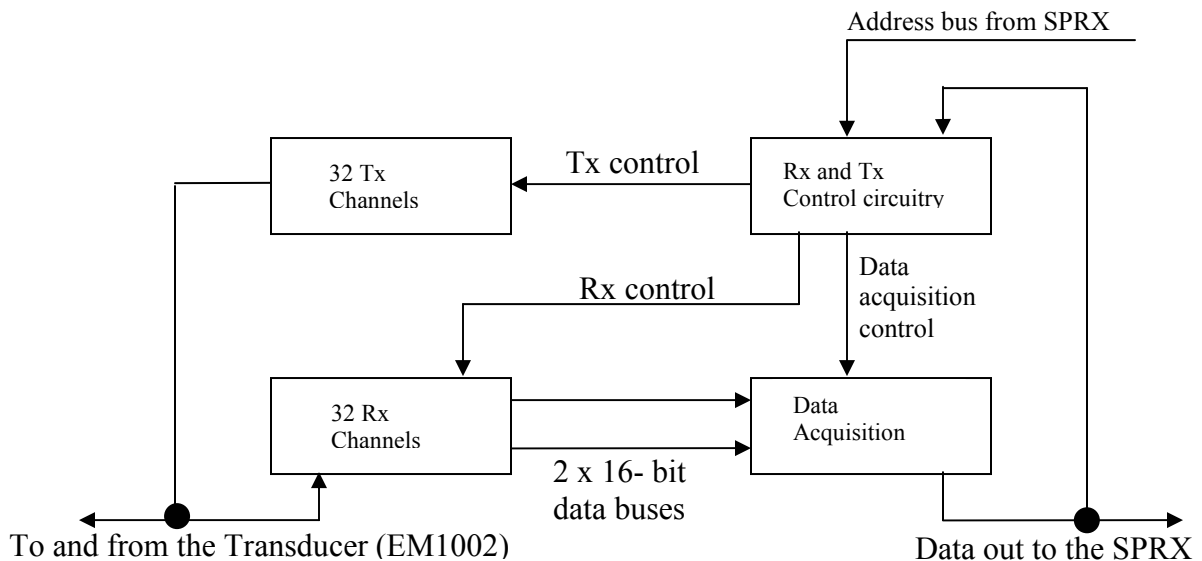


Fig. 1: Transmitter /Receiver Board (TRB) Block diagram.

2.3.5. SIGNAL PROCESSOR BOARD RX:

It's a high speed beam-forming and sonar signal processing board. The board design is based on the floating point digital signal processor (DSP). It is equipped with a number of front mounted LEDs, test points, potentiometers and coax connectors. The Texas digital signal processor operates

with standard peripheral circuitry (RAM, PROM with software) and the interface controllers. An emulator for the digital signal processor is developed, which consists of a controller board in a PC and an active POD which is connected to the target board by a 12 pin plug.

2.4. OPERATOR STATION:

The workstation used is comprising of all standard PC parts. The HWS-10 workstation is used as a operator station for EM1002 and is equipped to handle the heavy processing requirements and high speed, large volume data storage demands of hydrographic systems. As per M/s Kongsberg maritime, this workstation is specifically designed as the optimal platform for running real time operating systems which includes real time gridding of sounding data, filtering of sounding data, 3-D visualization of sounding data and storage and visualization of high resolution backscatter data from the seabed and the water column.

The primary task of the operator station is to safeguard the collected data and to visualize it for quality control. The acquired data is first getting stored on the pair of serial ATA disks which RAID 1 configured, thus are ensuring the loss of data even if one disk fails.

2.5. RAW DATA LOGGER:

It is an optional unit. Its main purpose is to log the samples through out the water column for all 32, 64 or 128 receiver staves. The sample data can also be presented on the display.

The raw data logger consists of beam former signal processing (BSP) boards, control processing unit (CPU) Board, harddisks for storage etc. The ribbon cable connecting the EM1002 Transceiver unit and the raw data logger is used for data transfer. The software is loaded on BSP boards and the harddisks which run automatically on reception of data on BSPs.

2.6. MOTION SENSOR:

The motion sensor used is of OCTANS surface mount type. The compass is an IMO certified survey grade gyrocompass and complete motion sensor. It is based on IXSEA's fiber Optic gyrocompass (FOG) technology, which outputs true heading, roll, pitch, surge, sway, heave, speed, acceleration and rate of turn. The gyro is a plug and play system that can lock onto true North in less than 1 minute even subsea as it does not need GPS input. No service limitations on roll and pitch since it involves no moving parts.

2.6.1. Technical specifications:

Housing (Lx W x H)	280 x 136 x 150 mm
Weight in air	4.8 Kg
Water proof.....	IP66
Material.....	Aluminium
Inputs	3 serial / 2 pulses
Outputs	3 serial / 4 analogue / 2 pulses
Power supply / consumption	24 VDC / 11W.

Heading:

Accuracy	0.1 ° secant latitude
Resolution	0.01 °
Settling time (static conditions)	<1 minute
Full accuracy settling time (all conditions)	< 5 minutes

Heave/ Surge/ Sway:-

Accuracy.....	5 cm or 5 % (whichever highest) Set-up free (SAFE- HEAVE TM)
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Roll / Pitch:-

Dynamic accuracy	0.01 ° (for +/- ° amplitude)
Range	no limitations (-180 ° to 180 °)
Resolution	0.001 °
Output protocols	NMEA 0183, binary.
Serial I/O.....	RS232 or RS 422 (user definable)
Baud rates.....	600 bauds to 115 kbauds
Output frequency	0.001 Hz to 100Hz.
Operating temperature range.....	-40° C to +60 ° C

No warm up effects, insensitive to thermal shocks

No latitude or speed limitations.

The gyro has applications in multi-beam hydrographic survey, AUV, dynamic positioning vessels, dredging, emergency gyro for submarines and main AHRS for navigation and dynamic monitoring. No spinning elements inside and hence maintenance free.

2.7. POSITIONING SYSTEM:

The system used for positioning the soundings is thales Aquarius² 22 DGPS system. After acquisition of sounding data the signal processing is done by BSPs and later each soundings collected are geo-referenced. the system has RS422 output to the motion sensor and the TRU of EM1002. The 1 PPS signal is tapped from the DGPS to the TRU's processing unit, which gives corrections to the Processing unit's clock used for time stamping. The data after corrections is placed with lat , long and time stamps and gets stored in the HWS-10 operator station. The system specifications are given below.

2.7.1. Technical specifications:

GPS/GNSS

- 32 x L1 channels
- C/A code and L1 phase, P code and L2 phase with multi-path processing
- Differential modes: WAAS/EGNOS, Numeric RTCM Version 2.2, messages 1,3,5,9,16,18 & 19.
- Precision: XY -1 to 2 m ; Z – 3m
- Raw data output:- 10 Hz
- Computed Data:- 20 Hz
- Latency :- <5 ms (0.005 s)
- Integrated TRM100 navigation and control terminal, ¼ VGA screen.
- GPS & Radio antenna connections.
- 4 – two way I/O ports (1 x RS232, 3 x RS422).
- Baudrates:- 1200 to 115200 bauds.
- AUX port (1 PPS output, external event input, etc).
- NMEA 0183 messages: GGA, GLL, VTG, GSA, ZDA, RMC, GRS, GST, GSV, GMP, HDT, HDG, ROT, VBW, VHW, OSD, HRP.
- User messages via ConfigPack.
- Rx 1635 HM-Link HF/MF Reception
 - Dual channel in HF band 1.6 to 3.5 MHz (BCPSK modulation).
 - Dual channel in MF band 270 to 330 KHz (MSK modulation).
- Power source: 9 to 36 VDC, floating input.
- Consumption: 12 to 25 W depending on configuration used.

2.8. SOUND VELOCITY SENSOR:

The sensor is supplied by M/s Applied Microsystems Ltd (AML). It is designed to measure sound velocity and temperature at the surface of the EM1002 transducer. The sensor has its internal calibration coefficients and outputs real time data to allow a “plug and play” environment. The optional addressable feature provide for daisy chaining with other sensors allowing the user to create their own system. This sensor plays an important role in beamforming and beam steering process.

2.8.1. Technical specifications:

- Proprietary “Time of Flight” technology.
- 1400 to 1550 m/s standard sound velocity measuring range.
- Dual channel
- +/- 0.050 m/s accuracy.
- Temperature range -2 to 32 ° C.
- Single channel.
- External power 8 – 16 VDC (12 VDC nominal) at 40 mA sampling current.
- 10 ms response time.
- RS-232 ASCII communications at 2,400 to 38,400 baud.

3. OPERATIONAL THEORY:

As described above the EM1002 multi-beam echo-sounder system have different parts, Viz. operator station, transceiver unit (which hosts maximum circuitry for signal processing), transducer and other external sensors. The operational diagram is given below. Initially all the instrument offsets pertaining to alignment or external sensor locations etc were fed in the acquisition software and the system is calibrated for roll, pitch, heave etc. During operation, the system is kept in the service mode (available on TRU), which allows the automatic adjustment of the power supplies in accordance with the power required by the system boards for transmission and reception.

As given in the functional block diagram above the sensors are started prior to EM1002 TRU and allowed for stabilization for atleast 5 min, however the sound velocity probe is made to stabilize for atleast 30 min. (sequence for start-up is Sound Velocity probe → DGPS → Motion sensor → TRU). Meanwhile the operator station and Ethernet switch is started. After about 5 minutes stabilization time, the EM1002 TRU is started and the Ethernet connection with HWS10 is established. Now first the Seafloor information Systems (SIS) software is started. The planning and survey administration modules in SIS allows survey planning of the cruise, which in-turn gives flexibility for entering survey locations and marking areas having geological importance while on run. The module also allows for real-time coverages and grids to be transferred to the helm display, which helps the sailor to maneuver the ship in proper direction. Once the SIS software is stable, the status of inbuilt modules of the TRU Viz, Processing unit (PU), Beam-forming and signal processing (BSP), shell status (SH) turn green which enables the operator to ping the transducer array. Once pinging is started, the various parameter settings made on the operator station are sent to the control processor of the Transceiver unit. The information is interpreted and passed on to the signal processor RX (SPRX) in the receiver rack, which inturn enables the TRB 32 (transmitter/ Receiver board – 32 Bits) to send the acoustic signal towards the seabed. The angular coverage sector and beam pointing angles are variable with depth, according to achievable coverage to always maximize the number of usable beams. The beam spacing is normally equi-distant, corresponding to 1.5% of depth at 90°, 2.5% at 120° and 4% at 140° angular coverages. The transmit fan is split in several individual sectors with independent active steering according to the vessel roll, pitch and yaw to get a best fit to a line perpendicular to the survey line and thus a uniform sampling of the bottom. Once the signal gets reflected back from

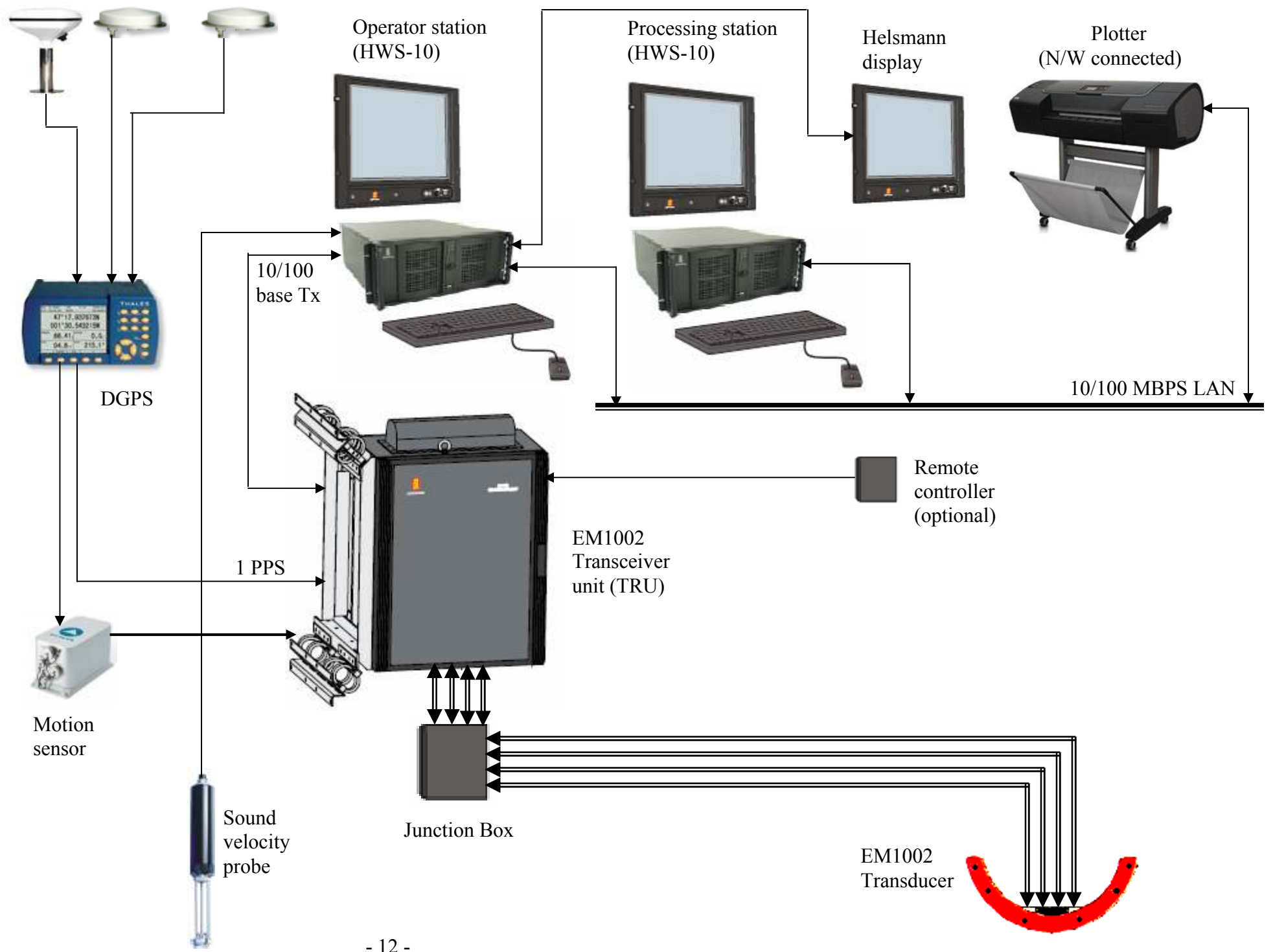


Fig: 2 Showing Block diagram of EM1002 Multi-beam Echo-sounder system.

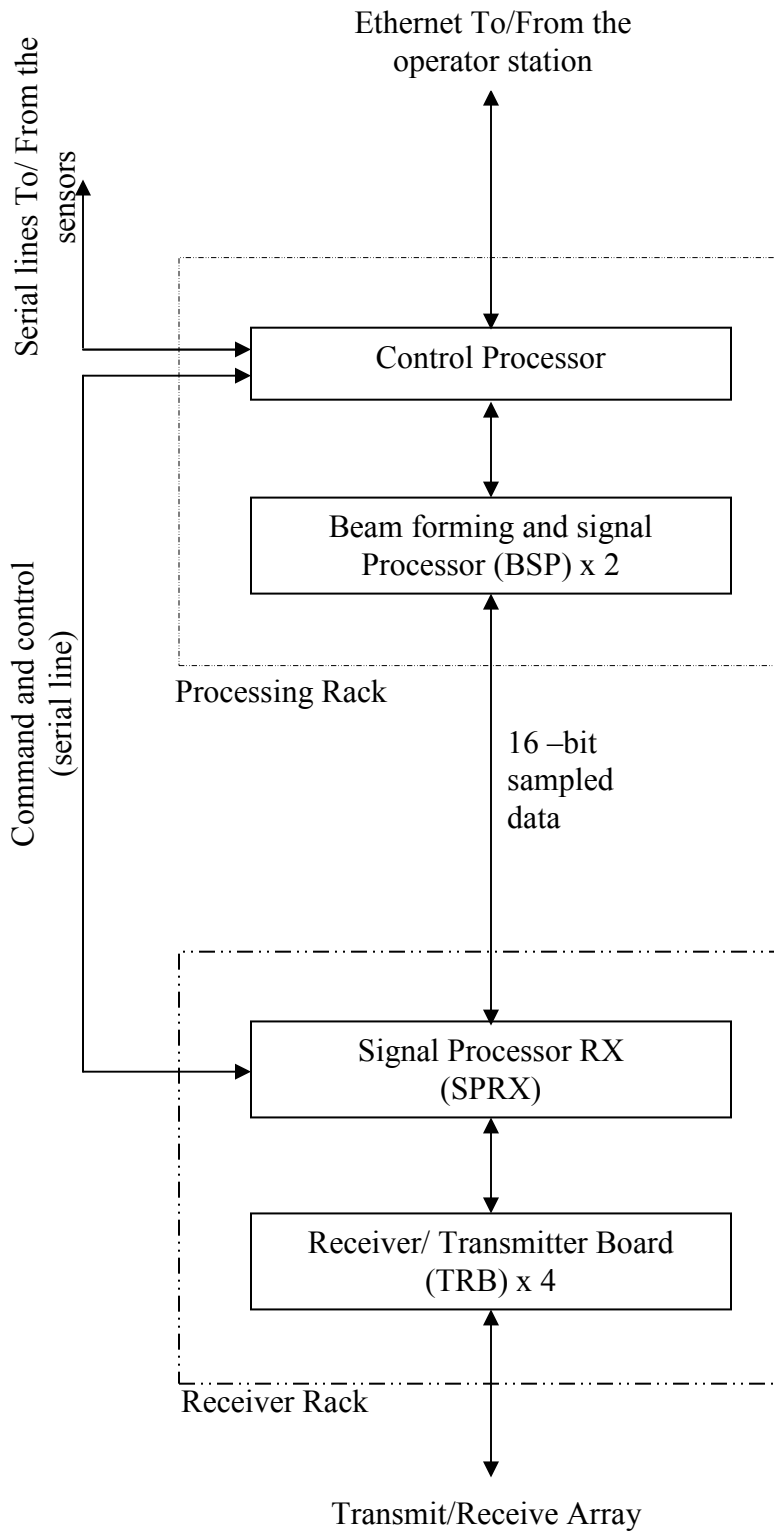


Fig. 3 Transceiver unit, simplified block diagram.

the seabed, the signal processor RX (SPRX) receive the echoes and pass them to the two beam-former and signal processing (BSPs) boards. The heart of the EM1002 Multi-beam echo-sounder system is the beam-forming and signal processing circuit boards, where multiple digital signals are

processed, hence also called as Digital signal processor (DSP)boards. It is designed to perform the beam-forming and signal processing in sonars and multi-beam echo-sounders. It is controlled from a host processor. The task of beam-forming and beam steering is done considering the sound velocity probe values and the beam transmission through the entire water column is taken care by considering the sound velocity profile values. The beam forming is done using time delay technique. The beam-forming and signal processing boards are multi digital signal processor boards, which have fixed point digital signal processors working in parallel while beam forming the data. In addition there are four floating point digital signal processors interconnected to use both parallel and sequential processing of the beam-formed data. Once the beam forming is done, the data is sampled and geo-referenced in the control processor unit. The Beam-steering is fully taken into account when the position and depth of each sounding is calculated, as is the sound speed profile effect on ray-bending. All the data logged gets transferred to the main operator station through a Ethernet cable 10/100 base Tx. Hence all the parameters are also get logged with the data pings on the hard-disk in the operator station. The data stored is in the binary simrad90 (used to save the space and CPU time required to store data) format. The helmsman display is used on wheel house, which helps the operator to give necessary instructions to the sailor for the proper navigation.

Onboard data quality check been done online in SIS software panel and also by post processing the data through Neptune (cross-line, backscatter and sound velocity checks modules). In SIS software the quality checks were carried out by visualizing the cross-track, beam-intensity and quality values of the data and also the seabed image compared with the grids developed on screen. Simultaneously the attitude and heading data is also been checked for any errors in post-processing software. As all the systems are connected to each other by means of a Ethernet cat5 cable. Hence data can be accessed at any time for post- processing purpose. The acquired raw data from each research cruise are archived on HDD and later on compact discs (DVD - ROM). Further analysis and bathymetry chart preparations are done at shore.

4. CALIBRATION:

For any system to perform within the accuracy, requires it to be well calibrated with proper offsets. The correct calibration of the vessel attitude sensors and the time delay of the positioning system is vital to the quality of multi-beam echo-sounder data. Reliable data can only be acquired after proper calibration has been performed on the system as a whole. This calibration begins with the alignment and static offsets of the sensors referenced to the centerline of the vessel and the transducer. The alignment will reduce the static corrections of each sensor and can be performed with either GPS receivers or a total station geodetic instrument. After the static offsets are determined, a patch test is performed. This test is designed to reveal the following residual biases: pitch offset, roll offset, positioning time delay, and azimuthal offset. The test consists of a small survey of several lines that are evaluated for inconsistencies and then corrected using software designed for multi-beam surveys. There are several mathematical equations developed for analyzing these biases that are incorporated into the processing software for the patch test. The performance test is the final check of the offsets and biases to verify whether the data meets accuracy requirements for the survey. This test is a series of parallel and cross lines with significant overlap to give redundant data. With the improved resolution and coverage comes the need for much greater control and calibration to ensure that the sounding is recorded from the correct position on the seafloor (geo-positioning). This geo-positioning is accomplished by using a high accuracy differential global positioning system (DGPS), heave-pitch-roll (HPR) sensor and a gyrocompass. In addition, the time synchronization for all these components is critical. For this reason, the system accuracy is comprised not only of the multi-beam sonar accuracy, but also of the various components that make up the total system. This overall quality control assessment must be performed in the field before the actual survey been conducted. The field procedures necessary for proper calibration are the alignment of each sensor, the patch test, and the performance test. These are discussed below:-

4.1. ALIGNMENT AND STATIC OFFSETS:

The process of physical alignment of the vessel platform, transducers, gyrocompass, and motion sensor is referred to as static offsets. This process ideally will take place with the vessel stabilized on blocks or on a stationary platform, usually at shipyard, where more exact measurements can be made. This stability will minimize errors in the positioning of the sensors and, with the proper offsets applied, the static corrections will be determined. The sensors should be measured from a

reference point in the vessel that is typically the center of gravity (CG) or the intersection of the pitch and roll axis. The center of gravity will change with varying load conditions of the vessel, thus must be chosen to represent the typical conditions expected while surveying. This information can be obtained from the blueprints of the vessel. The reference point should be a place that is easily accessible and from where measurements to the sensors will be made.

The sensor offsets are measured distances from the reference point to the center of the sensor. The center of the sensor can be found in the manufacturer's schematic of the sensor, or can be accurately measured with a survey tape. The magnitude and direction of the measurement should be verified and recorded.

4.2. CALIBRATION WITH RESPECT TO MOTION DATA (OCTANS):

If possible, the motion sensor should be placed on the centerline of the vessel as close as possible to the center of gravity or the intersection of the pitch and roll axes of the vessel, with the same mount angles used for the transducer. The x-axis of the motion sensor should match the x-axis of the transducer (x-axis is defined as the bow-stern axis of the vessel while the y-axis is the beam axis of the vessel). Azimuthal misalignment of the motion sensor will result in the depth measurements being in error proportional to the water depth.

In practical case, most modern sensors have little or no drift with time, but sometimes the time delay of the positioning system may vary according to system setup. It is therefore important that the calibration values are checked at regular intervals or at the start of the survey. Hence the calibration cruise was proposed soon after the dry-dock. At the dry-dock all the offsets related to multi-beam transducer, DGPS antennas and motion sensor positions were noted so that these parameters can be fed in the acquisition software during calibration task. The built in calibration utility in SIS was used to find the offsets in roll, pitch and heading etc. The area was selected after consulting with OEM engineer and the calibration task was initiated. Inbuilt calibration module is available in SIS software for online calibration of the multi-beam echo-sounder, which is intended for analysis of data from a calibration survey. Depths from different survey lines may be compared and it is possible to apply different roll, pitch, heading and time offsets to verify the consequences on the computed depth values. This module is compatible with online and offline operations. The calibration details for each parameter are listed below:-

4.2.1. Roll calibration:-

The roll calibration is normally done in the area having no features or smooth area. So the area was selected and lines were run in opposite direction with 100% overlap. Once done, by activating the calibration module, the swaths of both the lines were imported and by using the numerical control panel, the values were determined for roll offset. Then this offset is saved through the installation

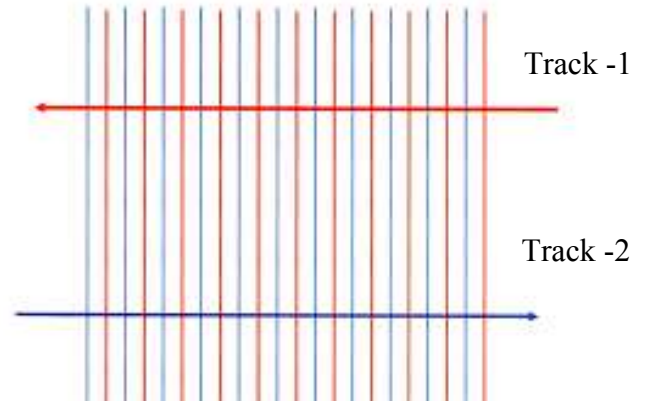


Fig. 4: showing details of roll calibration.

parameters module of SIS software in to the control processor (PU) memory of TRU for the EM1002 system utilization. The figure shows how the roll calibration is done.

4.2.2. Pitch calibration:-

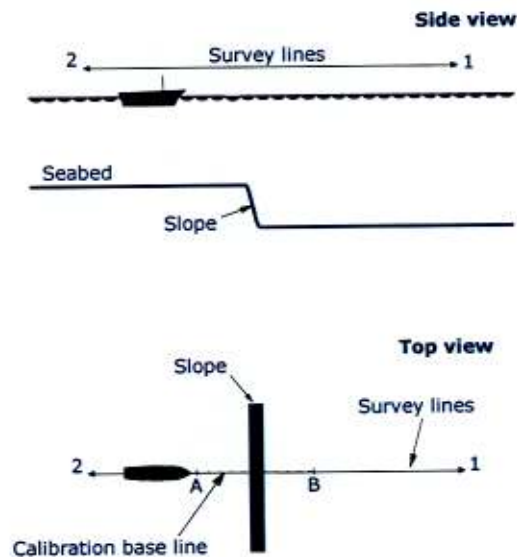


Fig. 5 :- showing details of pitch calibration

The pitch calibration is normally requires a distinct object (preferred) or feature or a slope of maximum 20 °. for determining the offsets. In this case the ship is made to pass over the slope in both the direction. The data get logged once logging is done. Once finished with the line survey, the data is later imported in the calibration module by marking a corridor. The swaths of both the lines are adjusted in the calibration module and the offsets are then stored in the installation parameters module.

4.2.3. Heading calibration:-

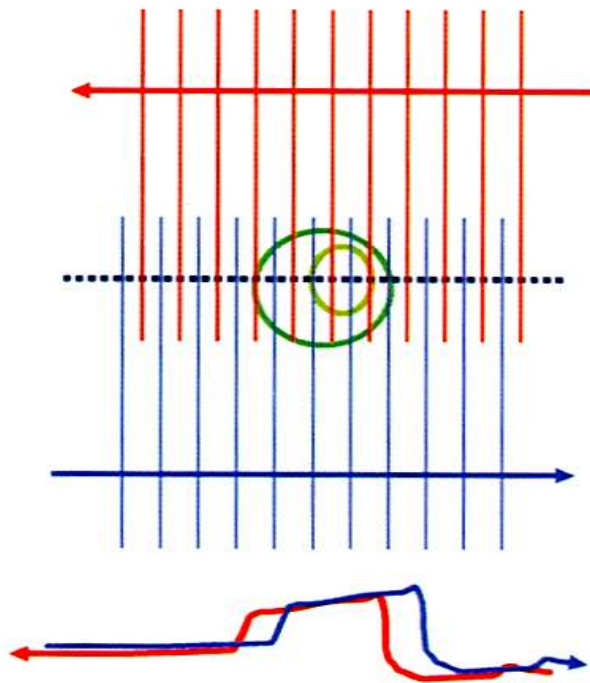


Fig. 6 :- showing details of heading calibration

In heading calibration preferably an object is considered by the side beams, however due to oblique angle of the transducer it is necessary to run the lines in opposite directions to get an overlap. This makes the calibration dependent on time and pitch. And these parameters must be solved first.

4.2.4. Outer-beam calibration:-

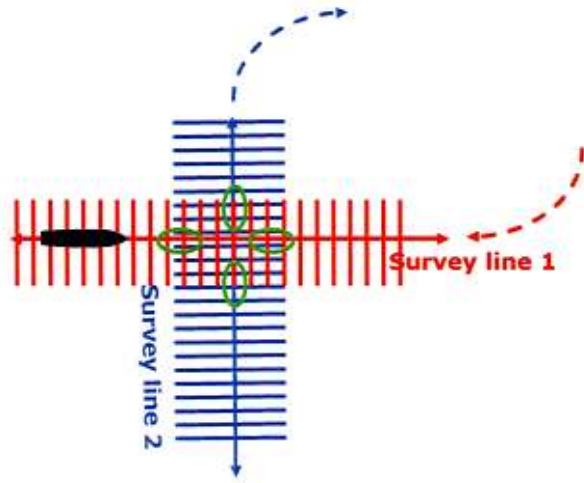


Fig. 7 : - showing outer-beam calibration.

For outer-beam calibration it's been required that the two lines are surveyed perpendicular to each other and the outer beams are then calibrated taking over a reference of center beams on each line. The test is normally done in smooth surface or flat areas, where there is no feature. Before performing this test the roll, pitch and heading factors are well calibrated.

4.3. SOURCES OF ERRORS:

Several sources of errors and biases exist in multi-beam surveying that are not found in single beam surveying.

- Static offsets of the sensors are the distances between the sensors and the reference point of the vessel or the positioning antenna.
- Transducer draft is the depth of the transducer head below the waterline of the vessel.
- Time delay between the positioning system, sonar measurement, and HPR sensor is the delay or latency that must be accurately known and compensated for in the processing of the hydrographic data.
- Sound velocity measurement is the velocity of sound in the water column that must be accurately known so the correct depth can be measured.
- Acceleration and translation measurements of the HPR are critical for corrections to the vessel's roll and pitch.

These parameters must be measured and corrected in the multi-beam sonar system. It is assumed that the software used in the processing will accommodate these inputs and that the correct sign is used when entering the offsets and corrections.

5. DATA COLLECTION AND PROBLEM IDENTIFICATION:

Soon after multi-beam transducer re-installation at Goa Shipyard Ltd, Vasco- Goa, a cruise was proposed for calibration and commissioning of the equipment. The planning of this sea acceptance test cruise was done during our ongoing dry-dock at shipyard in October 2006. The survey site for calibration work was chosen in-accordance with the OEM engineer. The data collected by EM1002 multi-beam echo-sounder system at the calibration site found to be very good and required very less amount of processing. Subsequently the cruises were undertaken for mapping the exclusive economic zone of India (west coast). The data was collected in usual settings and found to be bad after analyzing the data through the post processing software. The system is meant for medium water depths and hence it was very difficult to maintain the good accuracy or quality of data in shallow waters, which system has proved. The processing task had been handled by the group of personals. The analysis were undertaken to locate the problem with the multi-beam echo-sounder data. The steps followed have been described below:-

The data was analyzed in Neptune software supplied with the EM1002 multi-beam echo-sounder system by M/s Kongsberg Maritime. Norway. In post processing, the raw data collected is been converted to survey format by a sub program patch called “replay”. This survey format files been imported to main “Neptune” program and the main task of post processing takes place by making rules. The rules contain the information to be fed to the module to correct the data for certain parameters like tide, roll, pitch, heave etc. The sequence of data processing of EM1002 multi-beam echo-sounder system is given in Appendix – 1. Once importation of data in Neptune is done, the position processing module is executed. This module corrects for the positional errors caused due to uneven satellite geometry, shadow region, less number of shore station etc. And hence the positions (center beams positions) are merged with the corrections for further processing. Other important modules are data cleaning, cross-line, gridding etc. Gridding module is basically used for gridding the raw (survey converted) or processed data in to required binning size. This module allows the operator to visualize the seabed topography. While the cross-line module enables the user to locate any fault with the data. The series of Neptune processing steps are executed to obtain the final product, which can be then utilized in CFLOOR software (3D image/plot/map generating software).

At shore, we analyzed the EM1002 multi-beam echo-sounder system data through above mentioned modules by using the given processing procedure (Appendix -1). The problem was detected at initial stage of gridding and crosschecked with cross-line module. The data was

showing parabolic shape as shown in Fig: 8. and the contours made were of irregular shape which proved that the data collected was wrong.

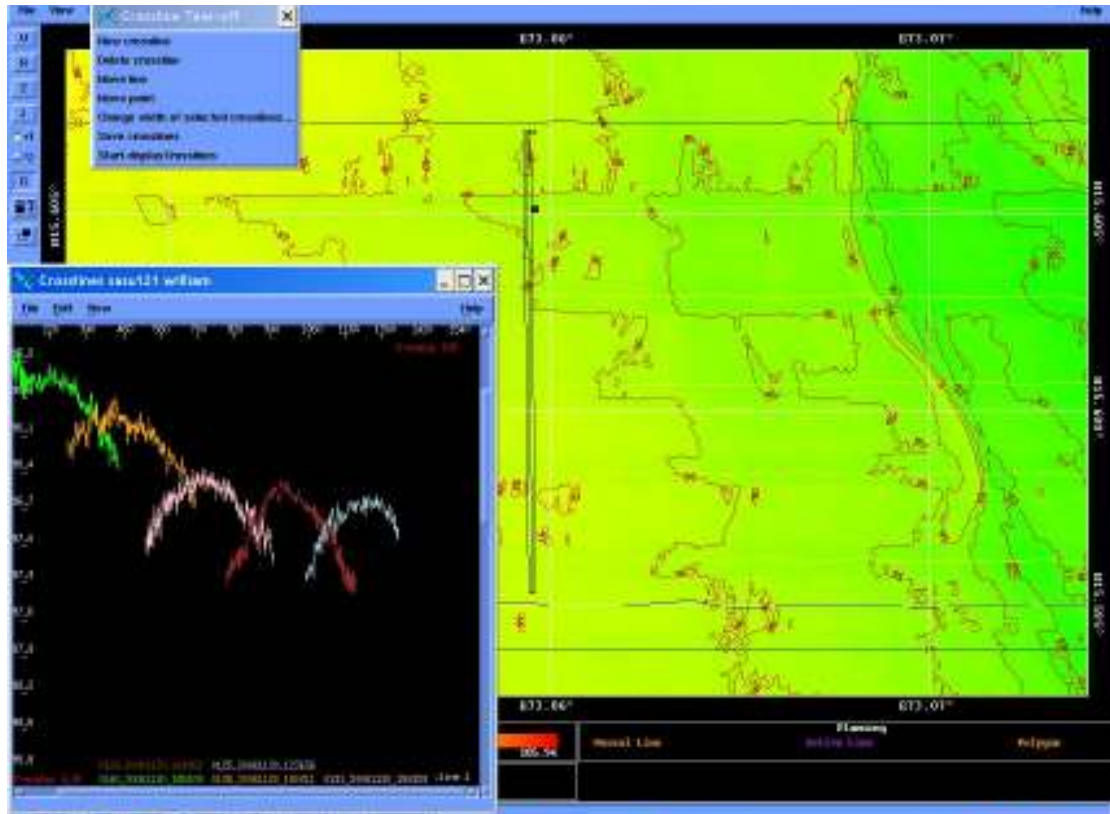


Fig. 8 :- showing refraction artifacts through cross-line and grid modules.

More analysis on the multi-beam data was carried out, using different available modules in Neptune as well as through CARIS Hips and Sips processing softwares. The data was checked for both predicted as well as observed tide at the reference station (Marmugao), but this didn't shown any improvement in the data. The use of correlation plotting and depths rules had improved the data to some extent, but found that these methods eliminate lot of valid data beams. The binstat module provides good flexibility in handling these type of data, but again the techniques found to be inappropriate. The fig 9. show the refraction artifacts in data cleaning and correlation plot modules.

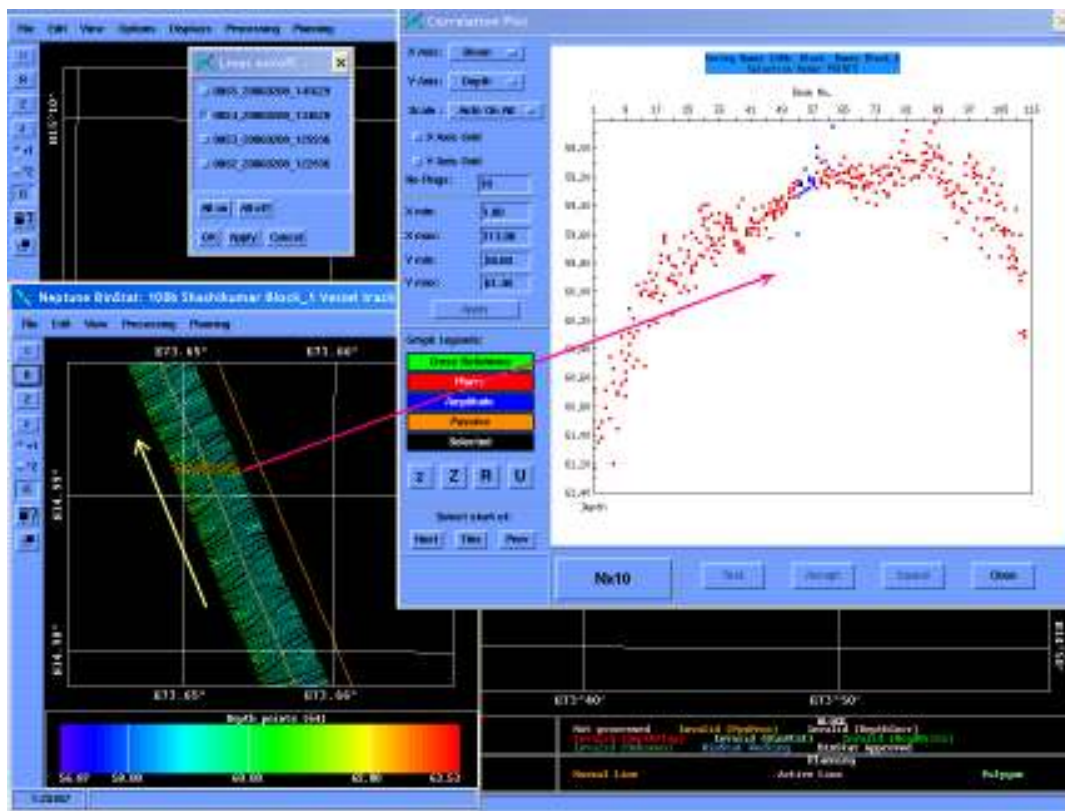


Fig. 9 : showing refraction artifacts in Bin-stat & correlation plots modules.

The bunch of programs were utilized for finding the cause of the problem. Some of these programs are mentioned below:-

1] smlGraphs.exe:-

It is used for plotting beam intensity (amplitude and phase detected), waterfall, beam quality, track visualization, cross-track, filtered amplitude ,stave data etc either in realtime or playback. The data can be of survey or raw format.

2] Showrawparam.exe:-

This external program is used for displaying the used installation and interfaced parameter. These parameters are getting logged into the raw files while data acquisition. The program is a dos utility and can be executed from command prompt.

The output filename is the input filename with extension “*.param”.

3] printSSH.exe:-

The module is a DOS utility, and used for printing out the sound speed values at the transducer surface. This utility is mostly used to find out if the sound speed values supplied to the BSP cards for beam forming and beam steering process are correct. It displays all values of sound velocity values acquired and used during the multi-beam data acquisition.

4] PrintRuntime.exe:-

This DOS utility sends all the runtime parameters from a particular file to screen. The parameters can be utilized to verify inputted runtime parameters. These parameters were introduced during data acquisition. The output of this program includes depth datagrams and other runtime parameters such as Tx /Rx beam width, abs coefficient, ping numbers, beam spacing, coverage etc.

5] printAttitude.exe:-

the utility prints the datagrams available from motion sensor. This datagram was checked up if there were any problems with the transmission rates of motion data etc. the programs prints the sensor number, ping number, time in milliseconds, status, roll, pitch, heave, heading etc.

Note:- for any help or information on above utilities, type the below syntax and hit return:

```
C:\simrad\bin> [program] -h
```

6] Recalculating depth:-

when raw data was analyzed for any errors, it was found that the data had latency problem. Even by using above utilities for diagnostics, the problem appeared to be on the same status. From our email communications with the OEM engineers, they suggested to check for raw data through replay module and recalculate the depths with new attitude data if found wrong. The procedure is as follows:-

A) Running replay module.

1. double click on replay module.
2. select the input and output directory.
3. select extract attitude and UTM.
4. now start the process

B) Open a terminal window and type

```
set SLEEP_TIME=0
```

Now navigate to the raw data directory with *.all files

```
cd (directory with the .all files)
```

```
cat *.all | ddsemx -s india user -G 25 -
```

In this case:-

india is the new survey name

user is the operator

25 is the millisecond time delay on the motion sensor

These steps were also done and finally the data was studied thoroughly by using number of tools available within the system and found to be affected by refraction artifacts, which were noticed, especially in the outer beams. The attempt was made to define these refraction artifacts as the bending or curving of a sound ray that results when the ray passes through a sound speed gradient (the sound speed gradient is the rate of change of the speed of sound with distance) from a region of one sound speed to a region of a different speed. The amount of ray bending is dependent upon the amount of difference between sound speeds, that is, the variation in temperature and salinity of the water. The problem was analyzed and an effort was made to manually edit the sound velocity profile. The Idea of manually editing the sound velocity profile worked fine and a considerable change in the cross-line profile was noticed. The cross-line module gave the flexibility to visualize and edit roll, pitch, heave, time and sound velocity corrections etc. but the actual changes will be made once the rule is applied. This module reported encouraging results.

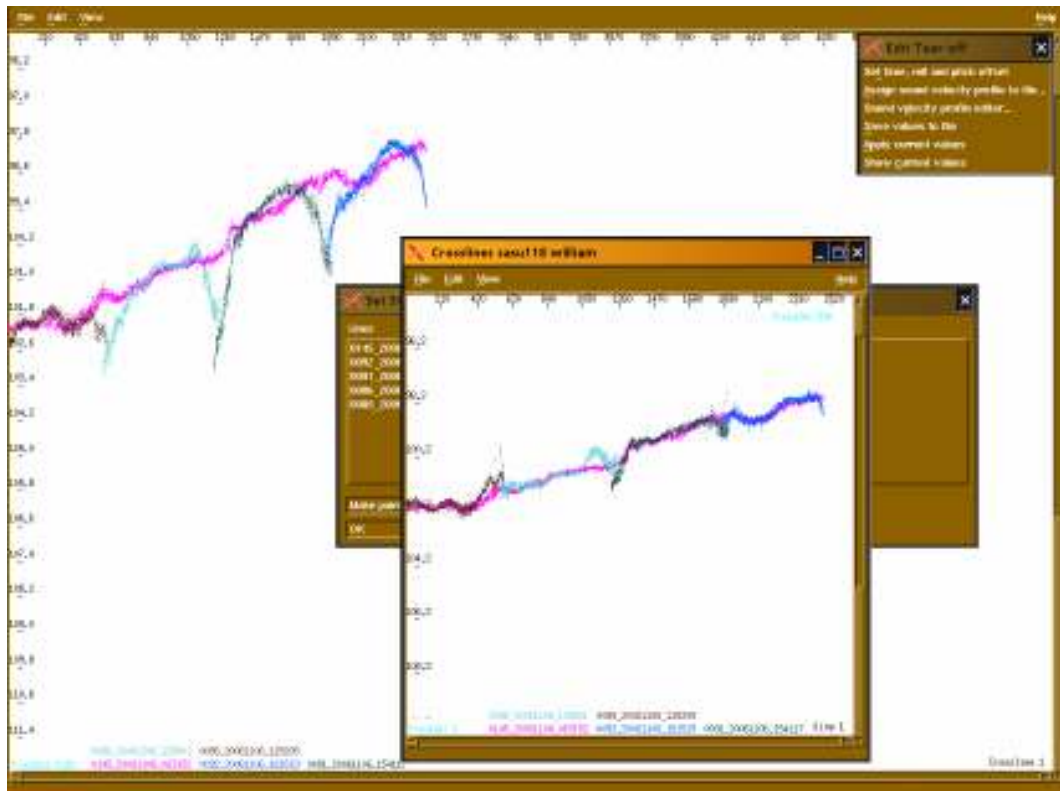
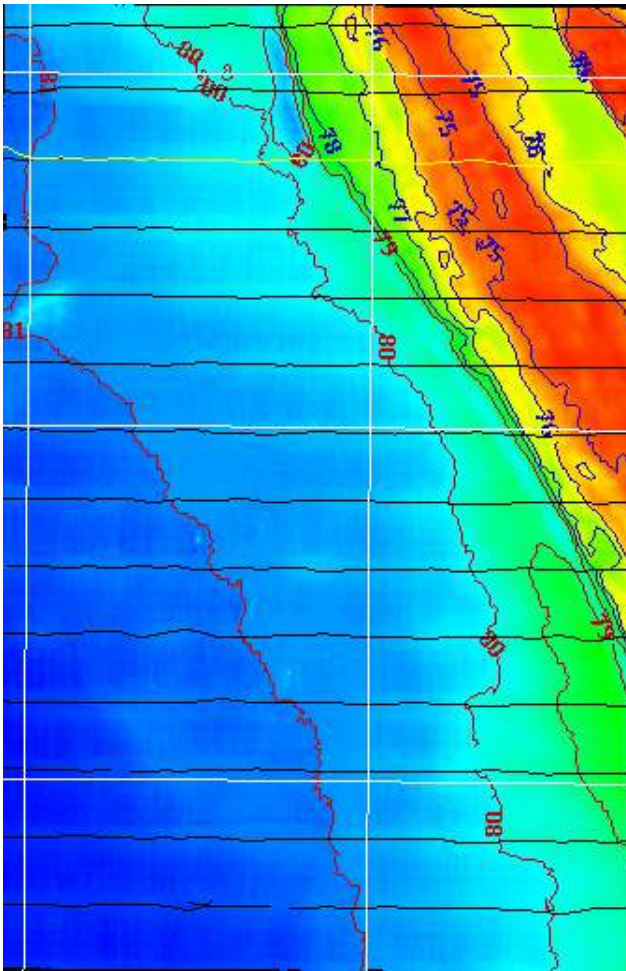
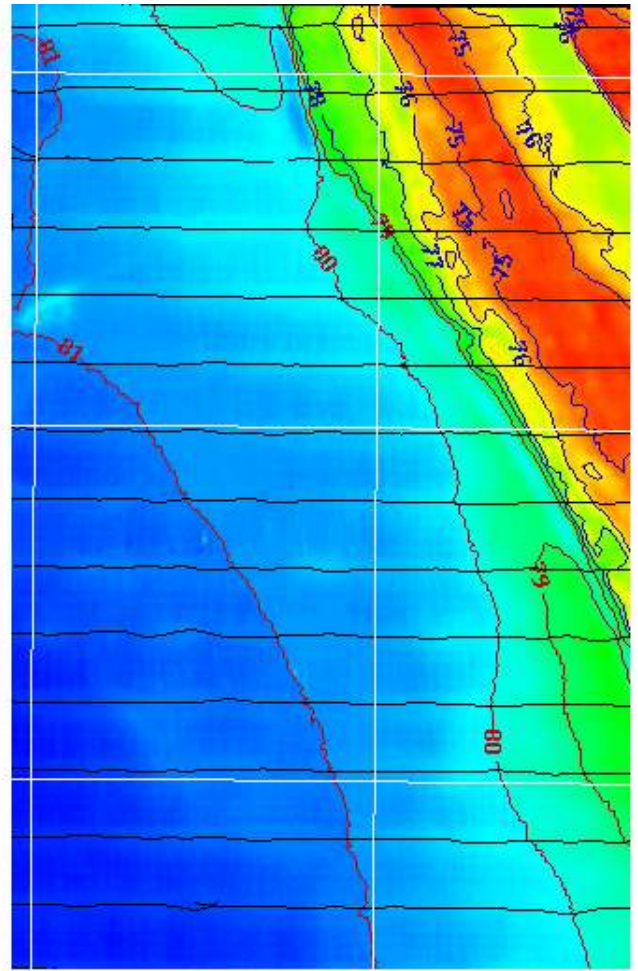


Fig:- 10 showing swath match after refraction correction in crossline module.

The outer beams which were bending and showing more depths were found to be aligned with the center beam as shown in above fig: 10. Hence a statement was made which reflects that, the final refraction corrections are to be performed on the multi-beam data as a part of post processing. The references were been searched to validate this type of data processing. The number of references from J. Hughes Clarke and others who performed the refraction corrections through a software called “swathed”. They have either used the corrected sound velocity profile or corrected sound velocity probe values, this in-turn calculates the new beam pointing angles and assigns new beam receiving sectors. Hence calculating the new correct bathymetric depths from the original data files, thereby reducing the refraction errors. The example of corrected data is shown in fig: 11.



Before refraction correction



After refraction correction

Fig: 11 Shows the refraction corrected data.

6. DATA ANALYSIS (A PROBLEM SOLVING APPROACH):

The EM1002 multi-beam echo-sounder data was analyzed at NIO as well as by OEM engineers from M/s Kongsberg Maritime, Norway. And final approach was made to replace the underwater multi-beam transducer. Due to this the dry dock for CRV Sagar Sukti was made at M/s Goa Shipyard Ltd. Vasco –Goa.

Just after finishing with the re-installation of EM1002 Multi-beam transducer, the calibration cruise was undertaken. The cruise left the GSL jetty on 23rd October 2006 at 1830 Hrs the calibration area plan was made by NIO marine surveyors in association with the project leader (EEZ) and the OEM engineer. And hence, the survey was conducted at off Ratnagiri coast in the Angria bank region, as the calibration job required the feature-full areas. The normal calibration job for the EM1002 system requires feature to calibrate for pitch and heading and a smooth area for roll component. The calibration was done successfully at heights ranging from 40m to around 1000m approximately and the data was analyzed in post-processing software and found correct. Later the same system was operated in shallow water areas off Marmugao in the depth range of 63m to 78m approximately and found that the data is containing artifacts of refraction in nature, which had created unwanted features and rough contours in the smooth areas but hardly affected the featureful areas. The cause to this problem was later identified during the analysis at shore laboratory. And an approach was made towards solving this problem.

In post- processing software it was noticed that the slight variations in sound velocity make a lot of difference in calculating the depths, hence on trial basis the two adjacent track lines and a cross-line over them was taken for analysis. The data was acquired with equi-distant beam- spacing and it was noticed that there exists the refraction problem in the outer beams, which was due to the wrong mean sound velocity (C_{mean}). The post- processing (Neptune) software gives flexibility to recalculate the depth values with new set of parameters (like installation parameters, attitude or sound velocity etc). so the effort was made to recalculate the depths with new modified sound velocity to cancel out these refraction effects in the slant outer beams. This was found to be successful and about 90 to 95% of refraction problems in the outer beams were solved, which gave good crossline fit with the tracks. The procedure for manually editing the sound velocity profile and recalculating the depths through Neptune software are given in appendix -2 & 3. The international papers of Hughes Clarke (scientist from Ocean mapping group) on refraction corrections were found and the knowledge was utilized for correcting the previously acquired SASU data.

7. EXERCISE CONDUCTED TO SOLVE REFRACTION PROBLEMS ONLINE:

With our continuous efforts to improve upon refraction artifacts, suggestions were made to trap the problem at early stages of acquiring sound velocity. Previously same SBE19plus CTD was used for acquiring Sound speed data (derived from conductivity, temperature and pressure sensor values). The analysis were done for CTD data (all cruises) with all its sensor values individually plotted for comparison to locate the problem with CTD and found to be much variations in salinity sensor. Later these data was verified by the senior scientists and other members of the project. The group was made to counter attack this problem, and ultimately a cruise was taken for conducting an exercise to locate the best CTD, which can be further used during multi-beam cruises to acquire sound speed data. The exercise was carried out with 4 individual CTDs Viz. SBE19plus (2 Nos.), SBE19 (2 Nos.). the deployment procedure were finalized and with 2 CTD at a time (since CTD - winch had a limitation). The procedure was repeated for another set and later alternately. The data acquired was simultaneously analyzed onboard for all the parameters (salinity, temperature, scans, sound speed by Chen-Millero, Delgrosso, Wilson equations). The problem was noticed in one of the CTD, when compared with the reference, giving variations in salinity values and hence the sound velocity. Other two CTDs were found to have some offset with the reference CTD. After completion of the CTD exercise the cruise was taken, to acquire and test for the data. In spite of a bad weather having sea state more than 5, the data was acquired and found to have less problems compared to previously acquired data. The repetitive analyses were done at shore for finding any errors. Subsequently the 3D plots were made for more details. The above bathymetry data quality checks were done by using Neptune and CFLOOR software supplied by M/s Kongsberg Maritime, Norway and also using CARIS Hips and Sips software.

Through this it has been revealed that the refraction problem is due to the wrong mean sound velocity, which can be either sorted out by using correct sound velocity profile during data acquisition or by applying refraction corrections during post-processing. One drawback of the CTD is that it measures the sound velocity values from the derived parameters like salinity, temperature etc and hence could lag in accuracy as compared to the accuracy which the multi-beam system demands in shallow water. Hence a sound velocity profiler is needed, which measures the sound speed on the principle of time of flight technology. The operation of the profiler is simple and requires software activation for data acquisition. The instrument acts as a portable system, which can be operated at any time even in turbid waters unlike CTD, which cannot be operated in most turbid waters ex. Port and harbour areas etc.

In our recent mapping operation (Mandovi Experiment) in Mandovi river which was carried out by using a sound velocity profiler from M/s Applied Microsystems, Canada, it has been found that the profiler is more suitable to measure sound velocity in water. Hence it is been revealed that either a good calibrated CTD should be used or profiler is the only option. Below given figure shows recent acquired data in Mandovi river using sound velocity profiler.

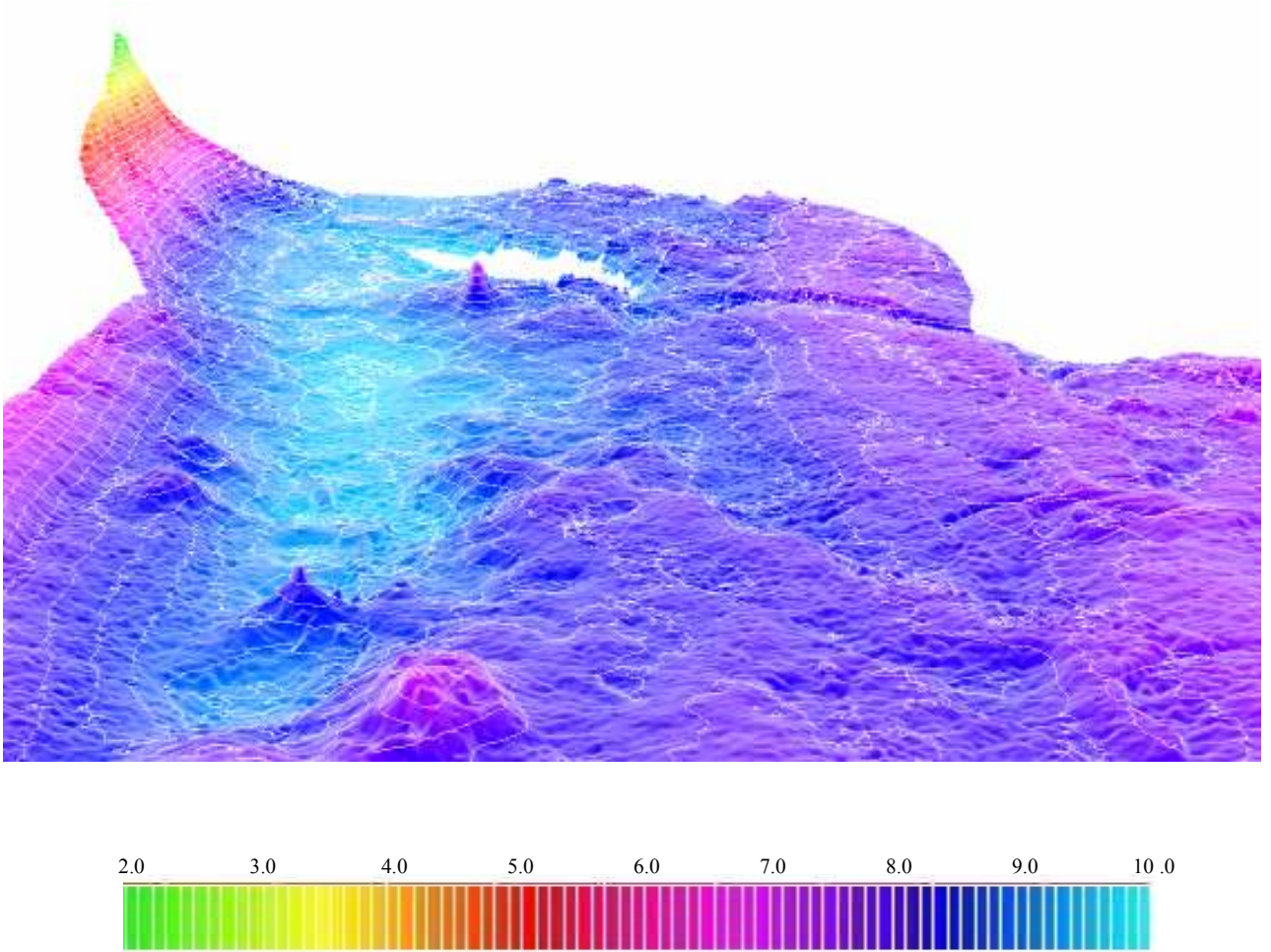


Fig: 12 Shows the 3D of recently collected data in Mandovi river.

8. MERITS OF EM1002 MULTI-BEAM ECHO-SOUNDER SYSTEM:

The EM1002 multi-beam echo-sounder system is basically a medium water multi-beam echo-sounder. The system has applications in the hydrographic field and for navigation purpose. Some of the merits of the system are given as follows:-

1. The EM1002 multi-beam echo-sounder is extensively used in marine geological research works.
2. The system has wide operating depth range, i.e. from 3m to 1000m.
3. It is been highly used for navigational channel mapping and surveys in rivers, port and harbour areas, which is very helpful to port authorities.
4. In our institute, its been used for mapping our exclusive economic zone of INDIA.
5. On knowledge of bathymetric maps produced from the system, the dredging and route surveying operations can be carried out.
6. The terrain models generated by system can be utilized for defense purpose.
7. The bathymetry soundings collected from the system can be utilized for seabed sediment classifications.

9. DEMERITS OF EM1002 MULTI-BEAM ECHO-SOUNDER SYSTEM:

1. The system is bulky with semicircular transducer array. The two options are available for mounting of array on vessel. Viz. side mounted or hull mounted. In case of hull mounted the transducer is mounted on vessel hull, hence calibration pattern is not frequent, but the draft of the vessel increases significantly, which makes the navigation of the vessel difficult in the channel. In case of side mounted or bow mounted (signifies portable use) the calibration of the system is required to be performed frequently due to change of installation parameter and involves lot of time.
2. The water column imaging facility is disabled in EM1002 multi-beam echo-sounder system. Hence visualization of sampled data at every depth within the water column is not possible.
3. In EM1002 multi-beam echo-sounder system, its required to have a sound velocity profile at regular interval. Hence it should have been a good help to operator if the equipment is compatible to acquire real time SV profile and correct accordingly for beam-forming and steering processes.

10. DEBUGGING OF EM1002 SHALLOW WATER MULTI-BEAM ECHO-SOUNDER SYSTEM.

The EM1002 shallow water multi-beam echo-sounder system displays numerous messages related to software and hardware of the system. This section is basically stressed upon the basic debugging of the system, involving operator level maintenance and repairs. Some of the frequently experienced problems with the system are discussed as follows:-

A. Communication error with BSP.

a. Indications:-

1. When clicked on ping button, PU status –Red; BSP status – Green; SH status – Green.
2. BIST shows BSP failed; SPRX/BSP link – failed, but other tests are passing.
3. Missing BSP rangetry again
4. Received something raw from O.S: RAW.

b. Action:-

1. In this case the BSP cards get locked when wrong sound velocity profile is fed. Hence to unlock the cards use a default sound velocity profile in runtime parameters.

B. Link Failure between PU and operator station.

a. Indications:-

1. TRU connection established
2. SIS not getting activated

b. Action:-

1. check for physical link between PU and HWS-10
2. check for IP address of both the units
 - a. PU – 157.230.15.60
 - b. HWS-10 – 157.230.15.30
 - c. Subnet mask should be same – 255.255.0.0
3. Check for the network card (PCI slot).

C. Big difference in Time of PU and ZDA.

a. Indications:-

1. In numerical display the ZDA and PU time blinks red.
2. Message service shows warning messages of too big difference between PU and ZDA.

b. Actions:-

1. Check the installation parameter module of SIS software.
2. Check time to use option in sensor setup→settings.
3. If possible verify all the installation parameters thereafter.

D. Fluctuations in depth values.

a. Indications:-

1. Depth display fluctuates
2. Waterfall display not coming proper (maximum spikes)
3. Poor data quality.

b. Actions:-

1. Check for depth settings in runtime parameters→sounder main.
2. Fix the min. depth and max. depth values with respect to survey area.

12. APPENDIX -1 (OPERATIONAL PROCEDURE)

Procedure for operation of EM1002 shallow water multi-beam echo-sounder system:-

1. Switch on all the external sensors (sequence SV probe → DGPS → Octans motion sensor)
2. Switch on the video adapter and the helmann display before starting operator station HWS-10.
3. After approximately 10 minutes, switch on the Transceiver unit and wait until it boots-up normally. The normal booting can be checked by listening to the beep sound. The ready status of the TRU will be given by the voltmeter on the power supply board.
4. Once ready SIS (seafloor information system) software can be started by going through start → programs → Kongsberg Maritime → SIS.
5. The SIS software tries to communicate with the TRU and as the communication is established, the status gets displayed. On successful connection of EM1002 TRU and the HWS-10, the SIS imports all the installation parameters into the HWS-10 operator station and the ready status is displayed by the three LEDs glowing green (PU status/BSP status/SH status).
6. this indicates that the system is ready for pinging. Operator can now check for status of the full system by performing BIST (built-in- self tests). BIST menu can be accessed from installation parameters → BIST.
7. once system does BIST successfully, operator can start pinging.
8. during actual data acquisition, once survey area is reached, the sound velocity profile (CTD/ SV plus V2) should be taken.
9. the profile is then extended and done thinning in SV editor found in Tools → customs →SV editor. Open the file and first do extend the profile and then thinning the profile at 0.1 binning size. If problem is found in the data points while extending the profile, delete those points and extend again.
10. now click on scroll button for runtime parameters and select the sound speed tab. Select the file which was thinned in SV editor module. Press the yellow button “use this profile”.
11. check that the sound probe is active and temperature, salinity data is entered properly.
12. start helmann display from start → programs → SIS Menu → helmann.
13. activate the planning module by pressing show/hide button in geographic window and then press on “P”. plan the survey by clicking on “new job” → type the plan name and save. Now

- plot the line by selecting “line” button. The software also allows to feed the position data for plotting the lines. Activate the line required to survey by selecting it and later clicking on activate line.
14. As the line is activated, it gets displayed on the helm display.
 15. Now the system is ready for pinging and logging the data.
 16. The logging of the data can be started by clicking on “logging” button.
 17. The navigator can now start the survey. The grids appearing on the main operator station can be transferred to the helm display. This gives good idea of overlap to the navigator on wheel house and hence the navigation job can be performed with perfection.
 18. Plot the new line as desired “make parallels” (if parallel to original), specify the distance between lines and press ok.
 19. Stop logging the data as soon as the line is finished as the data on turns seems to have problems.
 20. And log the data as soon as the next line starts.
 21. Once the survey is finished, stop logging by pressing on “logging”.
 22. Stop “pinging”.
 23. Switch off sequence: - close SIS → TRU → Octans motion sensor → SV probe → DGPS.
 24. The data quality checks are done online by checking cross-track/ beam intensity/ grids etc. At shore the data quality checked are done by importing the data in Neptune software, applying all the related correction such as tide, positioning error etc and later cross-line module should be used for verification of the data. The cross-line module actually shows the cross sectional view of the line swath or lines swaths.

13. APPENDIX -2 (NEPTUNE DATA- PROCESSING PROCEDURE)

Data processing through Neptune:-

1. Using “check / Replay” module convert raw data to survey format, which is later readable in Neptune.
 - Select raw data directory
 - Select which process to be executed.
 - Select output directory
 - Select projection and position time tag as default.
 - Start the conversion process.
2. In Neptune, select survey window (survey to be displayed and processed).
3. Edit → selection → cancel selection.
4. Processing → positioning.
 - In positioning, select the lines and processing → rules
 - Create basic rule with Navigation system -1, system ranking -1, navigation sensor-active, suspicious std limit – 3, rejection std limit – 6 and set other required parameters as desired for position processing.
 - Execute with new → Accept → ok.
5. Now again select all the lines and go to processing → rules
 - Select Merge/smooth mode
 - Use cut-off frequency → 0.07
 - Filter length → 20
6. Once done click on save from file menu and later exit.
7. in main Neptune survey window, click on view → update.
8. Now apply the corrections for bathymetry data.
 - Processing → depth corrections → setup rules.
 - Setup required parameters, such as roll/ pitch offsets, beams to use/depth thresholds, tide, sound velocity (if required) etc.

- Execute the rule by clicking on New → Accept → ok.
 - Click on processing → Depth corrections → start processing.
 - Now the processing of bathymetry data starts.
9. Neptune has in-built calibration module, which allows calibrating the data before post processing.
 10. Now make grid and later display grid for visualization and verification.
 11. Inspect the statistics.

Note: - Grid should be 10% of the Maximum/Average depth.

12. Now create blocks for detailed processing of the bathymetry data. Define the processing area and create blocks.
13. Select one block at a time and click on processing → data cleaning.
14. In data cleaning module, click on processing → create grid → define grid size.
15. Once finished click on processing → rules → create a rule as desired (more definition is available in training manual for Kongsberg system).
16. Click on new → accept → ok. Now the rule gets applied to the data within the block.
17. For more filtering of the data, select the data (CTRL+MB2) where artifacts are visible and click on processing → correlation plot. The plot allows visualizing the cross section of the swath and rejecting or accepting and filter-out more data.
18. Once done save the processing by clicking on File → save and later File → exit.
19. Now in the main survey window click on view → update.
20. From main survey window create the grid again by clicking on grid → create grid and select the grid size (10% of the maximum depth).
21. Check for any artifacts or errors in bathymetry by visualizing the data by using different visualization tools in grid display window, like sun-illumination, backscatter, mean depths, diff depth, min depth, max depth etc. These tools can be accessed from view → grid/cell.
22. If data involves features, it is advisable to filter or clean the data blocks individually. Else data cleaning can be done in batch, from processing → data cleaning batch processing. The new window will open, where the operator is asked to select the format and type of data to export, rules to be applied etc. and click on OK.
23. The output data is available in xyz\survey folder. This data can later be imported to CFLOOR or other software for further analysis or plotting.

14. APPENDIX-3 (SOUND VELOCITY RE-CALCULATION PROCEDURE)

Recalculating depths with new sound velocity:-

1. Continuing from the above appendix-2, in the cross-line module click on edit → sound velocity editor.
2. Import the suspected sound velocity from the line data.
3. If it is required to edit the profile, click on file → open editable profile. And now a sample profile can be opened and edited from edit menu either by selecting move point or create new profile or add point.
4. Once created, save the profile with “.asvp” extension.
5. Now click on edit menu in cross-line module, click on apply sound velocity profile. The list of profiles and lines will be displayed. Select the line and profile to be merged and press on OK. This will correct the line for sound velocity errors.
6. The cross-line module only gives previews of the data cross sections. The actual applications of any corrections take place in depth rules.
7. To setup rules for corrections select the line or lines to be corrected and follow from the main survey window. Click on processing → depth corrections → setup rules. And now select the sound velocity profile file in the specified entry and press new → accept → ok. And later start processing from processing → depth corrections → start processing.
8. This will process the data or lines as selected.

15. APPENDIX -4 (FILE FORMATS)

Tide file format:-

The **tide** file should be located in the survey directory in question, with the extension *.tide*.
The layout is as follows:

- **Header: (Tide Version Vessel Id start_time end_time)**

Version: an identification of the file type (tide file).

Vessel : the vessel name.

Id : a possible identifier.

start_time: the start time of the tide file (YYYYMMDDhhmm)

end_time : the end time of the tide file (YYYYMMDDhhmm)

- **Data : Time Correction**

Time : the time of the correction:

Correction: the correction to be added to the measured depths at the given time.

A high water level must be corrected by a negative tide number since the correction is added to the measured depths.

Example:

(Tide 1.00 Simrad 12 199205290813 199206151210)

199205290813 0.55

199205290923 0.45

Sound Velocity file format:-

The sound speed profile (**SVP**) file layout is as follows:

• **Header:** (**SoundVelocity Version Id Time Lat Long Radii Valid_from Valid_to Src Hist No_val**)

SoundVelocity: an identification of the file type
(sound speed profile file).

Version : the file format version number.

Id : a possible identifier.

Time : the time of creation for this file (YYYYMMDDhhmm).

Lat : the latitude of the profile generation (decimal degree).

Long : the longitude of the profile generation (decimal degree).

Radii : the radii around the lat/long position for which this profile is valid (m).

Valid_from : the time interval in the year from which this profile is valid (YYYYMMDDhhmm).

Valid_to : the time interval in the year to which this profile is valid (YYYYMMDDhhmm).

Src : the source of the profile (probe name, database name, editors name, etc....)

Hist : the history of modifications on the profile (P=probe, E=edited, M=merged, N=new).

No_val : the number of values that are used in the profile.

• **Data:** **DepthSoundVelocity**

Depth : the water depth(m).

SoundVelocity : the sound speed at the respective depths (m/s)

An example:

(SoundVelocity 1.00 12 199205290813 22.3452678 66.4483298 4500 199205290813 199206151210 SVP-16 PE 6)

5.0 1484.2

7.0 1485.3

12.0 1488.1

20.0 1485.7

25.0 1484.0

40.0 1483.8

If no SVP file is present in the rule, no corrections are made.

16. REFERENCES:

- 1) Hydrosweep swath bathymetry system on ORV Sagar Kanya: An assessment of its deep sea performance by Y. Satyanarayan Raju. (Geological Oceanography Division, NIO). –TR-6171.
- 2) Installation Manual of EM1002 shallow water multi-beam echo-sounder system from M/s Kongsberg Maritime, Norway.
- 3) Maintenance Manual of EM1002 shallow water multi-beam echo-sounder system.
- 4) Operational and training Manual for SIS and Neptune software for EM1002 shallow water multi-beam echo-sounder system.
- 5) The effect of refraction on oblique angles of multi-beam echo-sounders due to sound speed changes through the water column. By Desiree batton.
- 6) New method for the removal of refraction Artifacts in multi-beam echo-sounders systems. By Edouard Kammerer and John E. Hughes Clarke.
- 7) Shallow water imaging Multi-beam Sonars: A new tool for investigating seafloor processes in the coastal zone and on the continental shelf. By John E. Hughes Clarke, Larry A. Mayer and David E. Wells.
- 8) Retracing (and raytracing) Amundsen's Journey through the Northwest Passage. By Beaudoin, J.D., Hughes Clarke, J. E., and Bartlett, J. E.