AN EXPERIMENTAL THREE-DIMENSIONAL SONAR SYSTEM

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An experimental 3-D sonar system is described, based upon a WPSS sonar equipment used in conjunction with a mechanically scanned transmitter. 3-D information from a small range interval is presented in a "stacked profile" type of display.

Introduction

This paper describes a research project carried out at Birmingham University in 1973. The aim was to continue previous work in the Department on the problem of target recognition (1) and 3-D displays (2,3) utilising the departments electronically scanned sonar system.

Perhaps the most difficult area in 3-D work is the presentation of the information, and various techniques have been used. Graphic methods have been investigated in the fields of radar for air traffic control (4) and sonar (5). The use of contours, as in cartography, has been applied to 3-D displays (6), and intensity modulated displays have been used, as in the recently successful EMI Scanner for X-ray brain examinations (7).

Many of the available techniques have already been applied to sonar and ultrasonics. Acoustic imaging systems possess the capability for 3-D display, in the same way that a TV picture does (8,9). This type of display can be greatly enhanced by the use of an isometric presentation (10). Two other well-known techniques that have been used are holography (11) and stereoscopy (12).

The display used in the system to be described, the stacked profile plot, is not new and has been applied widely, including to sonar displays. Examples of its use include scanning infra-red microscopy (13), video analysis systems (14) and many forms of computer output of 3-D variables (15). In 1962, Fahrenholtz used this form of display in his area echograph system for surveying navigation channels (16). Finally, in 1969, whilst investigating various displays, Hudson found this type extremely promising and produced displays as in Figure 1. For this work he used a high frequency, mechanically scanned pencil-beam sonar system, in a small tank (17). The main disadvantage of his system was the long time required to build up a display frame (several minutes) and it was largely this fact which led to the use of the electronically scanned system to be described.

The 3-D Profile Display

Perhaps the most accurate name for this type of 3-D display is the "stacked-profile plot". As can be seen from Figure 2, a number of parallel cross-sections or profiles of a target surface are stacked vertically to form an impression of the

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Figure 1 - PROFILE DISPLAYS

Showing an upturned car hub cap, and objects on a tank floor (after Hudson).

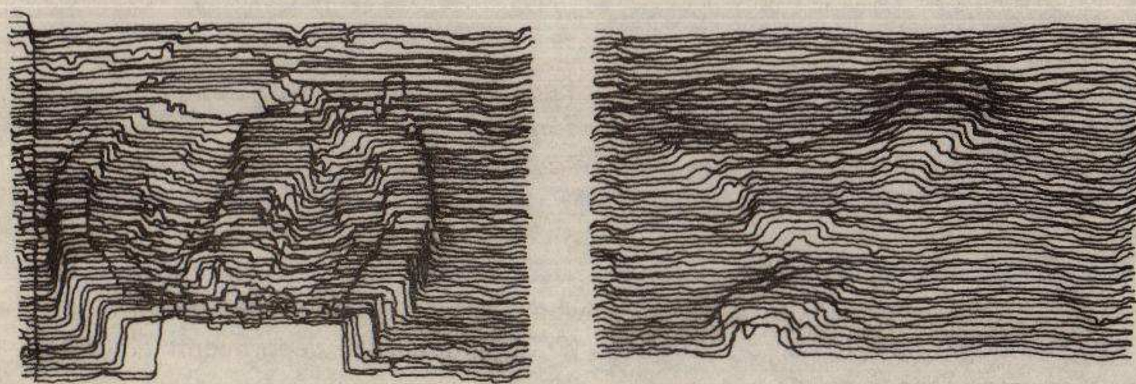
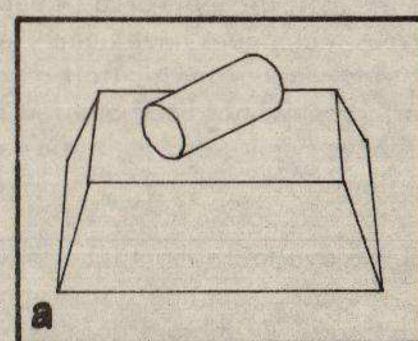


Figure 2 - Showing how the 3-D display is built up from cross-sections of an object.



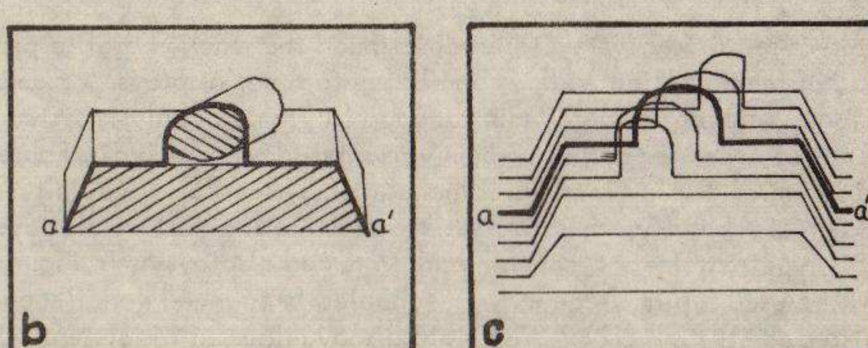
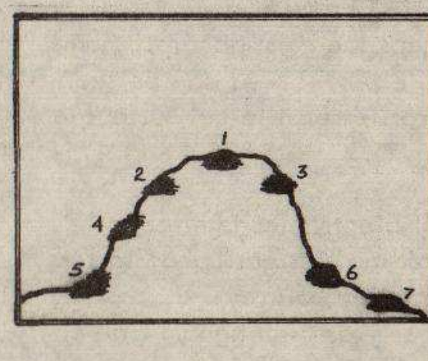


Figure 3 - Illustrating the need for target storage when converting a "scanner" display into the profile form.



surface shape. The display is a slightly distorted version of what an observer would see if parallel lines were actually marked on the target surface. In this application a sonar system determines the co-ordinates of points on the sea-bed, and these are used to produce the profile display.

It is apparent from the form of the display that only targets with a single-valued function can be represented accurately, or in other words the target should have a non-re entrant surface. Since the target is the sea-bed the above condition is usually satisfied. Mid-water targets such as fish shoals violate this condition and are represented incorrectly, appearing joined to the sea-bed on a pedestal. This restriction is not severe however, because many of these targets can be eliminated by a range-gating technique if they are unwanted.

The Method of Operation of the 3-D System

The 3-D system is based upon a conventional 2-D WPSS sonar equipment. 3-D information is obtained by the addition of a mechanically scanned, fan-beam transmitter. The technique is illustrated in Figure 4.

The electronically scanned sonar may be considered as having a fan beam (30° x 1°) scanning a sector (30°) very rapidly (10,000 times a second). In one sonar "ping" it gathers range and bearing information from all detected targets in the sector. The scanning action is performed by the "receiving beam" and so normally a wide beam transmitter is used (30° x 30°). If, however, a mechanically scanned fan-beam transmitter (30° x 1°) is used, scanning slowly and orthoganal to the electronic scan, 3-D information can be obtained.

The sonar system is mounted so that its beams point vertically down towards the sea-bed. The information obtained is thus the depth and two angular bearings relative to the sonar of all significant targets within the insonified volume. However, they cannot all be shown because of the nature of the display. In fact, for each two-dimensional bearing cell, only one target depth can be represented. Usually this will be the echo from the sea-bed and so the shape of the sea-bed is shown on the display. This is achieved in practice by selecting the first target to cross an amplitude threshold for each bearing cell.

A simplified block diagram of the system is given in Figure 5, and consists of three main areas; the sonar equipment, a display generator and the display. The three outputs from the electronic scanner and the output from the mechanical scanner (a voltage proportional to its angle) supply the display circuits with range, two bearings and amplitude information for each target. The display generation circuits are much more complex than those required for 2-D displays, and this is only partly due to the extra information involved. The other factors are due to the requirements of this type of display and these will be discussed in the following paragraphs. The final item in the system is the display itself, requiring X, Y and Z inputs from the generation circuits, the Z in this case being intensity, of course.

Figure 4 An Illustration of the 3D System

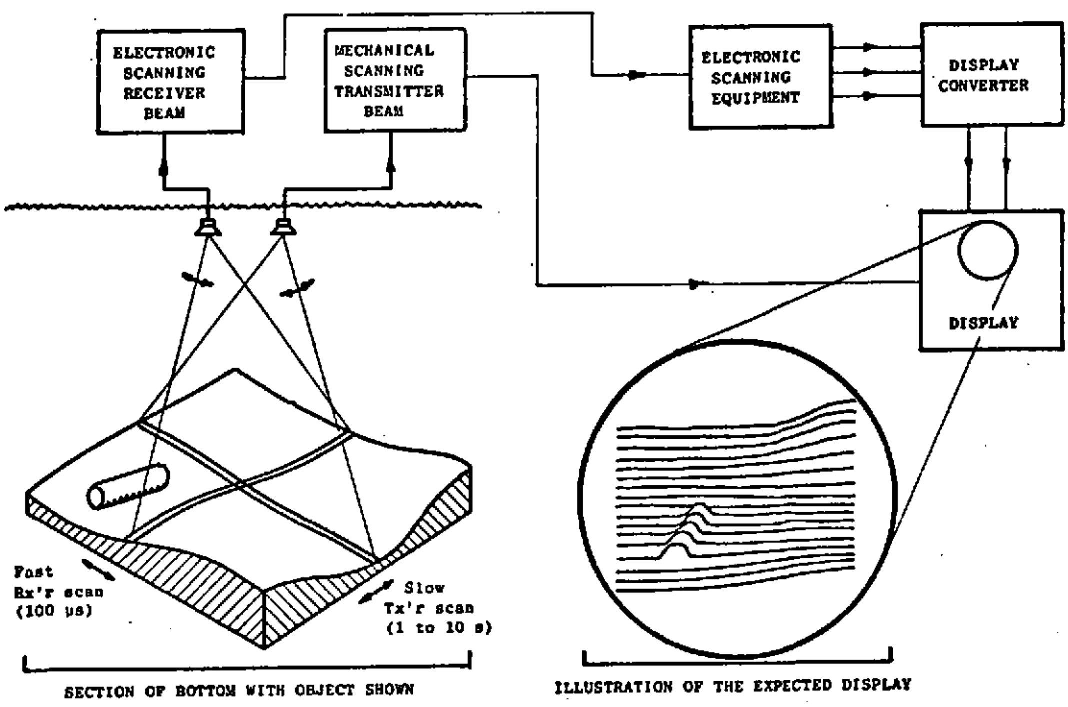
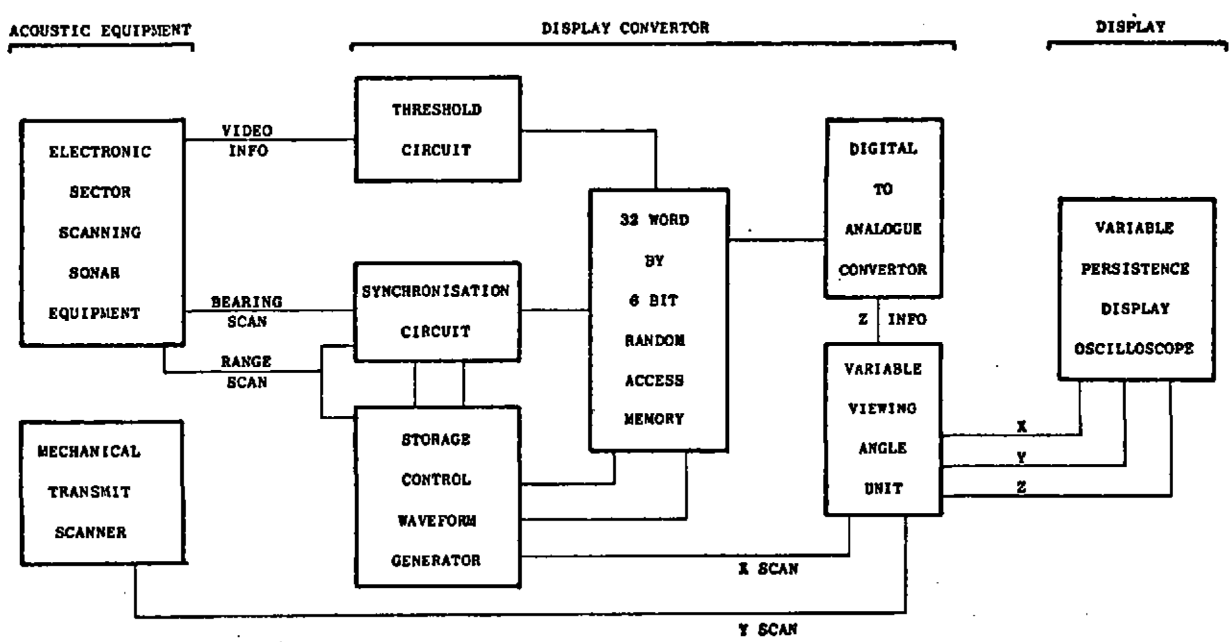


Figure 5 A Simplified Block Diagram of the Electronic System



The most important factor complicating the display generation is the need to store targets. This is most easily explained with reference to Figure 3, which depicts a simplified WPSS sonar display, obtained with the sonar looking vertically downwards. Targets delineating the sea-bed are shown numbered in the order in which they are received. Also shown is the sea-bed profile the 3-D display must produce. It is quite obvious that the targets are required in a different order to produce this profile, for example, target 5 is required first in the profile although it is among the last to be received. To overcome this difficulty all significant targets in a defined range interval (the range interval is limited to economise on storage) are stored in a digital store when they are received, and read out in the required order later, to produce one line of the profile display per acoustic "ping". The store is then emptied (meanwhile the mechanical scan has moved onto a new position) ready to accept targets for a new line of the display.

Although each target has four parameters of interest, range, two bearings and amplitude, there is a need to store the value of only one of these, range. The store is synchronised to the electronic scan so that the range of a target is stored (as a 6 bit binary number) in an address (1 of 32) proportional to its bearing in the fast scan. There is no need to store the bearing in the slow scan, since there is negligible movement of the transmitter during the short time in which the targets remain in the store. Finally, the target amplitude is stored (as a 1 bit binary number) inherently, since only those targets exceeding the threshold are stored.

In addition to the store itself, other circuits are required to control the entry and removal of targets, and to synchronise this with the operation of the electronic scanner. The use of a digital store necessitates some form of A to D and D to A conversion, although these circuits are quite straightforward.

Of the two remaining circuits used, the threshold detector has been mentioned already. It is used to detect the amplitude of targets so that only the first significant target in any given bearing cell appears on the display. The final block in the system can be used to adjust the apparent viewing angle of the target surface, which is a useful aid to the interpretation of the display.

Constructional Details

The constructional effort carried out on this project falls into three main areas, the mechanical scanner, the electronic circuitry and the acoustic arrays. Although the first two categories represented the greater part of the work, they are of little interest here (some details may be given during the presentation if time permits). The work on the arrays consisted of manufacturing a duplicate of the 64 element WPSS sonar receiving array for use as a transmitter, and of applying a taper function to the elements of both arrays to reduce sidelobes. A Dolph-Tchebychev weighting function was used, and the first sidelobes of both arrays were reduced to less than 24 dB below the main beam (again, further details will be given, time permitting).

Testing and Results

Throughout the period of the project, tests were made in the Department's test tank, and in addition to these, trials were carried out at two field locations. Since these results are in photographic form, they cannot be reproduced here. However, this section is included to describe the scope of the testing and to present graphic copies of some of the displays obtained.

The tank tests consisted mainly of observing spherical targets, both singly and in combinations forming larger recognisable shapes. These were designed to assess the performance of the system, its resolution, and the effect of sidelobe echoes and threshold level on the appearance of the display.

A series of tests were conducted at Belvide reservoir in May 1974. Being shallow, the site was not ideal for the system, and the sonar had to be operated at oblique angles instead of pointing vertically down, and this caused some problems in the interpretation of the display. A variety of targets was investigated, ranging from natural targets such as the reservoir floor or surface (on rough days) to man-made targets such as spheres, tripods and the remains of a "fish cage" used for other experiments. This series of tests produced some useful results, but a deeper-water site was required.

The final series of field tests were carried out at Dosthill quarry, where the 20-30 m depth allowed the system to be operated in its planned mode. The transducers were mounted underneath a dinghy, pointing vertically down. The dinghy was fastened to ropes attached to opposite banks of the quarry, so that it could be pulled across the quarry in a straight line, repeatedly. No man-made targets were used in these tests, only the bottom of the quarry and objects on it being observed. Two of the displays obtained are reproduced graphically in Figure 6.

Although the testing of the system was by no means exhaustive, it was sufficient to identify the significant features of the display and system. A number of disadvantages exist, some due to the system, and some to the display, and these are summarised below.

1. The display is suitable only for surfaces such as the sea-bed.
2. Mid-water targets are represented incorrectly, being connected to the sea-bed via a pedestal.
3. Only a limited dynamic range of target echoes can be observed, since echoes from sidelobes degrade the resolution and integrity of the display.

In addition to these general disadvantages, the particular system used had two more. One was that the resolution of both the electronic scanner itself and the digital conversion equipment, was limited and in some cases insufficient to describe the target accurately. The other was that no ping-to-ping integration was incorporated into this experimental equipment, such that lines on consecutive scans were not repeatable.

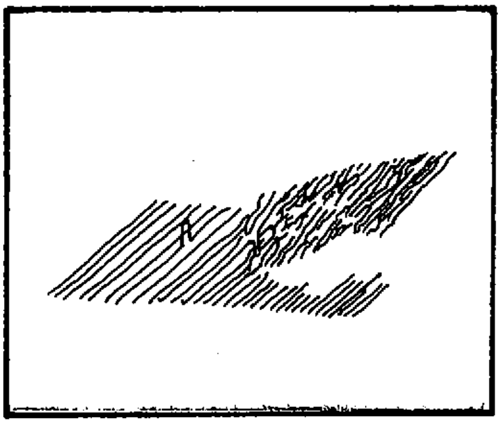
Of these disadvantages, the first two are of a fundamental nature, and cannot be overcome. The third problem, that of sidelobe levels is often encountered in acoustics and often proves to be formidable. However, recent advances (18) suggest that multiple beam systems, with as low as -50 dB sidelobes are possible, using acoustic lens techniques. Such a sidelobe level would certainly make a significant difference to the 3-D system.

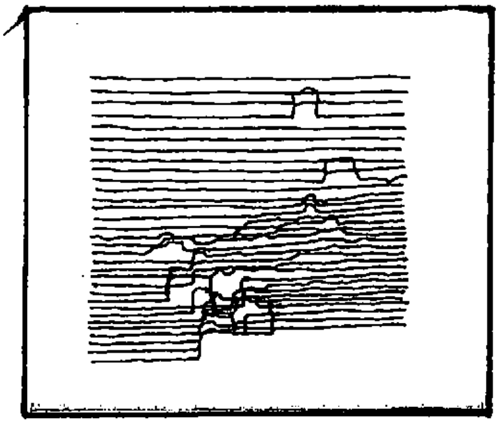
There is no doubt that the last mentioned problems can be overcome by the use of more complex electronics and that the implementation of a higher resolution scanning system with some form of integration would greatly improve the quality of the pictures obtained. However, such a system would be costly and is unlikely to be undertaken without the backing of a positive application of the system.

Nevertheless, this research project has produced some worthwhile conclusions. In it, a 3-D sonar system and display has been constructed, and evaluated. Many of the limitations, both practical and fundamental have been highlighted, and ways of overcoming these have been suggested. Above all, the work has demonstrated that this type of system is a rapid means of obtaining 3-D data about the sea-bed and that the profile type display can be a means of conveying this data, in a qualitative manner at least, just as rapidly to an observer.

Figure 6 - 3-D Displays

Showing two views of the bottom of a quarry. The left view is enhanced by the use of an isometric-type presentation.





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