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SIMULATION OF ACOUSTIC BACKSCATTERING FROM A RANDOM SURFACE USING OPTICS

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INTRODUCTION

There are a number of underwater applications of acoustics where a fundamental understanding of the character of the backscattered field or reverberation from a static irregular boundary, such as the sea bed, is of interest. A knowledge of the first and second order statistics of the random field is usually sufficient in most of the applications. Experiments to measure these statistics are difficult to conduct and an image of the spatial nature of the backscattered field is extremely hard to realize. However such a spatial image if it existed would be of interest because the dependence of this field on either, the nature of the boundary or on any relative motions, could be easily assessed.

In the optical case with the availability of coherent light sources and video equipment it is a relatively easy process to produce such spatial images, for example on a video monitor by placing a defocussed video camera in the plane of the backscattered field to be visualized. These optical images are called speckle patterns and they show the random distribution of the light intensity.

The purpose of this paper is to report on the progress made in some experiments which make use of the analogous wave behaviour of light and sound and which are intended to show how an optically produced speckle pattern may be employed to observe some of the reverberation effects that would also occur in acoustics. In particular the statistic of interest to the authors is the spatial correlation function.

THEORETICAL CONSIDERATIONS

There are two main theoretical approaches to the study of the scattering of waves from randomly irregular boundaries. The first is a physical method which uses wave theory. In this the boundary characteristics are described in terms of a random height function, its spatial correlation and the local reflection coefficient. These are incorporated into a scattering integral of the Kirchhoff-Helmholtz type [1]. The second method is phenomenological in character. The boundary is described as a collection of point scatterers and the scattered field is the summation of many contributions whose number and individual amplitudes and phases are stochastic variables [2].

These two approaches may be shown to be essentially the same when each scatterer is localized. In the extreme the scatterers are represented as a collection of spatial delta functions [2]. A more detailed study [3] for narrowband signals suggests that the two methods coincide provided that the width of the spatial correlation function of the boundary's local height is less than the linear dimensions of the aperture of the source.

When the point-scatterer model is applicable the backscattered field has horizontal spatial correlation features which do not depend upon the nature of the boundary. This implies that information about the nature and size of the boundary features would be difficult to ascertain from correlations in the narrowband backscattered field. For example, for the oblique incidence situation [2,4], with small grazing angles and omnidirectional radiation, the backscattered field from an annular ring has a spatial correlation proportional to $J_0(kd)$, where d is the spatial separation between the two field points and J_0 is the Bessel function of zero order. This is independent of the boundary. The effect of a directional source in this case has the effect of producing a spatial correlation of the field with a width which is of the same order as the source aperture size [4].

In the case of normal incidence with omnidirectional sources and receivers the horizontal spatial correlation of the backscattered field can be shown [3] to be proportional to $J_2(kd)/(kd)^2$, where J_2 is the Bessel function of order two. With directive sources the conclusions obtained for normal incidence are the same as for oblique incidence in that the spatial correlation has a width which is of the same order as that of the source aperture.

For the case where the spatial correlation distance of the boundary features is no longer less than the size of the source then the boundary irregularities do influence the field correlation function. Some experimental results [4] for the horizontal spatial correlation of the backscattered field from normal incidence acoustic waves on boundaries comprising different gravel samples are reproduced in Fig.1. These show only a slight dependence on gravel size. The fine and medium gravels had a mean size (from qualitative observations) which was less than the source aperture size , but the coarse gravel had a mean size similar to that of the source. Fig.2 shows theoretical curves [3] corresponding to Fig.1 for the fine gravel case. The results applicable to an omnidirectional situation are also plotted in Fig.2 for comparison. The source had a circular aperture of 12.5 mm diameter and the widths of the correlation curves of Figs.1,2, may be seen to be closely comparable with this.

OPTICAL BACKSCATTERING

A particular aspect of the behaviour of the field spatial correlation of interest in applications such as correlation logs [6], is the " direction " of motion of the features in the backscattered field as the source moves horizontally over the boundary. It has been shown [6] that for a moving source, with a velocity v, then two field points which are separated by a distance d and by a time t, are correlated provided the following equation is satisfied:-

$$d=2vt.$$

The spatial correlation function of the field in this situation can be interpreted as moving with a velocity of 2v relative to the moving source but in exactly the opposite direction.

SPECKLE PATTERN EXPERIMENTS

Video system

A diagrammatic view of the video equipment layout used in the experiments for producing speckle patterns is shown in Fig.3. A 5mW Helium-Neon laser was used with a small decollimating lens to produce a spherically spreading wavefront over the scattering surface. It was mounted typically 500mm from the surface but could be moved both horizontally and normally to it. The region of illumination was of the order of 4mm diameter. The backscattered light was collected by a video camera whose lens had been removed. The speckle pattern formed in the camera could then be viewed on a video monitor. The monitor image could be " frame dumped " into a microcomputer for subsequent analysis. Examples of the speckle patterns obtained are shown in Fig.4.

A frame of data contained 256x256 pixels and was digitized to 8 bits in the frame store. A spatial correlation of the speckles was computed by taking a two-dimensional FFT of the light intensity, forming the angular power-spectrum and finally taking a two-dimensional FFT of this.

An example of the two-dimensional correlation obtained from Fig.4a is shown in isometric form in Fig.5. A section through this is plotted in Fig.6. The wider correlation hump in Fig.6 arises because of the non-uniform response of the camera over its aperture. This is clearly evident from the reduction in intensity of the speckle patterns at the vertical edges in Fig.4.

The effects of relative motion between the source and boundary were investigated. If the source moves in a particular horizontal direction over the boundary then it is predicted that the speckle pattern should move in the opposite direction whilst retaining its features. This was verified with the equipment.

The shift in the cross-correlation curve is clearly visible in Fig.7, (speckle motion is of course a standard optical technique for the measurement of small displacements). The speckles will progressively change and become decorrelated for larger time separations during movement, because the portion of the surface being illuminated changes substantially.

Changing the spreading angle of the laser illumination by altering the decollimating lens has the effect of modifying the effective source aperture and consequently the speckle size. This was observed with the equipment and an example of the results obtained with the decollimating lens removed is shown in Fig.8. The speckles are noticeably broader than those of Fig.4. A slice through the corresponding 2-dimensional correlation function is shown in Fig.9. Comparing this with Fig.7 the increase in the width of the correlation curve may be seen.

From theoretical considerations for a point-scatter model it is to be expected that this correlation is relatively independent of the surface characteristics. This was easily tested by using different surfaces. From qualitative visual observations the speckle size was found to be largely independent of the surfaces used. A correlation curve for a different surface is shown in Fig.10, the similarity with Fig.9 may be observed. Further work is planned in this area to produce quantitative data to test the region of applicability of the point-scatterer model.

Diode system

The video system does have a limit on the field area viewed because of the camera aperture size. An alternative scheme tried was to use a light-sensitive diode which was mounted on a x-y positioning table. The area viewed was then only limited by the traversing range of the table. The table used had x-y traverses of 500mm and a positioning accuracy of 0.01mm.

In the experimental arrangement the output from the diode was digitized directly for subsequent computation of the correlation function. Examples of the correlation curves obtained will be shown during the presentation.

CONCLUSIONS

A system has been described which uses coherent light to simulate the acoustic backscattered field from a rough surface. By using a television camera as a multi-channel sensor the field can be viewed for qualitative analysis or digitized and processed in a computer. This technique has a major advantage in that it enables the spatial nature of the backscattered field to be easily visualized.

OPTICAL BACKSCATTERING

The primary conclusions are:-
1. The speckle pattern is relatively independent of the characteristics of the random surface provided the spatial correlation distance of the surface heights is less than the aperture size of the source.
2. When a point-scatterer model is applicable, the correlation distance of the speckle pattern is equal to the source aperture size.
3. The field only becomes significantly decorrelated when horizontal movements in the source-sensor position, relative to the scattering surface, are a large proportion of the illuminated area.

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[6] F.R.Dickey Jr. and J.A.Edward,'Velocity measurement using correlation sonar,' IEEE Position Location and Navigational Symposium, San Diego, 255-264,(1978).

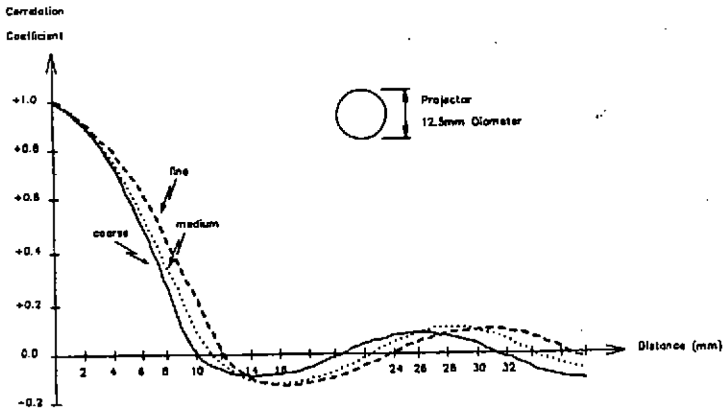

Figure 1: Measured Correlation Curves for Three Gravel Surfaces.

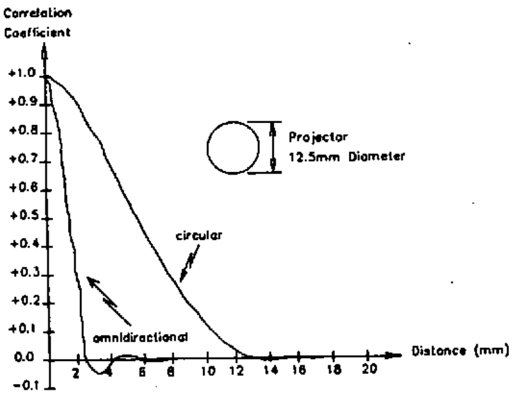

Figure 2: Predicted Correlation Curves at 500kHz

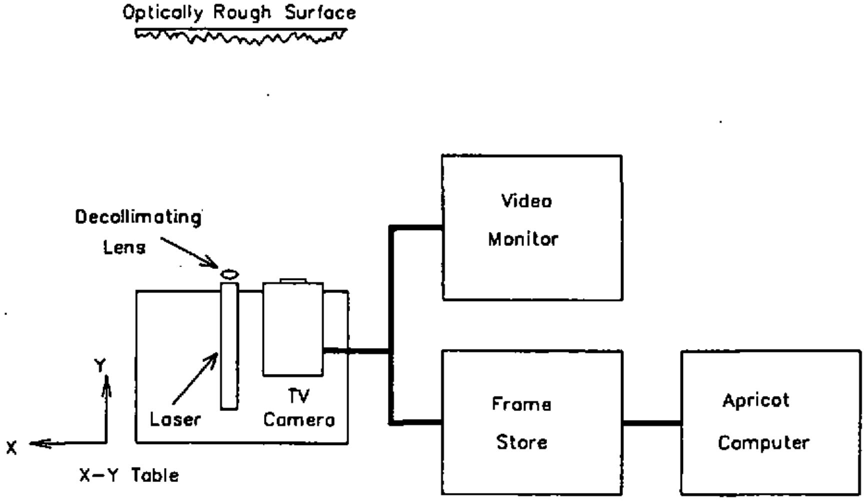

Figure 3: Block Diagram of Equipment Used to Examine Speckle Pattern

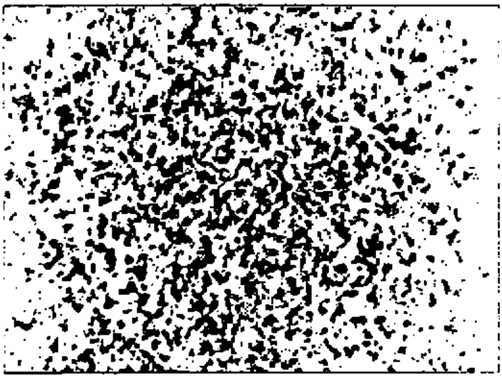

Figure 4a: Typical Speckle Pattern.

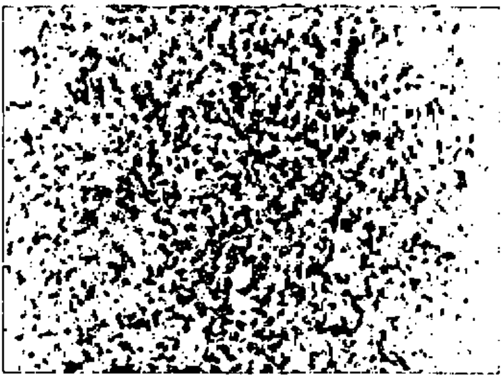

Figure 4b: Speckle Pattern of Figure 4a Shifted by 1mm.

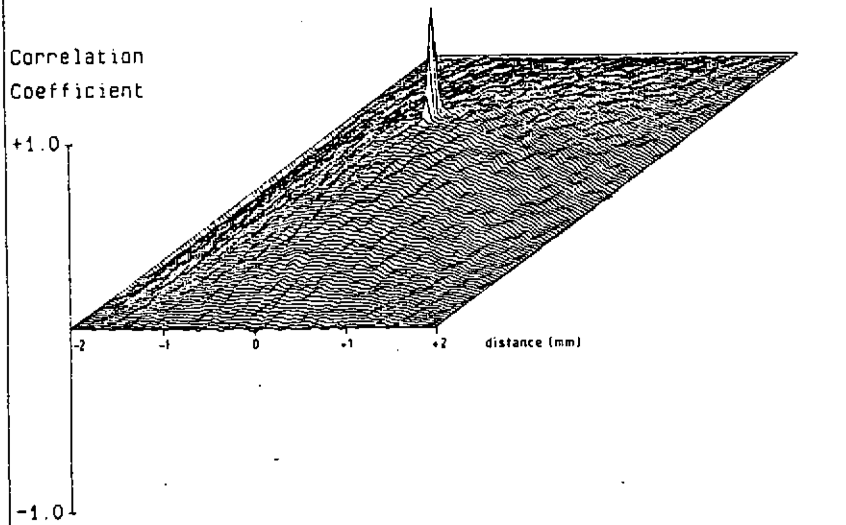

Figure 5: Isometric View of 2-Dimensional Correlation Function

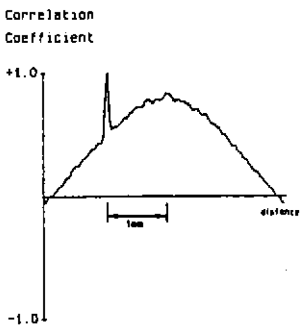

Figure 7: Slice Through Cross-Correlation Function between Speckle Patterns shown in Figures 4a and 4b.

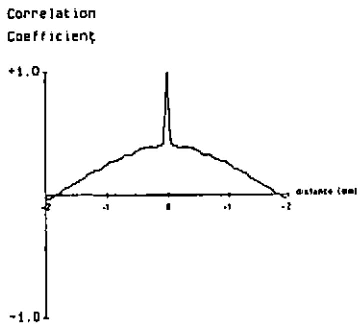

Figure 8: Slice Through 2-Dimensional Function shown in Figur

Camera Output

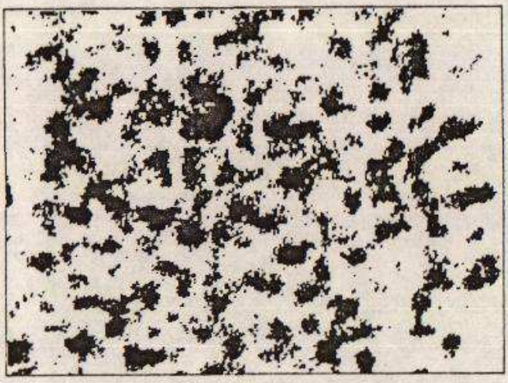

Figure 8: Typical Speckle Pattern Produced by Removing Decollimating Lens on Laser.

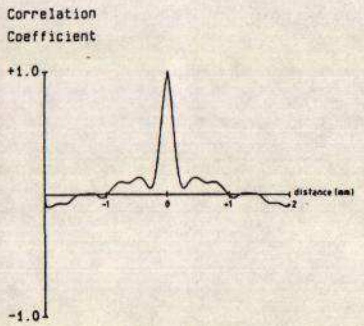

Figure 9: Slice Through 2-Dimensional Correlation Function For the Speckle Pattern of Figure 8.

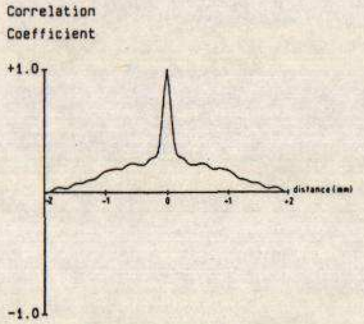

Figure 10: Slice Through 2-Dimensional Correlation Function as per Figure 8 but with a different Target Surface.