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# RAPID AND CONVENIENT ACOUSTIC SEA-BED DISCRIMINATION FOR FISHERIES APPLICATIONS

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## 1. INTRODUCTION

Knowledge of the nature of the sea bed is of importance in most areas of underwater acoustics. In sound propagation studies it produces unwanted reverberation but in other areas, it provides valuable information. Apart from the direct applications in which it is required to recognise what is on the sea bed in order to retrieve it (e.g. in dredging or mineral harvesting), and the considerable need for a rapid means of hydrographic surveying [1], knowledge of the nature of the sea bed is of considerable value in relation to fisheries activities.

Traditionally fishermen using fishing gear at or near the sea-bed have used the length of the tails seen on the ground echo displayed on conventional echo-sounder systems as an indication of the hardness of the ground and thus as a means of identifying potential danger to their gear. Some echo-sounders have sufficient depth of scale to display a second echo on the screen (or even a third or multiple echoes on hard ground). The tails on the second echo tend to be shorter than on the first. To some extent they tend to follow the lengths of the tails on the first echo but appear to be much less liable to erratic variation in bad weather [2] Several years' experience has shown that the combination of information derived from the first echo (E1) and the second echo (E2) is closely related to the nature of the sea-bed.

Identification of the sea-bed not only permits the 'safe' ground to be correctly identified for trawling, but has a more direct significance for the practice of different types of fishing and the associated marine biology. It is well known that different types of crustacea and bottom feeding demersal fish tend to have their preferred habitat as far as the nature of the sea-bed is concerned. However more information may be available. The system described in this paper was used during crab fishing in the Arctic, to determine the softest ground in a region in which crabs were often found. The subsequent catch was good in terms of numbers but the average size of the crabs was only moderate due, it was subsequently observed, to their being predominantly female. Excellent male crabs were found a little way out from this softest ground, presumably forming a ring around the females.

The behaviour of many types of marine life has also been observed to depend on characteristics of the sea bed. The discovery of a correlation between the depth of the sea bed and the distribution of krill stocks [3] has been followed by an investigation of the potential correlation between the type of the sea bottom and the horizontal distribution of cod, herring and sprat [4]. It was found to be positive for cod, but (as one would expect) not at a significant level for the pelagic species sprat and herring. It is, of course, important in performing experiments, to take into account systematic diurnal and seasonal variations that may occur in such distributions.

The present paper is devoted to a signal processing and display system that may be attached to any existing echo-sounder transducer. The system uses an analysis of the first and second echoes to provide an indication of the nature of the sea-bed. Before proceeding to a description of the main system, the principles of the analysis will be outlined.

## 2. PHYSICAL MECHANISMS

The possibility of exploiting the information available in the different echoes produced by echo-sounders has been identified by a number of authors over many years. One of the first was Jagodzinsky [5] who derived an expression for the depth at which a small target of a given echo area can be detected if the echo-sounder records n multiple echoes. The expression depends on the bottom and surface reflection coefficients. The depth at which a given target is likely to be detected increases considerably as the bottom becomes softer. Having discussed the effects of ship roll and surface topology, Jagodzinsky comments "The experimental data that we now possess are not extensive enough for drawing a definite conclusion from this fact, but it seems that there is some relation between the relative intensity of the traces and the bottom structure".

The definition of multiple echoes requires some care. It has been used by Li and Taylor-Smith [6] to indicate echoes produced by successive reflections between the sea-bed and sub-bottom strata. Analysis of these interactions permits an estimate to be made of the attenuation coefficient in the sub-bottom strata. This approach requires the presence of a strong and identifiable reflecting interface below the sea-bed (but not too far from it) such as the bed-rock. The present approach considers all these sub-bottom reflections to be subsumed into the "first echo", while the concept of 'multiple echoes' is taken to involve simply successive reflections from sea-bed and sea surface.

In this sense, Orlowski [7], has suggested using the ratio of the energies of the first and second echoes as an empirical index of the nature of the sea-bed. The model used has a number of reasonable assumptions for a first approximation. Its major limitation is that the formalism tends to obscure the essential physics of the situation, making successive closer approximations to reality a rather complex set of operations.

The present authors indicated several years ago [8] that different parts of the first and second echoes might contribute different information on the nature of the sea-bed. The main mechanisms will be outlined only, the relative significance of the different effects depending on the numerical values of many of the acoustic parameters associated with ground of a particular classification.

The first echo and second echo are shown schematically in figures 1 and 2 respectively. The former consists of all those reflections which return directly to the transducer before the echoes which have been reflected twice by the bottom and once by the sea surface. These latter are called the 'second echo'.

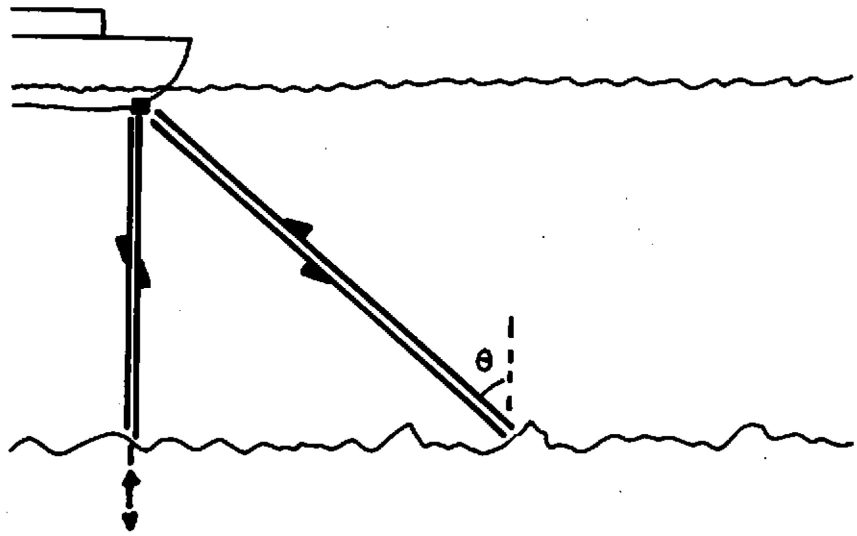


Figure 1: Mechanism of formation of the first echo

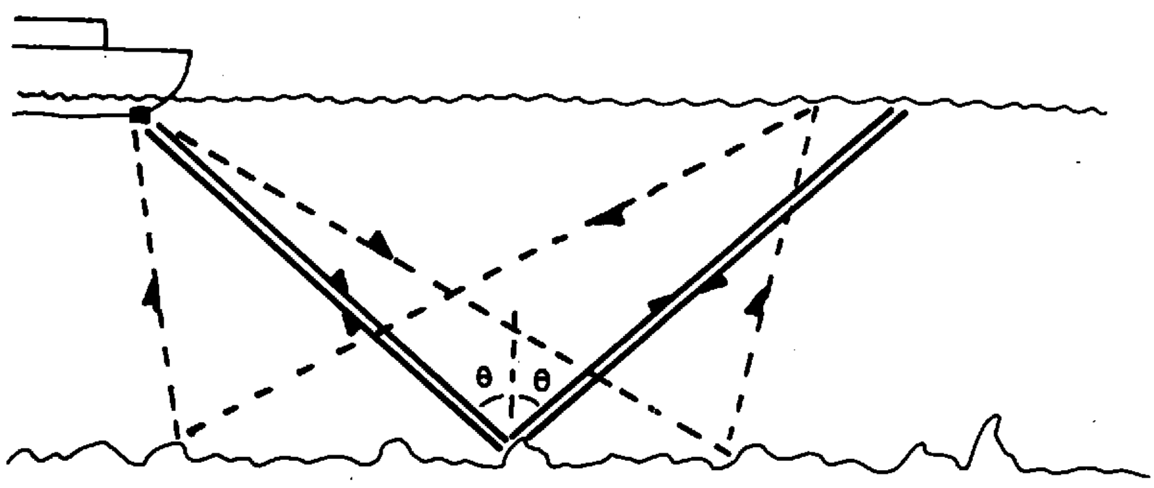


Figure 2: Mechanism of formation of the second echo

## 2.1 The First Echo

The initial part of the first echo is clearly caused by the first reflection at normal incidence from the sea-bed and provides information on the impedance discontinuity that the sea-bed represents, if it can be modelled as a step function. In this case the amplitude of the received signal is extremely sensitive to the pitch and roll of the vessel and cannot be used as a reliable index. If the sea-bottom interface cannot be modelled as an impedance discontinuity, but rather as a gradation of impedance, it will still produce echoes of a lower level (the analysis is given, for example in [9]) but some more complex form of signal analysis will be required [2]. Again this will be sensitive to the movement of the vessel.

The remainder of the first echo is caused by the alternative processes of oblique back reflection from the sea-bed and reverberation from structures within the sea-bed. Since these arrive simultaneously, they cannot be distinguished. The processes of reverberation are complex. For media continuously varying with depth, obliquely incident waves will suffer continuous 'leaking' of energy by mode conversion, as well as continuous refraction. In addition the presence of varying attenuation will not only stimulate a small degree of reflection [10], but will also cause the transmitted waves to become increasingly inhomogeneous.

The process of oblique back-reflection is, to some extent, more easy to define, provided that the sea-bed can be described as a discrete, if rough, interface. The strength of the reflection at a given angle will depend not only on the impedance discontinuity but also on the roughness exhibited by the ground. The parameters of the roughness are its spatial frequency spectrum and its (vertical) amplitude. Thus although the primary measure that can be obtained from the first echo is that of roughness, there is some direct relation to hardness through the impedance discontinuity, and also an indirect relation to hardness through the fact that harder ground has a greater capability of exhibiting roughness. This relationship is seen in the data in the very few references which deal with this problem in the literature, e.g. [11 - 13]. The movement of the vessel has the effect of convoluting the directivity function of the transducer with the oblique back reflection function. The numerical implications of this are under investigation by the authors.

## 2.2 The Second Echo

The second echo is produced by a double specular reflection from the sea bottom and a single reflection from the sea surface. For a planar bottom, the specular reflection is directly related to the hardness of the bottom through the impedance because of the double reflection. The oblique back scattering from the sea surface drops rapidly as the angle of incidence decreases away from the normal, reaching a low but approximately uniform value [14] at angles of incidence greater than $30^{o}$.

There is a small possibility of waves entering the sea-bed and, having suffered reflection, re-emerging to be reflected from the sea surface to contribute to the second echo by virtue of their arrival back at the transducer within an appropriate time interval. The total contribution from this mechanism is probably sufficiently small that it can be ignored. However, in addition to rays of the type shown by the full lines in figure 2, there are other combinations of reflections (such as those shown by the dotted lines) which may also contribute to the second echo. It is not quite so clear that the total effect of these is also negligible. They arise from the fact that the sea-bed is very rarely to be considered as a planar reflector, while the sea surface again exhibits a high degree of non-specular behaviour. (Indeed we rely on the non-specular behaviour of the sea-bed to produce the first echo and the non-specular behaviour of the sea surface to produce the second echo.) The only constraint on the non-specular reflections of the type identified by the dashed lines is that the sum of the secants of four angles involved lies within appropriate limits.

Thus it can be seen that the information from the first and second echoes is essentially complementary. In simple models, the former relates primarily to roughness with hardness enhancing it, while the latter relates primarily to hardness with roughness diminishing it. In both cases considerable care has to be taken with the amplification and time varied gain applied before the signals are processed [15] in order to minimise the dependence on instrumental characteristics and depth, [7].

## 3. DISPLAY OF INFORMATION

From the echo train received at a given position, it is possible to separate the first and second echoes and from them to derive two numerical indices, which will be called E1 and E2 in the following discussion, in addition to the time of first arrival from which the depth of the sea-bed can be calculated. The initial display chosen was that of 270$^{o}$ dials for E1 and E2 [8] which can be rapidly interrogated by a busy skipper. The major disadvantage of this type of display is a lack of recorded information, both for use at sea and also for subsequent review.

The simplest way of incorporating digital recording and display of information is shown in figure 3. The name given to this display presentation is RoxAnn. The main area shows continuously updated graphical displays of the levels of E1 and E2 (upper graphs) and of the sea-bed depth profile (lowest graph). In addition to the scaled graphs, it is possible to indicate by boxed numbers points of particular interest or importance. At the top of the screen numerical information is presented giving the times which delineate the information displayed on the screen and the instantaneous values of E1 and E2. In addition one or more coloured bands can be introduced across the screen corresponding to the ranges of values E1 and or E2 may take for ground of a type of particular interest. The introduction of audible warning signals triggered if preset values are exceeded is straightforward.

A more valuable type of display entitled RoxAnn Squared is shown diagrammatically in figure 4. The key to the display is the graph in the bottom right hand corner of the screen. The values of E1 and E2 at a particular location can be identified by a single point on a rectilinear display of the form shown there. The E1:E2 field can be subdivided by

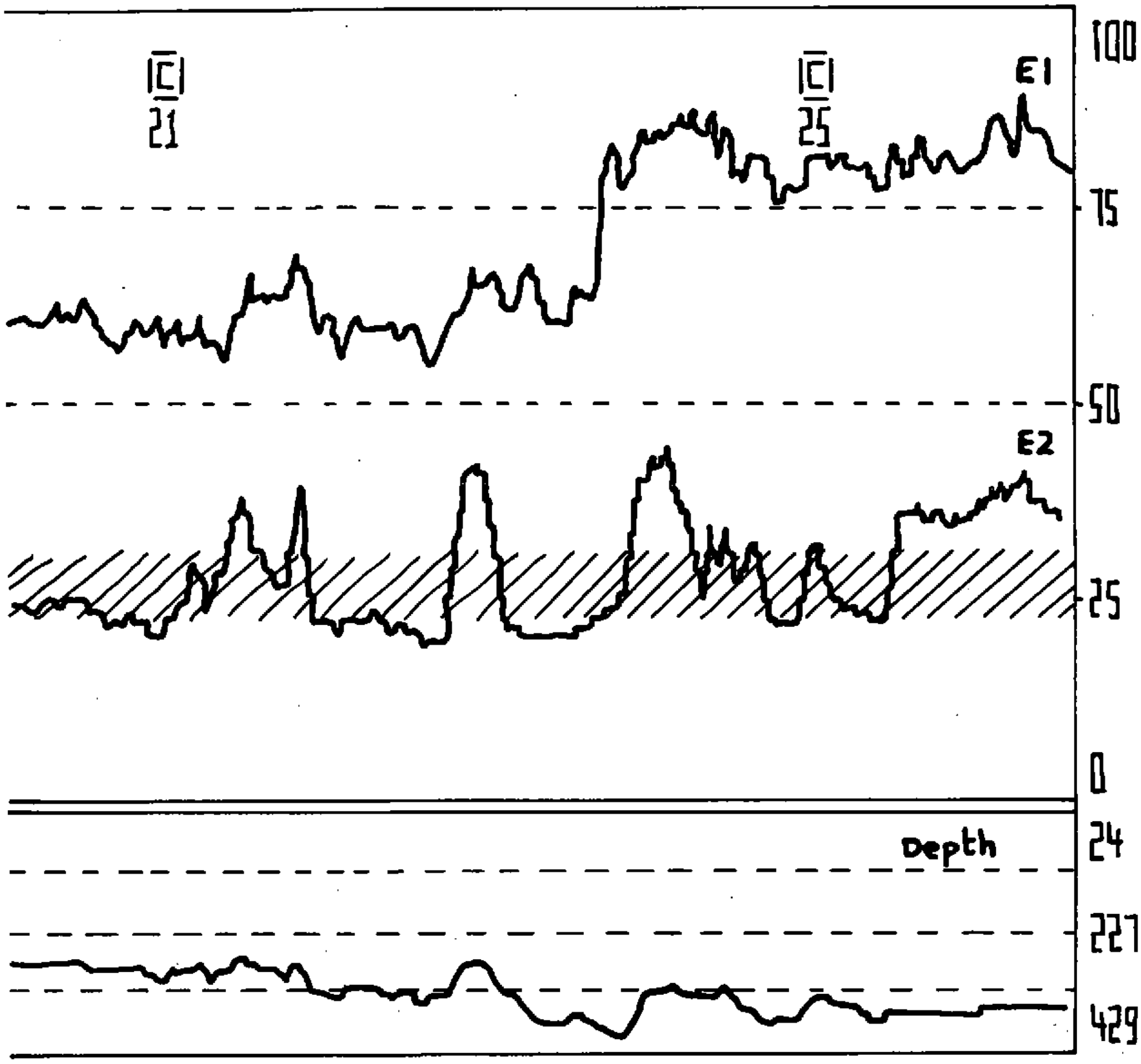


Figure 3: The echo level and sea-bed depth displays of RoxAnn

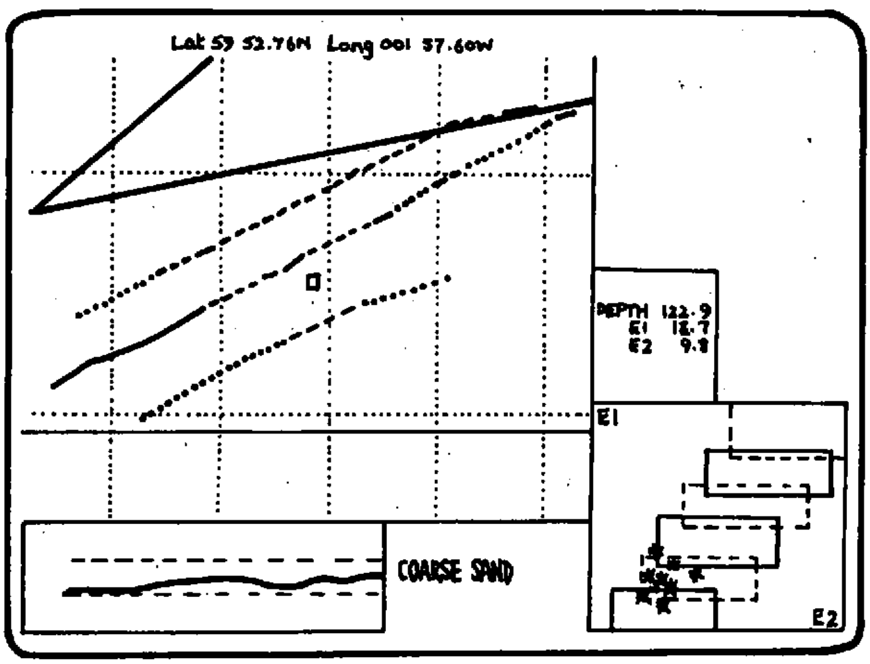


Figure 4: The RoxAnn Squared display (see text)

coloured boxes indicating the ranges of ground varying from mud through grades of sand, gravel and boulders to rock. These boxes can be defined from the fisherman's experience or from charts or from direct sampling of the sea-bed. It is usual to display a number of recent points (typically between 10 and 20).

The major part of the display in figure 4 (top left) is an electronic chart of the vessel's course, achieved using direct input from the navigational system (the coordinates are displayed at the top of the chart and are continuously updated). The scale of distance of the chart can be zoomed so that the horizontal dimension corresponds to any value between 150 miles and 12 metres. In addition the chart can include several valuable features including coastline, the positions of buoys and wrecks, and range circles from a particular point. Such electronic charting and logging displays are commonly known as "plotters" because the primary function is to show the vessel's navigational location or "plot".

Now, with the E1:E2 data available, the vessel's track can be colour coded, corresponding to the nature of the ground, the colours being the same as those used to define the different types of ground on the E1:E2 mapping.

Other information that is of importance is the variation of the sea-bed depth as the vessel steams. While this is routinely shown on the separate echo-sounder display it can now be incorporated in graphical form at the bottom left of the screen, being continuously updated and using the same E1:E2 colour coding.

In addition to the three main graphical displays the screen shows alphanumeric data: time, vessel course, speed, depth, E1 value, E2 value and a description of the type of ground (e.g. coarse sand) in the language or code of choice.

This integrated display enables areas of a particular type of ground, such as rock, to be mapped out by the vessel proceeding at full speed. The digital storage of the information permits an extra facility of colour coding the tracks not only by the E1:E2 value but, alternatively by E1 alone or E2 alone, or by depth.

## 4. CONCLUSION

The new RoxAnn Squared display of information derived from the first and second echo-sounder echoes not only gives information on the nature of the sea-bed but gives it in the context of all the other associated information that the fisherman (or hydrographer) needs to be able to utilise it fully. The design of the display permits the information to be readily assimilated at a glance after a very short familiarization period, without the obligation to interpret visually a complex image, such as that of an echo-sounder. It thus represents a major advance in fisheries instrumentation. The outstanding question relates to the subtlety of ground discrimination that it may be possible eventually to achieve, for very specific applications. Analytical and ground truthing studies are in progress.

**RAPID AND CONVENIENT ACOUSTIC SEA-BED DISCRIMINATION**

Acknowledgements

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