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POSITIONING AND SURVEYING REQUIREMENTS FOR EXPLORATION AND EXPLOITATION OF OCEAN WEALTH

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Abstract

Deep sea mining, such as is now being planned to be carried out in the Indian Ocean, requires an accurate positioning system for navigation and for the control of the equipment. Short range systems using electromagnetic principles cover only a limited area while the longer range systems which can be used for offshore, deep ocean work although covering large areas, have limited accuracy. This paper reviews the requirements for position fixing systems for deep ocean mining and the ways to reach the best solution at the most reasonable cost.

INTRODUCTION

The increasing demand for ocean wealth and technological advances have now made manganese nodules the prime target for massive national efforts in deep sea mineral exploration and mining by scientific and technological organisations in India. During the last eight years, the National Institute of Oceanography (NIO) has gained experience in operational and experimental surveying on the high seas, mainly in connection with the exploration of manganese nodules. With regards to the Indian Ocean, the areas of mining interest are located far offshore and the distances from land are up to 2 000 km and the depths from 4 000 to 6 000 m. The matter to be considered is the choice of positioning and navigation systems to be used in surveying the deep ocean.

Determining the position of a vessel at sea can be accomplished in a variety of ways, the choice of which depends on the accuracy, system mobility required and the cost. The position requirements for offshore exploration surveys are different in many respects from normal coastal surveys or navigation. With location obtained by a precise positioning system and a knowledge of specific

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specific mineral occurence, the selection for the design of further exploration and extraction programs has to be made. For rapid mapping and location of the deposits, the ship's position should be measured continuously along the survey lines. Surveys are carried out round the clock and in all seasons.

SURVEYING AND POSITIONING REQUIREMENTS

The mining site is preferably chosen in areas with less than 30 m of height variation, without vertical discontinuities and with slopes less than 10° (Amann, 1975). The exploration and exploitation task can be defined in phases, each with a different requirement for positioning and mapping accuracies. The following phases have been identified:

a. General bathymetric survey

b. Prospecting survey

c. Topographic survey

d. Sampling survey

e. Detailed surveys for developing mining plans

The requirements corresponding to these phases are shown in Table 1. (Siapno et al., 1978)

Table 1

Phase	Area coverage	Required accuracy in position	Reference system	Map scale	Allowable depth error
General survey	global regional	4-40 km	absolute surface	1:10 M	--
General prospecting	regional	400 m	absolute surface	1:250 000	50 m
Preliminary	150×400 km	400 m	absolute surface	1:200 000	4 m
Evaluation	100×150 km	2 000 m	absolute surface	1:120 000	4 m
Detail	20×20 km	25 m	relative	1:25 000	1 m
Mining	ship position	(400 m)	relative surface, bottom	--	--

The available positioning systems can be categorized into two types on the basis of the operational types.

a) Surface positioning systems.

b) Sub-surface positioning systems.

The main restraint for surface positioning is coverage vs. accuracy. Systems providing global coverage normally have less accuracy. Due to this fact various navigation systems could not be used in the deep sea areas. The Omega system has a global coverage but its accuracy is limited to 2 to 4 km. Integrated Navigation Systems (INS) and the Global Positioning System (GPS) can be used for deep sea areas, and the discussion concerns these two surface positioning systems only. In the requirement for sub-surface positioning the Underwater Acoustic Position System (UAPS) provides good accuracy and can be used to provide the position of underwater instruments. A comparative statement of these three systems, i.e. INS, GPS and UAPS is given in Table 2.

Table 2

System	Accuracy	Frequency	Operational type	Remarks
INS	± 30 m	mainly from satfix	Information from satellite	Require additional sensors
GPS	± 5 m	continuous	" "	---
UAPS	± 4 m	continuous	Network to be established	Initial positions from any surface system

INTEGRATED NAVIGATION SYSTEM (INS)

The INS is not a positioning system in itself but integrates the data from several positioning systems and sensors which provide a vessel's movement between observed positions. The INS linked with a dual channel TRANSIT Satellite receiver, with GPS, Omega and other sensor units such as doppler sonar (for ships speed measurement), gyro compass (to give ship's heading), velocimeter and thermistor (to give velocity of sound in water) and inclinometer (for corrections for roll and pitch) will enable the ship's position to be calculated with the high accuracy required for the task. A schematic network of the Integrated Navigation System is shown in Figure 1. The system software is able to provide high accuracy in determining the latitude, longitude and geoidal height at any location by making use of more than one satellite fix at that location. Optimal positions are obtained when all information is integrated statistically e.g. by using Kalman filtering techniques.

Static error budget	15 – 35 m.
Speed and course	40 – 400 m.
Roll and pitch	10 – 30 m.
Antenna height	5 – 90 m.
Geometry	45 – 400 m.

During post-processing the dead reckoning position is corrected by taking dead reckoning error with satellite fix position. The accuracy which can be

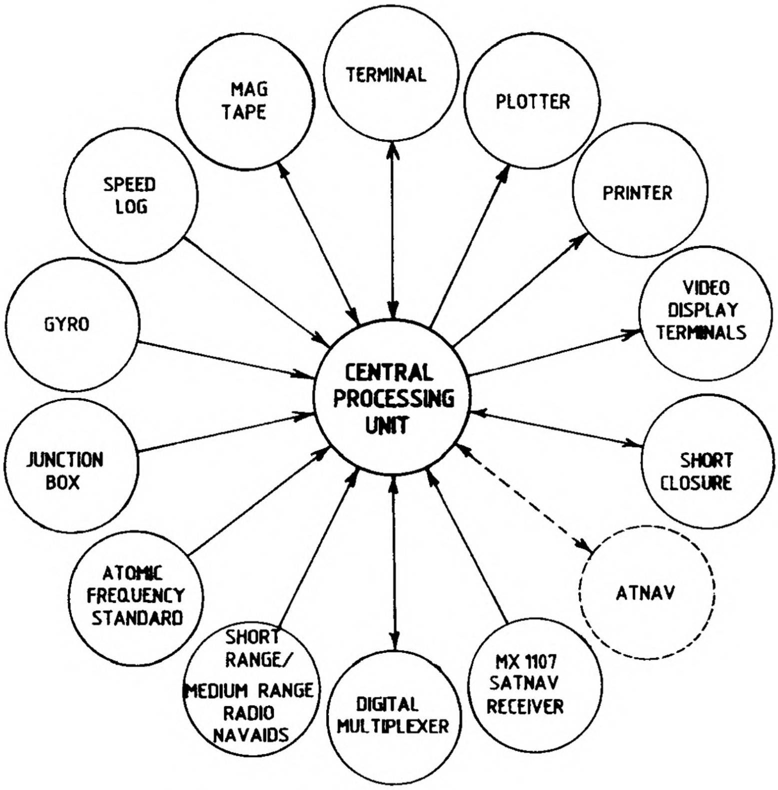

FIG. 1.— Network of Integrated Navigation System.

achieved from one satellite pass is within the stated limits of ocean mining. The position of the ship between satellite fixes is obtained by dead reckoning with the help of speed and heading measurements. The accuracy of the INS System output must be maintained between satellite pass by good Dead Reckoning (DR). In shallow water the speed log operates in bottom track mode and gives accurate speed. So the position obtained in the shallow near shore area is within the limits of required accuracy. In deep sea areas, the position obtained from INS shows more error during the dead reckoning runs because the speed log cannot operate in the bottom track mode in these deeper depths. This may be minimized by using Omega positions from which the speed component may be deduced. A description of the Omega system is given below :

The Omega system is a world-wide positioning system, providing hyperbolic position lines by phase comparison techniques on very low frequency continuous wave electromagnetic signals. The Magnavox 1105 (Omega) has an update every 5 minutes and from this, the speed and heading of the vessel is computed. These values are integrated with the NAVSAT system outputs and improve the quality of the position. The accuracy of the Omega system is given as two nautical miles during the day and four nautical miles during the night. This is mainly due to the errors caused by various unknown propagational effects, which ultimately limit the accuracy of the System (Ramsayer, 1977). The Magnavox

1105 Omega Nav has been used during surveys and it was found that the DR errors may be minimized by including this system in the integration.

GLOBAL POSITIONING SYSTEM

The GPS will provide extremely accurate three-dimensional position and velocity information to users anywhere in the world. The base line constellation when fully operational in 1992, will consist of twenty-four satellites operated in orbits at an altitude of 20,183 km. It will provide visibility of 6 to 11 satellites at 5° or more above the horizon to users anywhere in the world (Stansel, 1978). Except for applications requiring underwater operation or sub-metre precision, GPS will provide accurate positions for all activities.

The two characteristics which will make the GPS particularly useful are its availability and accuracy. Under the present U.S. Government policy, the accuracy expected is 100 m in civil user sets and 10 m in military sets. Increased accuracy can be obtained by using the GPS in the differential mode. However due to the fact that the area of interest for deep sea mining is far from any fixed shore location, differential techniques are of limited use in the Indian Ocean mining activities.

In the present area of offshore exploration of minerals, with particular reference to Polymetallic Nodules (PMN) in the Indian ocean, the Transit Doppler Satellite system has been used to date. For future mining operations new and better techniques of positioning are sought after in order to position transponders for acoustically positioning the mine site using a transponder array. As GPS provides continuous positions the difficulties encountered with Transit which could only provide positions at intervals of approximately 90 minutes will be overcome and consequently acoustic arrays can be established much faster than previously.

SUB-SURFACE POSITIONING

Detailed surveying with reference to an array of bottom moored acoustic transponders is the only practical method of accurately determining the surface and sub-surface positions beyond the line of sight. The first step in utilising a transponder array for navigation is to determine the relative positions of the transponders as accurately as possible by any one of the following methods:

a) Acoustic marker positions from accurately known surface positions;

b) Acoustic marker positions from cloverleaf and baseline crossings;

c) Ship manoeuvres and acoustic marker positions from an iterative least squares fitting procedure.

In the first method, acoustic markers positions are correlated with an accurately known surface positioning system. But when there is no good surface positioning system available, the other two methods are used.

In the line crossing method, to determine the relative position and azimuth of one transponder from another any one of the parameters is determined first. When the ship passes through the plane of the transponders the slant range comes to a minimum at the point of closest approach (Fig. 2). This minimum is converted into a distance. In this method, there is an initial assumption of depth and it affects the accuracy of the final co-ordinates.

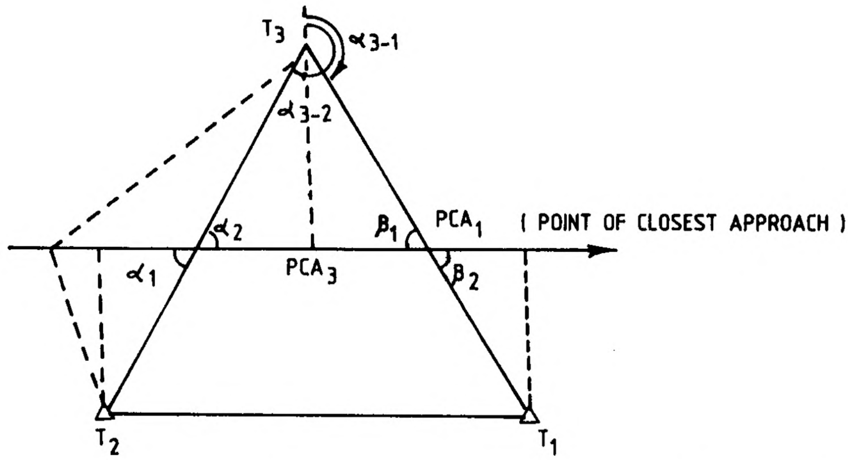

FIG. 2.— Determination of Geometry of Transponders by acoustic line crossing (Moured, 1977).

The improved method to solve three-dimensional co-ordinates is intersection (Mourad, 1977). Various sets of three-dimensional positions will be taken with different sets of ship's position (Fig. 3). A least square method is used to solve

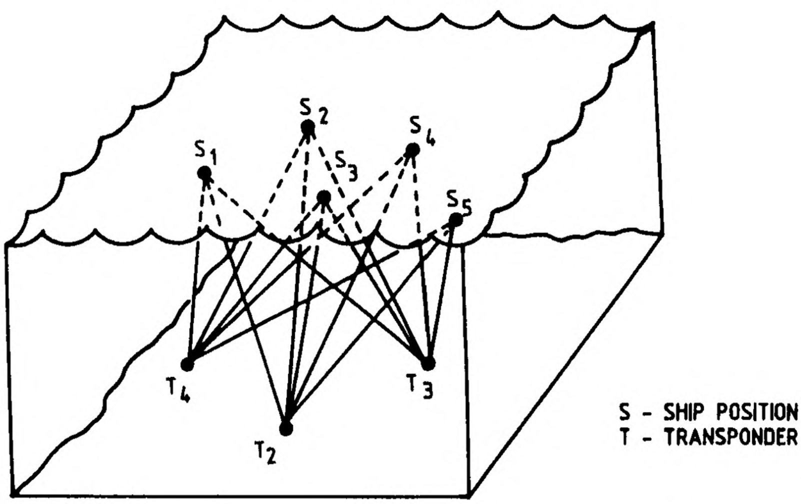

FIG. 3.— Principle of Intersection in Transponder location by surface position (Moured, 1977).

the three-dimensional co-ordinates for the velocity of sound profile and curved travel path of the signal. The intersection method is widely applied during deep sea mining surveys. Once the co-ordinates of the transponders are established, the position of the survey ship is determined in relation to the transponder.

The operational range of the transponders depends on the velocity structure of the sea, transmitting power, frequency and water depth. In order to cover a large mining area with a detailed survey, a great number of transponders is required or alternately the transponders must be moved frequently. The position of the transponders is linked to a surface positioning system. The system is particularly useful for detecting the displacement of position of a mining vessel. Thus the system is also being used for dynamic positioning of a mining vessel.

NIO uses a long base line system (E.G. & G.) for fixing the position of the survey ship. The depth range in the area is 4 000 to 6 000 m. The overall accuracy of the system depends on the accuracy with which the speed of sound is measured. The accuracy with which a position can be maintained is ± 1.5 m and the accuracy with which a position can be measured relative to a data point within 1 000 m is ± 2.5 m. The acoustic positioning system gives an effective solution for the 'Sea bottom relative to vessel' problem.

TOPOGRAPHIC SURVEYS

Wide beam echo sounders are unsatisfactory for portraying the bottom topography. The area of the sea floor acoustically illuminated is large and the signal received will be the shallowest point of this large area. In addition, in areas of rough terrain side echoes sometimes provide a grossly distorted picture. To avoid these problems, a narrow beam echo sounder, fitted on a gyro-stabilised platform should be installed so that the transducer points straight downwards. The narrow beam echo sounder measures the depth more correctly. For mining purposes a precise representation of the sea floor is necessary. To locate the narrow valleys or to survey seamounts by means of the narrow beam echo sounder is a difficult task. This can be resolved by using a multibeam echo sounder (Robert et al., 1980). One example of the multibeam echo sounder works by using 16 different acoustic channels (Fig. 4). There are 16 soundings obtained from these and a contour record is produced by the computer attached to the echo sounder. The Sea Beam multi-beam System can cover a width of twice the depth present in any particular place. By using a multi-beam system and an Integrated Navigation System, the topographical map of a large area can be prepared in a short time.

CONCLUSION

Integration of the Transit, GPS and acoustic navigation is most desirable. The integration will allow for continuity, time saving and where time is saved the

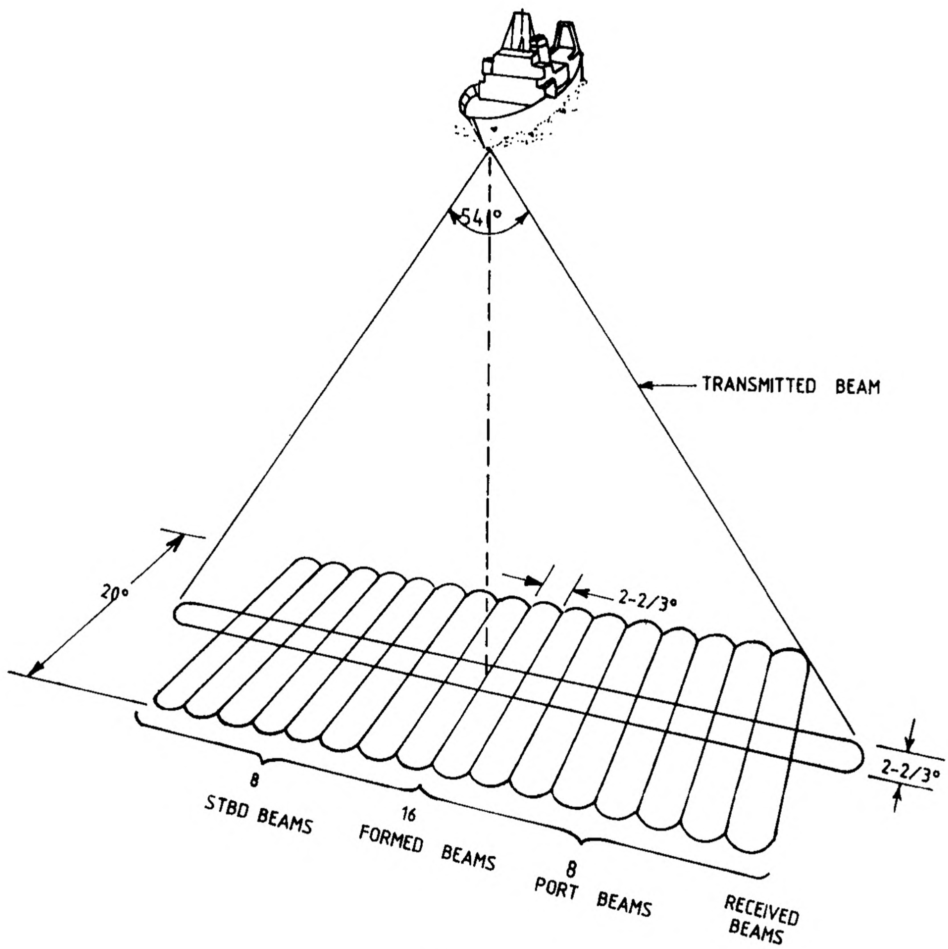

FIG. 4.— Sea beam pattern geometry.

economic factor too is directly affected. An acoustic navigation system combined with a surface positioning system will be an invaluable tool for position fixing and control in deep sea mining. The speed and heading sensors and manoeuvring systems of the ship should be accurate and precise. For providing accurate speed, doppler logs working in bottom track to greater depths need to be developed in order to achieve more accurate speed and direction and the vessel can maintain the required position while the mining operation is in progress. One of the limitations of an acoustic system for this work is that the calibration of the system must be frequently repeated. The precision GPS set (classified military set) will be the best position fixing device for this work.

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Errata:

p.94, line 16 instead of '(Siapno et al., 1978)' *read* (Zahn and Siapno, 1978)

P.95, line 2 instead of 'have less accuracy.' *read* 'have less accuracy, except GPS.'

p.96, line 16 instead of 'NAVSAT system' *read* 'TRANSIT system'

p.97, line 1 instead of 'NAV' *read* 'Navigation system'

p.97, line 7 instead of 'Stansel, 1978' *read* 'Stansell, 1986'

p.98, line 7 and 11, instead of 'Moured, 1977)' *read* 'Mourad, 1977'

p.99, line 30 instead of '(Robert et al., 1980)' *read* 'R. Tyce et al., 1986'

p.99, line 33 instead of 'The Sea Beam multi-beam system' *read* 'The multi-beam system'.