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THE USGS DEEP TOWED SEA FLOOR MAPPER

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1. INTRODUCTION

In June of 1989, the United States Geological Survey (USGS) identified the need for a deep ocean sea floor mapping tool in order to fulfil it's charter to map the Exclusive Economic Zone of the United States and territorial waters. In August of 1989 a group of scientists and engineers began formulating the scientific and technical goals for a deep ocean sidescan SONAR and swath bathymetry system. In June of 1991 with the technical specifications completed, a request for proposal was initiated for construction and delivery of the system. The contract was awarded to Datasonics, Inc. in February of 1992 and the USGS held field acceptance trials in July and in August of 1992. The intent of this paper is to describe the technology and capabilities of this deep towed vehicle and associated shipboard systems to the research community.

2. GOALS

There were several goals in the development of technical specifications for this next generation sea floor mapping system. The primary goal was to provide the Geological community with medium resolution sea floor images (intermediate between GLORIA [1] and high frequency systems). Our system was primarily designed as a geological mapping tool, but the design concept included a number of additional features that would allow upgrades to the system at a later date. The basic and most fundamental design criterion called for a quantitative acoustic platform with known and predictable acoustic properties. This quantitative approach allows the researcher the ability to classify bottom sediment physical properties from the backscatter data.

System flexibility was also addressed. We wanted the ability to add additional sensors to the vehicle that could allow a scientist the ability to conduct additional experiments. The vehicle can accommodate 6 additional analog, digital or serial sensors. Swath bathymetric capabilities are planned, and the system includes an additional row of receivers for this purpose.

Monitoring the vehicle health, status and the ability to remotely diagnose problems were designed into the shipboard and subsea systems.

The shipboard component of the system consists of two workstations. One is dedicated to the acquisition, display and logging of all SONAR data, subsea environmental data and external surface and/or acoustic navigation data. The other is responsible for command and control of subsea electronics and display of tow vehicle status, environmental data and external navigation.

3. SUBSEA SONAR SYSTEM DESCRIPTION

3.1 Tow Vehicle and Depressor Weight

This 3800 pound streamlined fiberglass tow vehicle is 17 feet long and 3 feet in diameter (Figure 1). It is 100 pounds positively buoyant in water and houses all electronics and sensors needed to carry out it's mission to a maximum depth of 6000 meters. During operation, the tow vehicle is attached to a 2200 pound depressor weight via a 100 or 200 meter neutrally buoyant coaxial umbilical tow cable.

The depressor weight decouples the ships motion from the tow vehicle and provides a subsea junction box for electrically connecting the ship-board system with the SONAR vehicle.

The tow point is on the forward bottom portion of the vehicle and incorporates an acoustic release which, upon command from the shipboard command unit, will release the tow vehicle from the umbilical allowing it to ascend to the surface. Additionally, there is a mechanical release system that will activate upon reaching an operator selected depth.

3.2 System telemetry - power distribution

440 Volts Alternating Current (VAC), single phase, 60 HZ power is supplied to the tow vehicle from the surface telemetry system. The 440 VAC is converted to 110 VAC in the subsurface telemetry system and distributed to 5 system power sources for conversion to DC levels. The Colmek telemetry system is the communications network for uplink status and sonar data and for down link command and control. There are two down link channels, one for power and one for commands, and there are two uplink channels, one for status, vehicle sensor data, and diagnostic results, the other for SONAR data. Each channel is assigned a specific carrier frequency for data transmission through the UNOLS 0.68 inch armored coaxial tow cable. Data transmission rates for uplink status and down link commands are 9600 baud, RS-232 coded, uplink sonar data are 1 megabit serial coded.

3.3 Sidescan transducers and receivers

The acoustic transducers consist of two 7 foot pressure compensated line arrays per side with an effective 1.5 degree horizontal beam width and a 55 degree vertical beam width (Figure 2). Each array is made up of 7 modules, each containing 5 mass piston transducers. Each module is weighted using Hamming shading coefficients for a total side lobe suppression of >20 decibels (db) for both transmit and receive. The transducers are adjustable for +- 20 degrees from the normal 20 degree down look angle. Currently, the upper array is the acoustic projector and the lower array is the receiver. When acquiring swath bathymetry, the upper array will be the projector and both arrays will be receivers. Each transducer array is driven by a 1.5 kilowatt (kw) power amplifier and transmits a linear swept Frequency Modulated chirp pulse. The chirp pulse width is a function of range with, 10 milliseconds for a 1500 meter swath up to 60 milliseconds for the 6000 meter swath. The port transducer is swept from 26 to 33 kilohertz (khz) while starboard is swept from 33 to 26 khz, minimizing acoustic cross talk. The FM chirp signal is "calibrated" to the SONAR system transfer function. This calibrated chirp pulse is stored in an electronically programmable read only memory (EPROM), and is clocked out of the EPROM at the beginning of each ping period which produces a well defined, repeatable SONAR signature allowing for studies in bottom classification and target analysis. Port and starboard acoustic backscatter is initially signal conditioned by a 32 db preamplifier and band-pass filtered to remove cross talk from the other acoustic projectors and vehicle generated noise. The filter output is base band detected and further amplified by a surface controlled 0 to 42 db programmable gain amplifier that feeds a digitally controlled Time Varied Gain (TVG) module. One of 8 TVG curves can be selected to compensate for grazing angle and spherical spreading loss. After the FM chirp echo is base band detected, each analog channel signal is multiplexed to a single 12 bit analog to digital converter sampling at 15.625 khz. The resulting digital number is tagged in the upper 4 bits with a channel identification code for a total of 16 bits for each sample. At the start of each SONAR transmission a 256 bit Barker code, used for synchronizing the surface systems, will precede the SONAR samples and is multiplexed to the surface at 1 megabaud via the telemetry system.

3.4 Subbottom seismic profiler

The subbottom profiler projects a 2 to 7 khz FM chirp. The signal conditioning section contains all the same features of the sidescan system minus the TVG amplifier (Figure 3). A total of 74 db of gain in three stages. The subbottom receiver consists of a 1 meter hydrophone array consisting of 8 elements. This hydrophone is mounted along the bottom inside of the tow vehicle with holes through the bottom at the location of each element in the array.

3.5 Auxiliary sensors

The tow vehicle is instrumented with a number of environmental and vehicle status sensors. The data from these sensors are telemetered to the surface on the uplink RS-232 vehicle status channel. All vehicle status information is transmitted to the surface at the SONAR ping rate and logged in the sonar data footer record and displayed within an X-Window client. These sensors include:

A) A Sea Bird 19 Conductivity, Temperature and Paroscientific pressure depth profiler (CTD) for continuous measurement of oceanographic parameters, real time sound velocity correction and tow vehicle depth.

B) A Humphrey 3-axis flux-gate magnetometer probe for detection of anomalies in the relative direction and intensity of the earths magnetic flux.

C) A KVH C-100 auto-compensating flux-gate magnetic heading sensor. This sensor is calibrated on each deployment to compensate for interaction of the earths magnetic field in the survey area with the vehicles magnetically permeable material and to allow for any changes in the magnetic signature of the vehicle.

D) A General Oceanics single-axis flow meter. This impeller driven instrument provides an estimate of vehicle speed through water.

E) A Lucas Accustar II dual-axis clinometer for measurement of tow vehicle pitch and roll angles. The claimed clinometer accuracy is 0.2 degrees, resolution of 0.001 degree and range of +- 60 degrees.

F) A Datasonics PSA-900LF 16 khz altimeter for measurement of tow vehicle altitude above ocean bottom. Maximum range of this system is 700 meters and resolution is 1 meter. The acoustic return is compensated for depth and temperature.

3.6 Tow vehicle status information
Information is telemetered to the surface that provides data concerning the health of the subsea electronics. This information is visually displayed and includes the following:

A) Salt water intrusion in either the multiplexer/power supply pressure case or the main electronics pressure case.
B) Subsea power supply voltage levels.
C) SONAR channel receiver saturation
D) Tow vehicle down link commands and command echo from tow vehicle
E) SONAR channel receiver gain

3.7 Tow vehicle diagnostics
The tow vehicle electronics and sensors can be tested for functionality either prior to launch or during operations. These tests are initiated by the operator from the status and control workstation and the pass/fail results are displayed in the diagnostic window. The following tests can be performed:

A) Check the operation of the single board computer
B) Perform tests on the analog to digital converter
C) Test the serial input-output board
D) Test the digital input-output board
E) Checks on the sonar burst and receiver boards
F) Checks for data from:
  1) Sea Bird 19 CTD
  2) Pitch and roll clinometers
  3) 3-axis flux-gate magnetometer
  4) Altimeter

Also, we can initiate a calibration routine for the KVH C-100 heading sensor within the diagnostic menu. In addition, we are able to test all electronics in the sonar signal path (except the transducers) with a predefined chirp pattern injected in to the sonar receiver boards.

4. SHIPBOARD SONAR SYSTEM DESCRIPTION

The shipboard systems consist of two workstations, the Status and Control workstation which provides the power and communications link with the tow vehicle, and control of all subsea electronics and the SONAR data acquisition and display workstation which receives SONAR data and telemetry data from the Status and Control workstation.

4.1 Status and Control workstation.
This workstation is a 80386 based PC running a Lynx-OS UNIX look alike operating system and utilizes the X-window system for graphical display. The system console, computer chassis and Colmek telemetry system are enclosed within 2 containers for shipboard installation. In addition to providing power

to the tow vehicle, the Colmek Chirp Telemetry system receives operator originated commands. These ASCII commands are transmitted to the tow vehicle on the down-link serial channel at the SONAR ping rate. ASCII up-link status data are made available to the Status and Control workstation, acquisition and display workstation, and one additional port for a user supplied system. Up-link SONAR data is amplified, band-pass filtered and transmitted to a synchronizer board. This synchronizer board detects the SONAR data 256 bit Barker code, synchronizes to the code and clocks data out via 5 connectors at 1 megabaud. Three of the 5 connectors carry data from the SONAR channels and, when upgraded, the other two connectors will carry bathymetry data. There is an additional connection for a user provided data collection system to record the full bandwidth of the SONAR.

Status and control software is written in the C programming language, and using the OSF/Motif toolkit, and displayed via the X Window system. Three windows are displayed during normal operation. The tow fish status window provides tow vehicle sensor information, power supply DC voltage levels, checksum information and vehicle gain settings. The ship navigation window displays information from an external shipboard navigation system. This position information includes time of day, ship position in northings and eastings or latitude and longitude, tow vehicle position in latitude and longitude, slant range to the tow, tow vehicle azimuth from the ship, ships speed, ships heading, water depth and amount of tow cable out. The tow fish control window contains five push buttons that allow the operator to select SONAR swath width, set acoustic channel gains, select high or low power acoustic signature transmission, turn on/off acoustic sources, select a TVG curve, and enter the diagnostic mode.

4.2 SONAR Data Acquisition and Display Workstation

This workstation is a 80486 33 MHZ PC running under MS-DOS 5.0 based system. The Triton Technology supplied Q-MIPS system is also housed within an enclosure and is composed of a SONAR display unit, a status display unit and the computer chassis. Installed within the computer chassis are a high performance graphics processor, SCSI interface, a high density floppy drive, a 410 megabyte disk drive and three Digital Signal Processing (DSP) boards based upon the AT&T 32C DSP chip. Two Exabyte 8200 8MM tape drives log the SONAR data.

Serial SONAR data are received at the three DSP boards from the Status and Control workstation. Clock pulses for each bit and a load pulse for each 16 bit word are received by each DSP board. The DSP boards look for and synchronize on a portion of the Barker code (transmitted from the tow vehicle), once synchronized each DSP board acquires SONAR data based upon the channel identification bits in the upper 4 bits of each SONAR sample. The SONAR data are matched filtered in the frequency domain with a chirp replica. Signals that do not match are attenuated by the filter. Filter data output is placed in the time domain and transferred to the Q-MIPS system for down sampling and pixelation. Q-MIPS displays a water fall image of SONAR samples

(Port, Starboard and Subbottom) and a bottom track indication in the subbottom display window (the source of the bottom track information may be selected from vehicle altimeter, or one of the SONAR channels). Tow Fish, Mensuration, and Status information are displayed on the second color display unit. The Tow Fish column includes navigation data from the external navigation computer, tow vehicle attitude, vehicle altitude, depth and altitude source. The Mensuration column includes information on cursor position relative to nadir (in meters), cursor position in latitude, longitude and time of day, SONAR range scale, and the length and width of SONAR pixels (in meters). The Status column displays information about the Q-MIPS software operating parameters, current tape file name, amount of storage left on tape, and color look up table name. SONAR data and a 256 byte footer recorded are recorded on the Exabyte 8MM tape unit. This footer contains data from the SONAR vehicle environmental sensors, SONAR vehicle operational parameters (gain, signal bandwidth etc), and navigation.

5. SONAR DATA PROCESSING

The SONAR data, logged on Exabyte tapes by the Data Acquisition and Display workstation, is read onto disk on a Digital Equipment Corporation DECstation 3100. Processing procedures correct for geometric and radiometric distortions to the data. After completing the processing steps, the resultant enhanced data are oriented in geographic space, output to a thermal printer, then used to create a hand-pasted shipboard mosaic in the Universal Transverse Mercator (UTM) projection.

Distortions inherent in the sonar record as the result of variations in ship speed, slant range geometry, low amplitude records, and acoustic properties have to be accounted for to gain a true perception of what the sonar backscatter record is displaying. Thus the following steps are taken to process the SONAR data:

1) Demultiplex the QMIPS data format into a format usable by the processing routines. Demultiplexing also suppresses speckle noise present in the data, if desired, by desampling the data using a moving median boxcar filter of user selected width and height.

2) Graphically check and merge corrected navigation with the SONAR data.

3) Correct for slant range distortion assuming a horizontal sea floor.

4) Correct for striping in the data and correct for it using an averaging algorithm.

5) Apply a beam angle correction to compensate for variations in shading in the near to far range due to non-linear responses of the transducer arrays.

6) Gather statistics from the SONAR data to determine the dynamic range of the data.

7) Apply a linear contrast enhancement based on the dynamic range.

8) Orient the SONAR track on screen, graphically select an output scale as well as outline the portion(s) of the SONAR data to project based on this scale, and transpose the data geographically onto a UTM grid.

9) Save to a disk file and output to the thermal printer.

All of the processing software is written to utilize the X Window System graphical capabilities, and was coded using the OSF/Motif toolkit.

6. CONCLUSIONS

We had several technical problems during our first field trial of this system. A second 5 day trip proved more fruitful. Our first research program for the vehicle was hampered by bad weather resulting in only 24 hours of data collection. Because of this limited sea time we still have much to learn. We have plans for a 2 week test program in May 1993 where we plan to cover areas previously surveyed with a SEAMARC [2] system and to acquire swath bathymetry for analysis and algorithm development.

7. REFERENCES

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[2] Kosalos, J.G., and Chayes, D.N., 1983, A portable system for ocean bottom imaging and charting: Oceans '83 Proceedings, p. 649-656.

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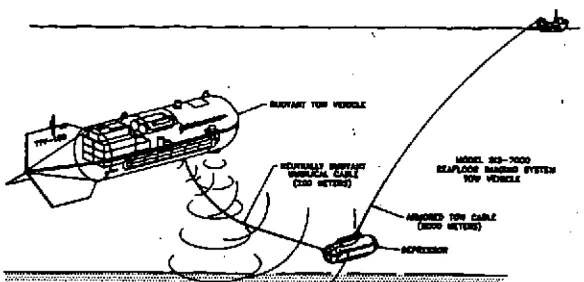

FIGURE 1

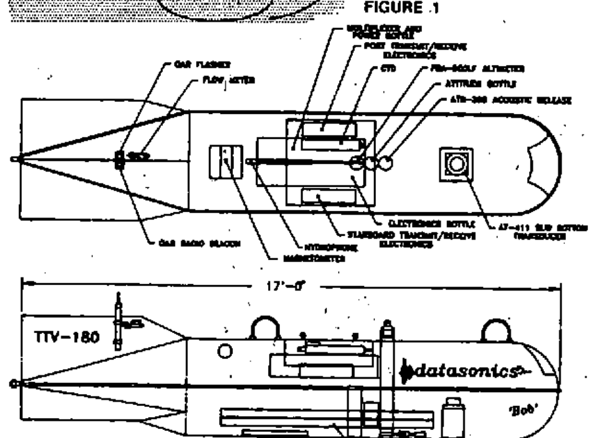

FIGURE 2

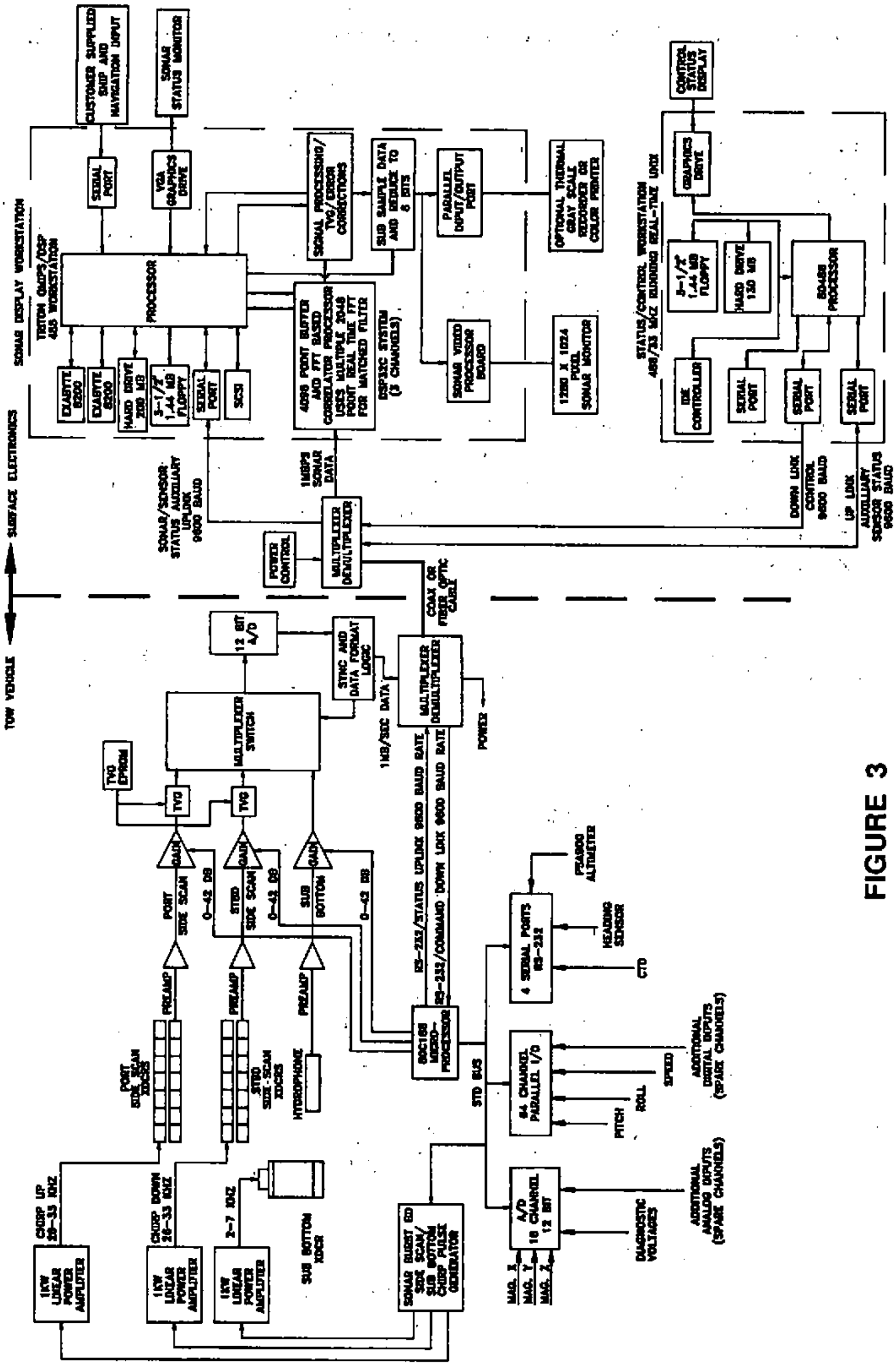

FIGURE 3