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UNDERWATER PHOTOGRAPHY FOR QUANTITATIVE DESCRIPTION OF BOTTOM ROUGHNESS

by

Tuncay AKAL

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UNDERWATER PHOTOGRAPHY FOR QUANTITATIVE DESCRIPTION OF BOTTOM ROUGHNESS

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1 April 1985

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Ralph R. Goodman

RALPH R. GOODMAN
Director

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INTRODUCTION

Knowledge of the roughness of the sea floor is obviously of great importance in marine geology for understanding the processes of the ocean bottom, and in underwater acoustics for understanding the scattering process. The ocean bottom contains a wide spectrum of roughness, ranging from a few millimeters to several kilometers, where small features are superimposed on much larger topographic features (Akal 1984). This complex structure, formed by different physical, chemical, and biological forces, can be quantitatively described in terms of their statistical properties, i.e., power spectral density and autocorrelation functions.

The gross-scale roughness of the sea floor is reasonably well known due to well-developed echo-sounding techniques. However, little is known about small-scale roughness (amplitudes and wavelengths ranging from centimeters to meters) due to the difficulties of measuring them.

The major technique for studying this small-scale roughness is bottom photography. By using photogrammetric techniques, a single pair of overlapping photographs taken with stereo cameras can subsequently be used to provide fine-scale contour charts of the sea floor.

To analyze these contoured charts quantitatively, a numerical method has been developed to calculate the two-dimensional bottom-roughness power-

spectral density and autocorrelation functions (Akal and Hovem 1978). This information gives, quantitatively, two basic parameters of a rough surface: its amplitude and wavelength content and its orientation. These parameters are closely related to the type of sediment and to bottom currents and their direction, hence to the sedimentation, transportation, and erosion processes. This information is also the main parameter for modeling the acoustic bottom scattering and acoustic propagation process.

PHOTOGRAPHIC EQUIPMENT AND TECHNIQUES

The photographic equipment consists of two EG&G deep-sea cameras, two strobe lights (250 watts each), two battery packs, and a pinger system.

To simplify the photogrammetric analyses, the two cameras are oriented vertically with a fixed base. The strobes are usually placed with a 25° light angle to the field of view, providing the best position for uniform illumination and reducing back-scattering. The whole system is mounted on a sled-type protective frame with two fins to maintain a stable orientation. (Figure 1).

Kodak Ektacolor Professional (type S), and later Vericolor II (5025, type S), negative color films have usually been used. This universal film, which has a speed of 100 ASA (21 DIN), allows high-resolution color prints, black-and-white prints, and color transparencies to be made from one negative.

For maximum resolution the system is usually lowered to a distance of 2 to 4 m above the bottom (using a pinger to control the height) and then allowed to drift over the seafloor.

This system has been operational over the last ten years in different oceans from water depths of a few meters to several thousand meters and has provided high-quality photographs from which the analysis technique has been developed.

METHOD OF COMPUTATION

Two-dimensional Fourier transforms and correlation functions are straightforward extensions of the corresponding one-dimensional functions. The block diagram in Figure 2 illustrates the methods of computation, which is made in steps: first the x dependencies are transformed for each y, and then the y dependency is transformed. The method of computation is summarized in the Appendix.

Before the computational scheme can begin, the following preprocessing procedures are necessary (Figure 3):

1. Digitization of data. The shapes of the seafloor surface are described by contoured charts. Therefore, an important problem is a simple

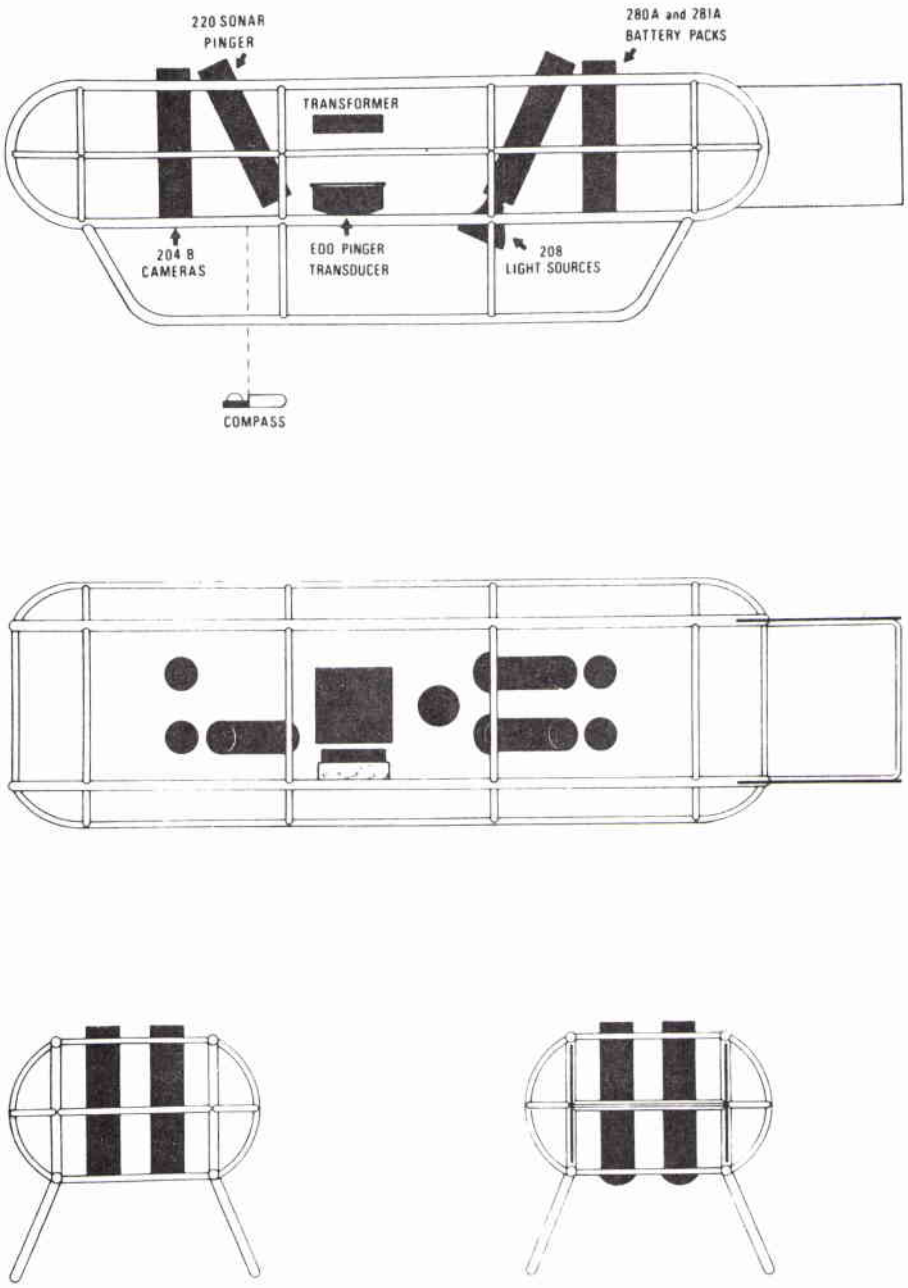

Figure 1. General view of the photographic equipment and the frame.

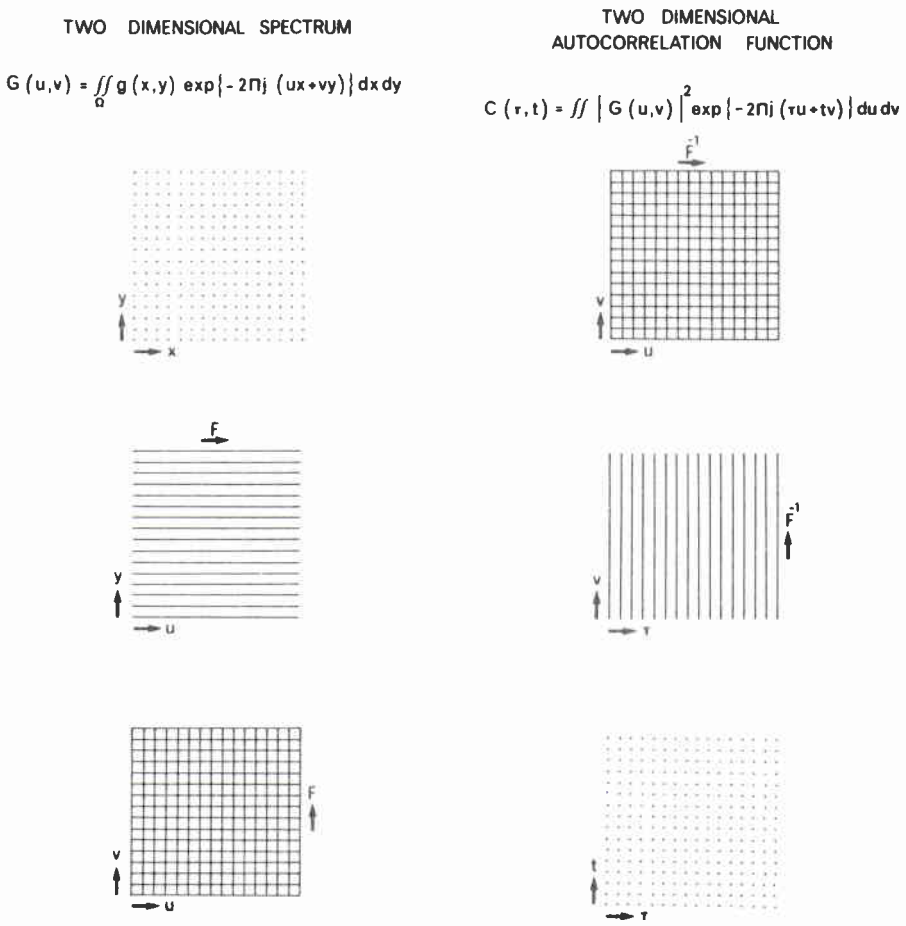

Figure 2. The method of computation *(after Akal and Hovem 1978).*

and accurate analog-to-digital conversion of a given contoured chart. This phase of work has been done by two separate operations: (1) Digitizing the contoured level using an electro-mechanical digitizer, which gives the coordinates of the contour lines in computer-compatible (UNIVAC 1106) format. (2) Construction of a matrix. For spectral analysis, numerical samples have to be obtained from a certain equally-spaced grid covering the contoured chart to be treated. This has been done by interpolating contoured values onto a rectangular grid by applying Laplacian or spline interpolation techniques. The type of interpolation is decided according to the

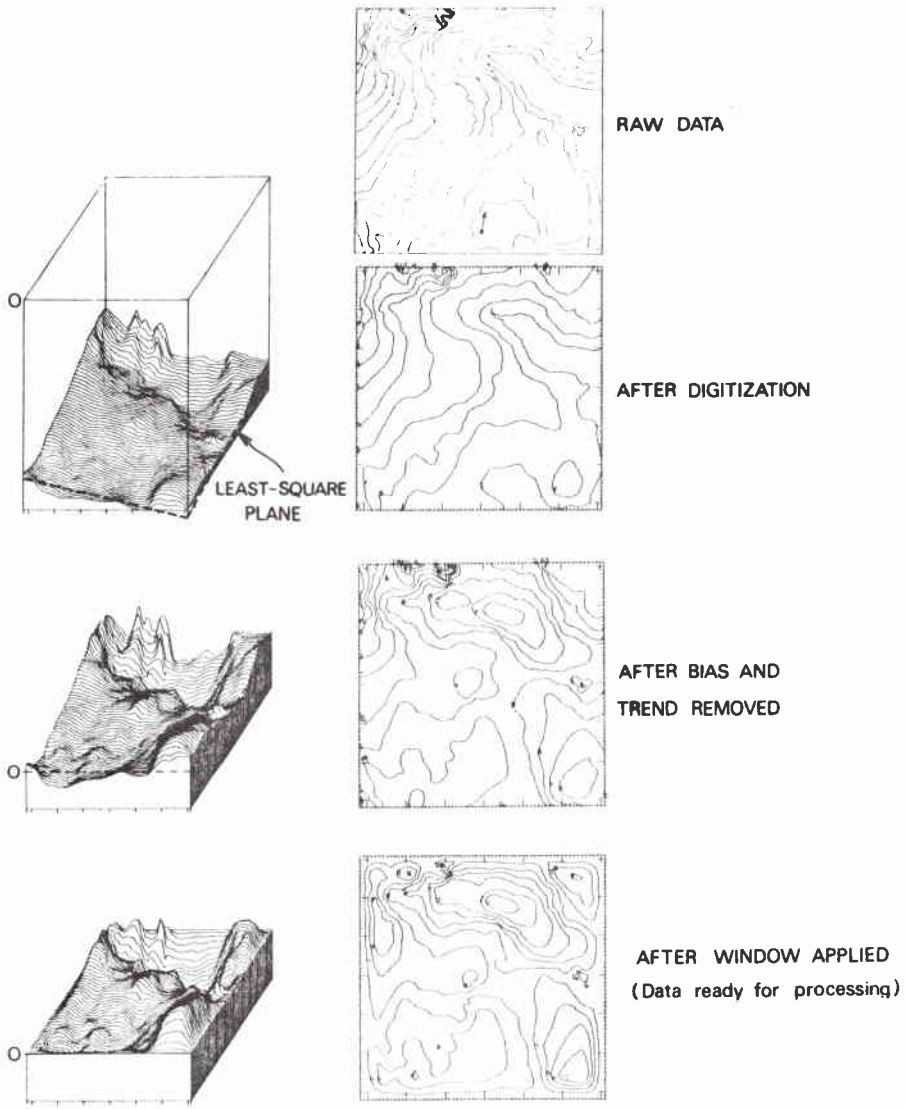

Figure 3. Preprocessing procedures *(after Akal and Hovem 1978).*

similarity obtained between analog and digitized data. Also, the grid size has to be carefully chosen to consider aliasing errors and available computer memory.

2. Removal of bias and trend from the data. The data we are dealing with are generally measured relative to a reference level. This means

that the surfaces we are interested in are superimposed on a rectangular box. For spectral analysis, it is desirable to transform the data to a zero mean value. After this, depending on the shape of the surface, a special correction may be needed to remove any wavelength longer than the surface being treated. This has been done by fitting a least-squares plane to the data for the two-dimensional detrending operation.

3. Windowing and filtering. To minimize the spectral distortion, there must be a broad and smooth data window without any sharp corners at the edges. Because of the size of the photographed area, the use of limited record size is inevitable in the two-dimensional spectral analysis, and truncation at the edges of a data window will erroneously introduce side lobes into the spectral domain. A two-dimensional filter that tapers off gradually with a cosine function towards both ends of the data window has been applied to suppress this effect. This certainly diminishes the effective area, but at the same time avoids severe distortion of the resulting spectral domains.

DISCUSSION OF RESULTS

Testing the Method

To facilitate understanding of the results obtained with this method, a simple test surface has been used. Figure 4 represents part of a cosinusoidal test surface $g(x,y) = \cos [2\pi(x \cos \theta + y \sin \theta)]$ in 30° orientation ($\theta = 30°$).

After this test surface has been analyzed by this technique, its resulting power spectrum and autocorrelation functions are as shown in Figure 4. As expected, the orientation and wavelength content in the x,y = plane are converged by the impulse pair that constitutes the two-dimensional power spectrum of the test surface.

Examples from Bottom Photographs

Five surfaces obtained from stereo seafloor photographs have been treated by this technique. These surfaces and the resulting power spectra and autocorrelation functions are shown in Figures 5, 6, 7, 8, and 9.

The surfaces in Figures 5 and 6 are taken from stereo photographs 12 m apart. Although these surfaces look completely different, as can be seen on

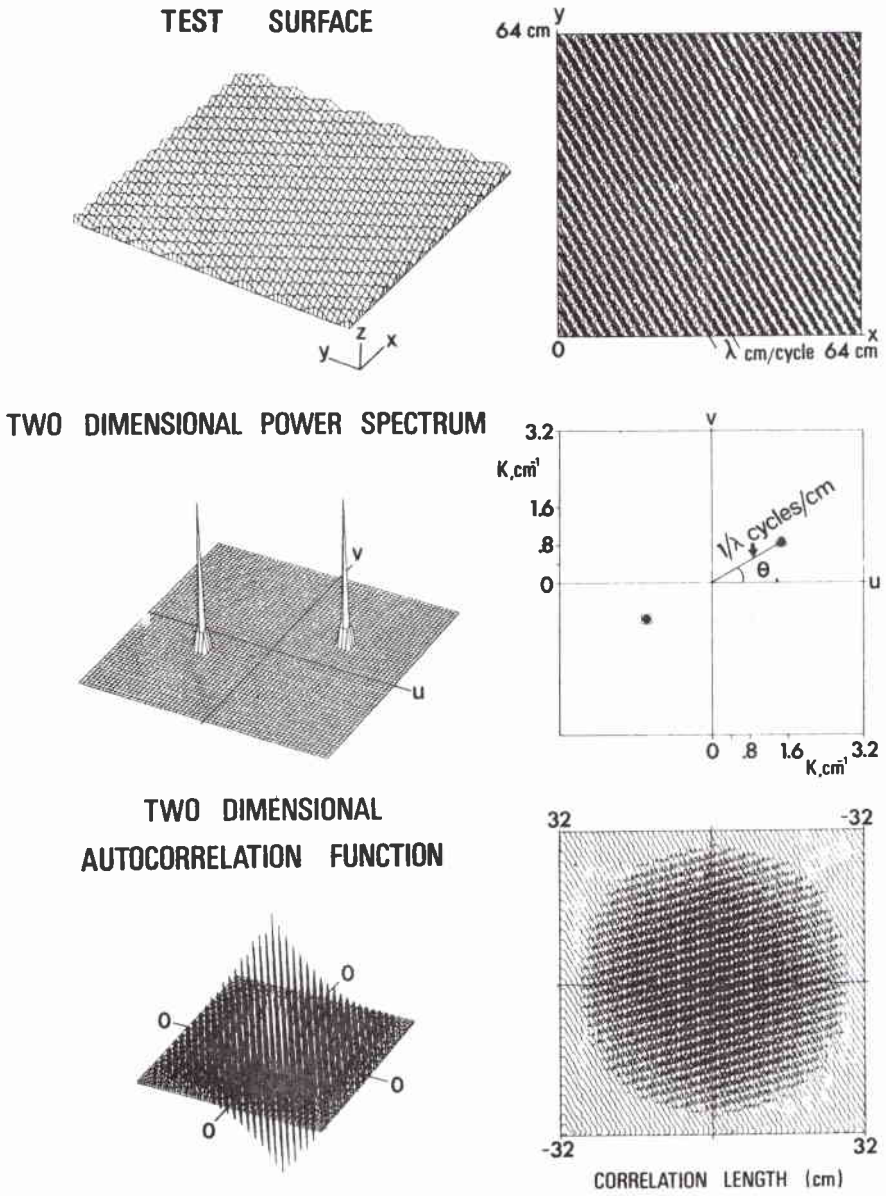

Figure 4. A cosinuisoidal test surface,

$$g(x,y) = \cos[2(x \cos\theta + y \sin\theta], \quad \theta = 30°$$

its two-dimensional power spectrum, and autocorrelation function *(after Akal and Hovem 1978)*.

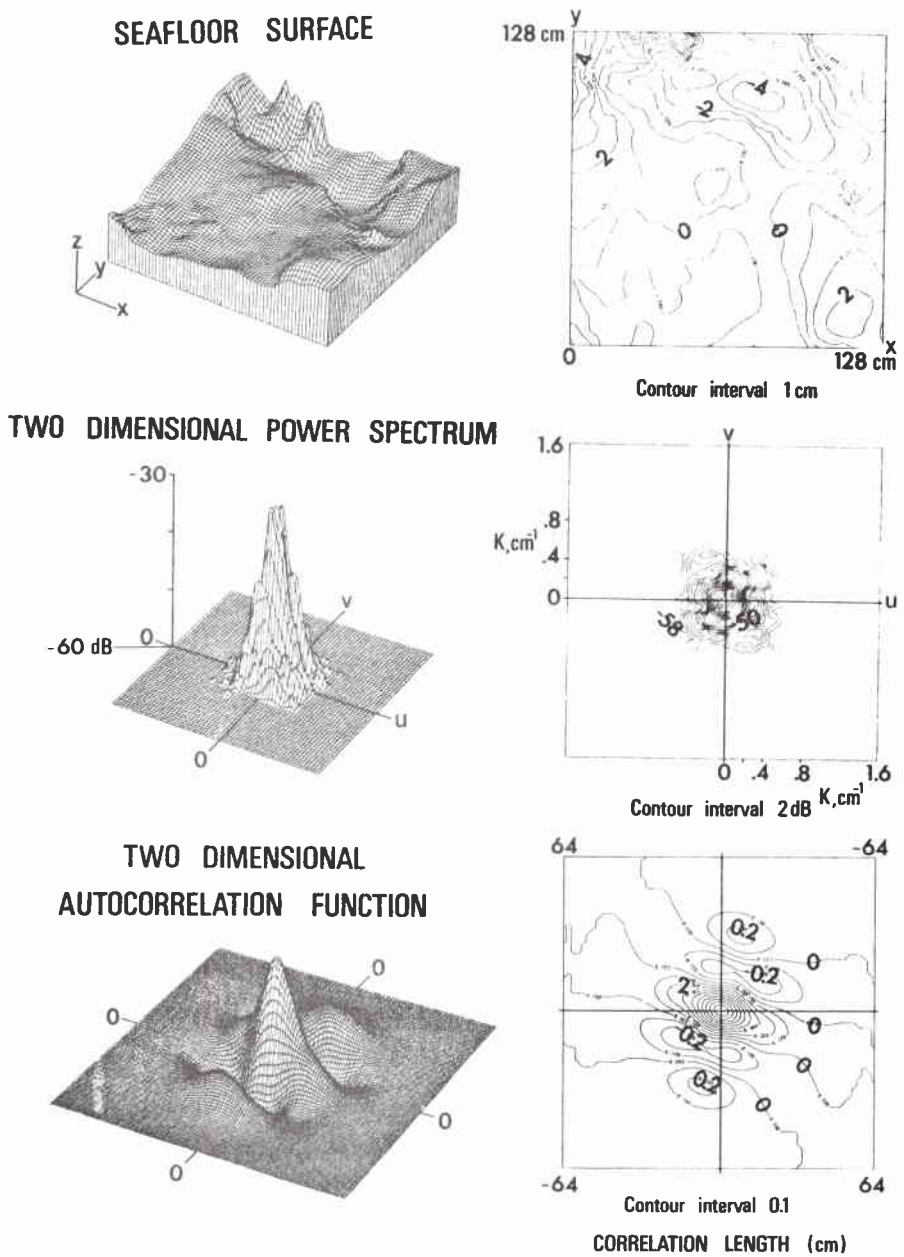

Figure 5. A surface obtained from bottom stereophotographs, its two-dimensional power spectrum, and autocorrelation function *(after Akal and Hovem 1978)*.

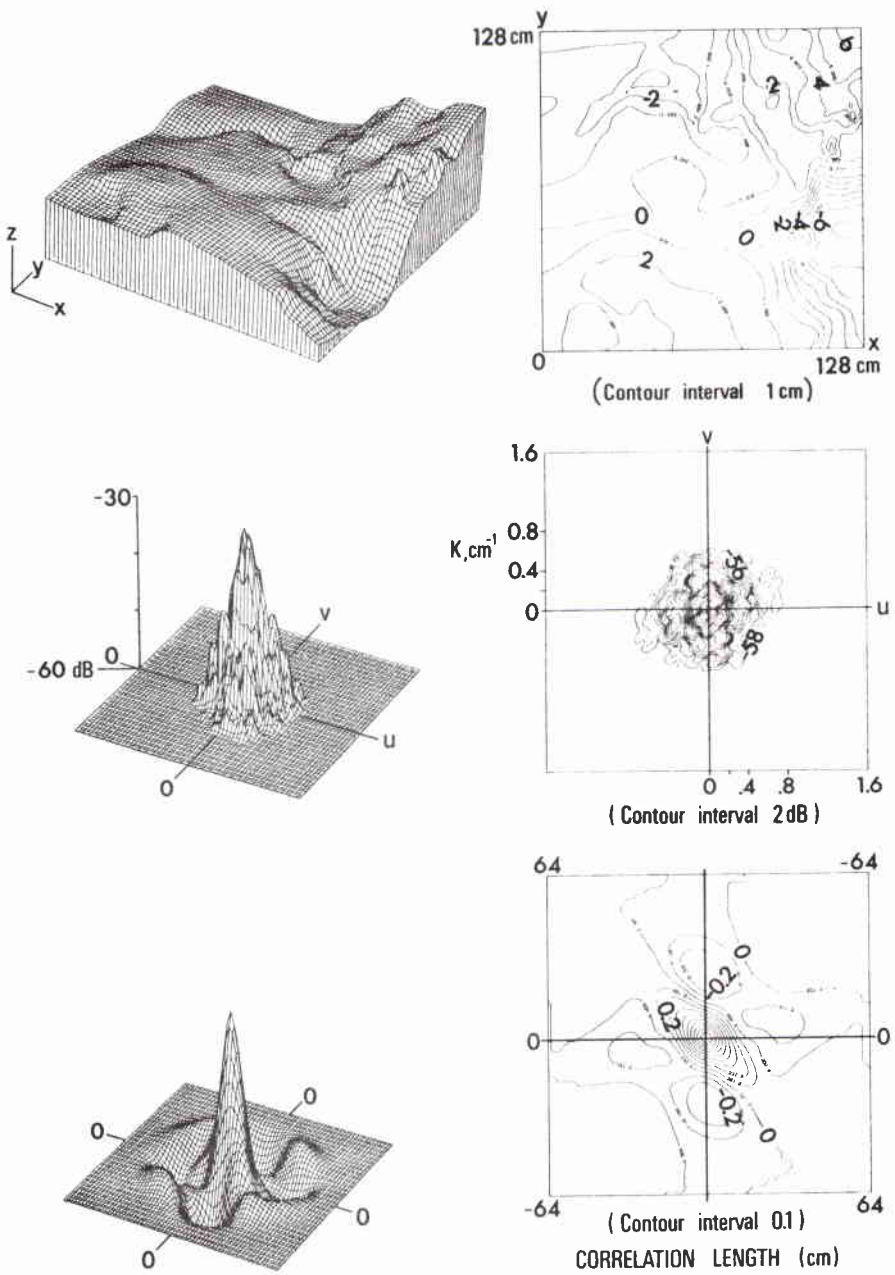

Figure 6. Another surface from bottom stereophotographs obtained 12 m away from the one shown in Figure 5, and the results obtained after processing.

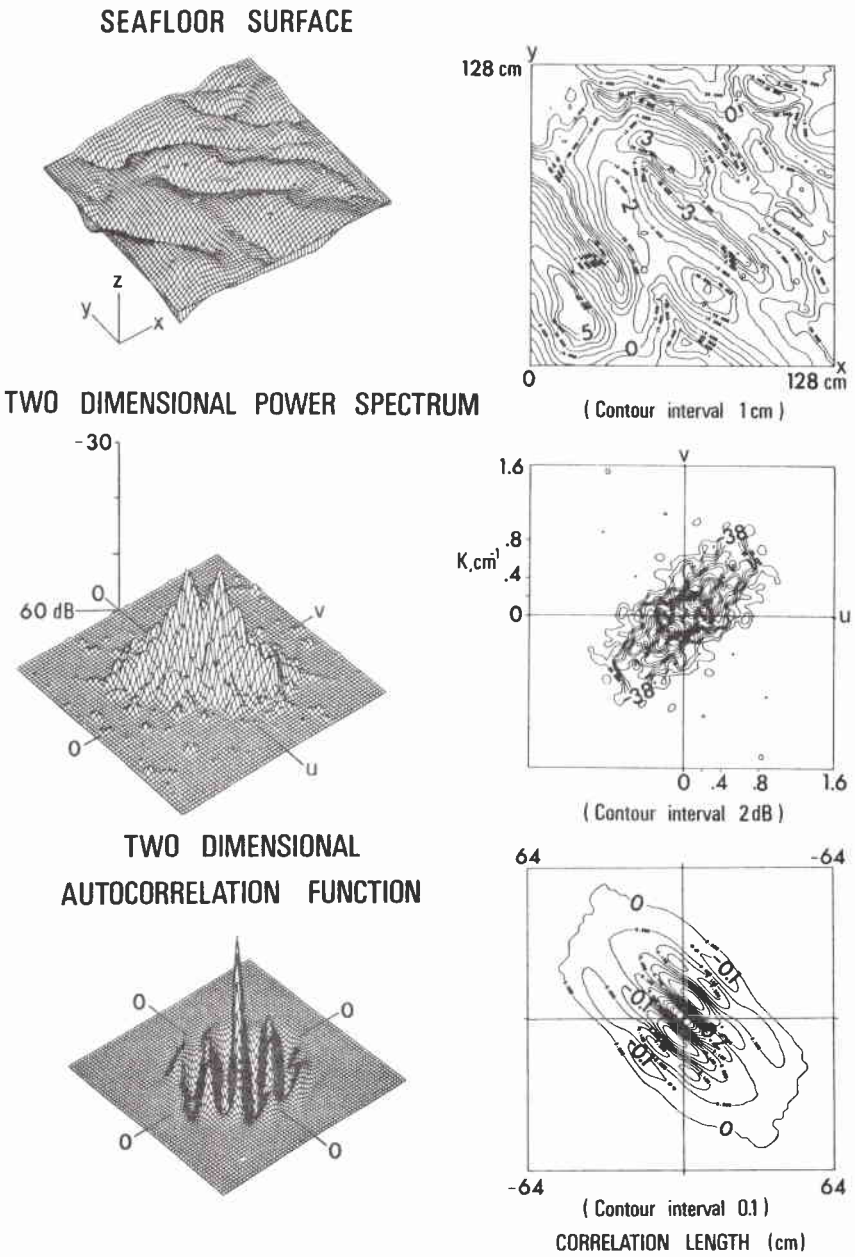

Figure 7. Seafloor with sand waves and the results obtained after processing.

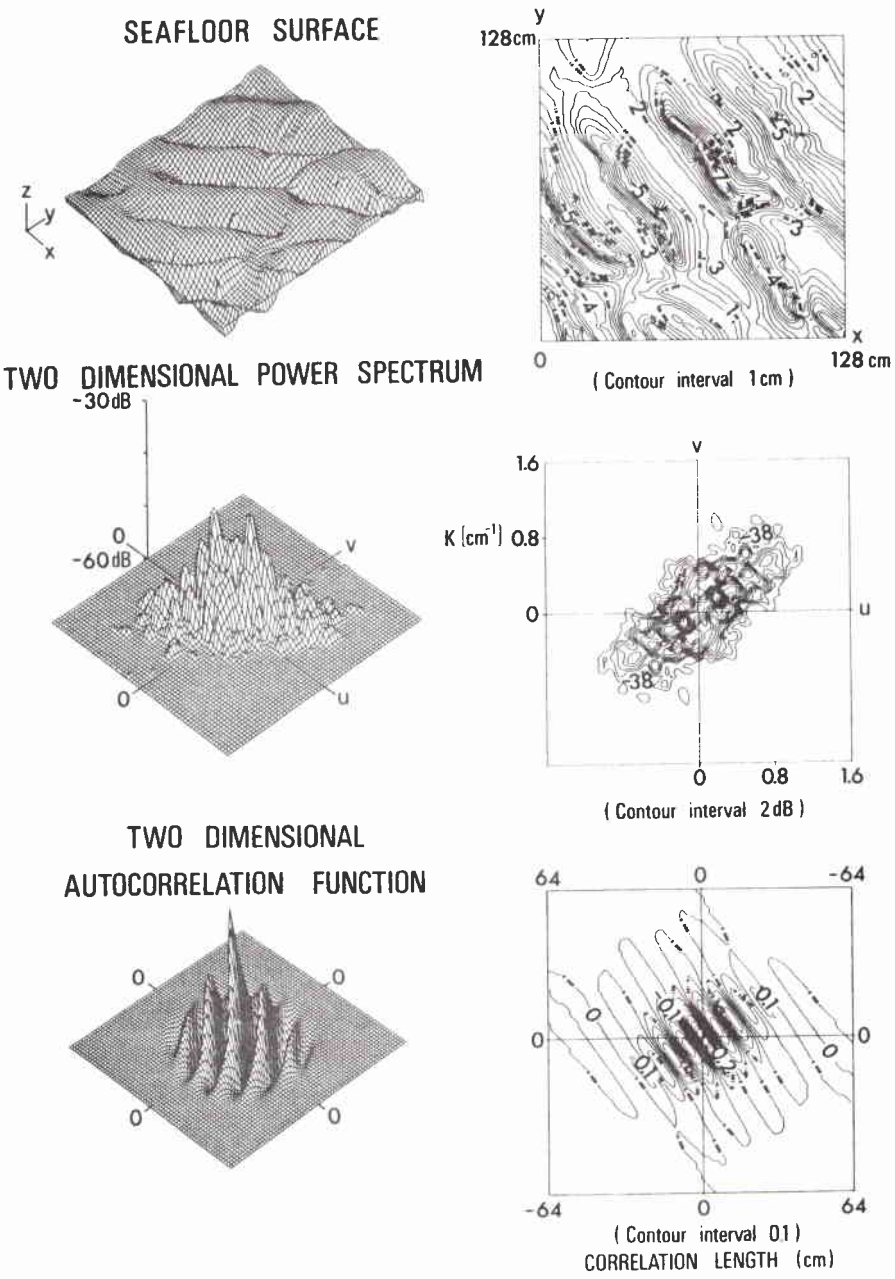

Figure 8. Another surface from the same area and the results obtained after processing.

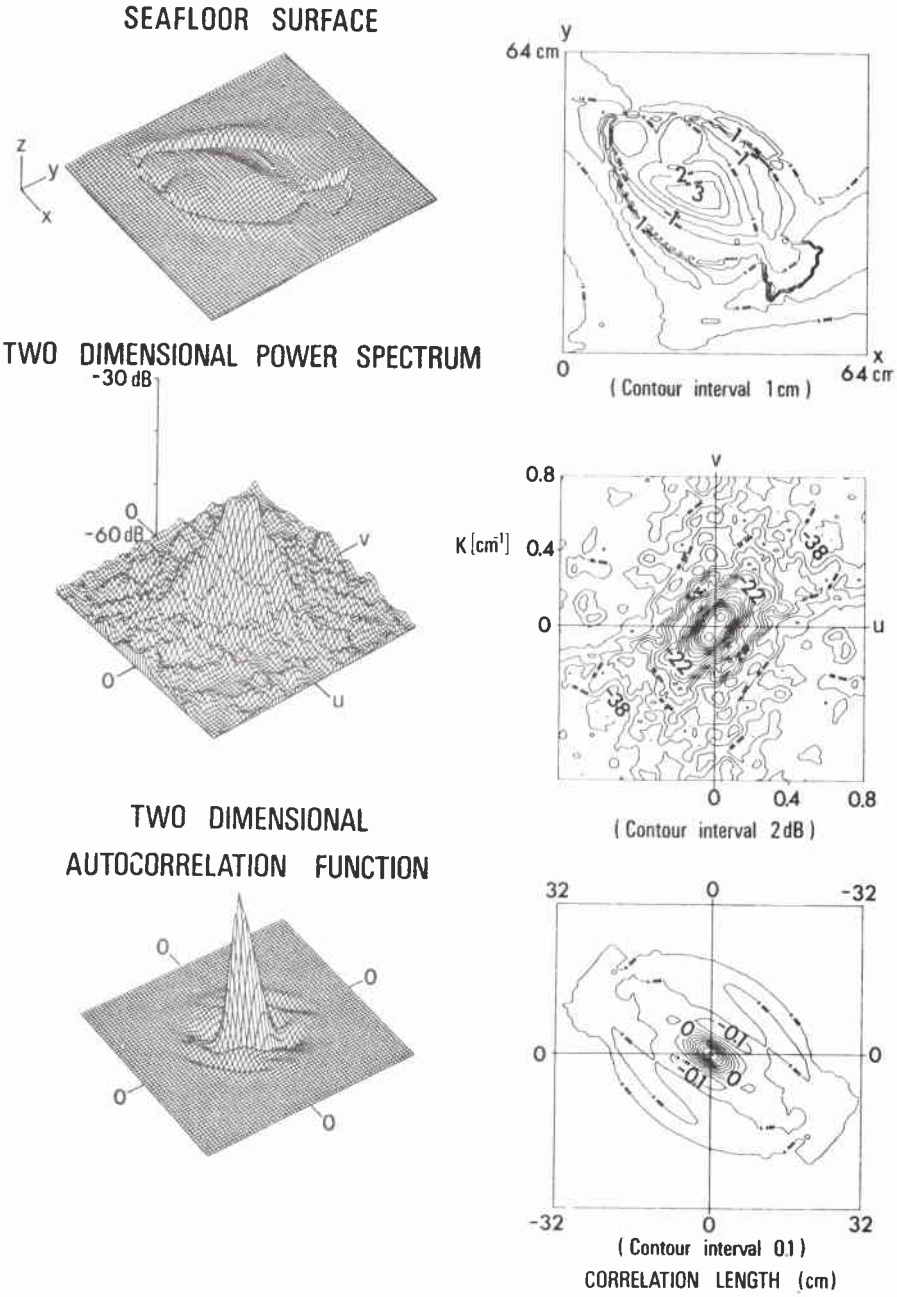

Figure 9. A plaice buried in the sediments, together with its power spectrum and autocorrelation function.

power spectrum plots, the wavelength components of the bottom roughness are the same, except that there is a small directional change in orientation that appears more clearly on autocorrelation plots.

Figures 7 and 8 represent two parts of the seafloor with approximately a one-mile separation. The spectrum plots show two peaks corresponding to the wavelength content of the sand waves that are present in the area. Figure 9 shows a fish (plaice) buried in the sediments, together with its power spectrum and autocorrelation function. As expected, due to its form it gives much broader wavelength content.

CONCLUSIONS

Using this method, the roughness of a contoured surface obtained from stereo photographs can be quantitatively described by its wave number composition and the direction of the roughness. This information is used for:

1. Investigation of the character, magnitude, and distribution of bottom roughness.
2. Classification of the quantitative roughness characteristics of the seafloor for different physiographic regions.
3. An input to different acoustic scattering and propagation models.

ACKNOWLEDGMENTS

We wish to thank the Istituto Geografico Militare, Firenze (Italian Military Geographic Institute), and Mr. B. Turgutcan for the stereophotogrammetric graphic results they obtained from seafloor stereophotographs, and Mr. P. Nesfield for his support during computer program development.

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APPENDIX: TWO-DIMENSIONAL POWER SPECTRAL DENSITY AND AUTO CORRELATION FUNCTIONS

Let us consider a two-dimensional function $g(x,y)_{\Omega}$ representing a part of the seafloor surface in a rectangle of the x,y-plane (Figure 2). The Fourier transform is defined by

$$G(u,v) = \iint_{\Omega} g(x,y) \exp\{ -2\pi j(ux + vy) \} \, dx \, dy \tag{1}$$

where

$$g(x,y) = \iint G(u,v) \exp\{ 2\pi j(ux + vy) \} \, du \, dv. \tag{2}$$

The squared amplitude spectrum $|G(u,v)|^2$ is related to the two-dimensional correlation function $C(r,t)$ by

$$C(r,t) = \iint |G(u,v)|^2 \exp\{ -2\pi j(ru + tv) \} \, du \, dv \tag{3}$$

or by making use of Equation (1):

$$C(r,t) = \iint g(x,y) \, g(x + r, y + t) \, dx \, dy. \tag{4}$$

In the discrete case in which the function $g(x,y)$ is sampled at regular intervals, the functions become slightly modified. Assume that the function $g(x,y)$ is sampled at intervals Δx and Δy so as to produce a matrix

$$\begin{aligned} g_{k,i} &= g(k\Delta x, i\Delta y) \\ k &= 0,1,\ldots,N-1 \\ i &= 0,1,\ldots,M-1 \end{aligned} \tag{5}$$

The discrete Fourier transform evaluated at frequencies

$$u = r/N\Delta x \quad \text{and} \quad v = s/M\Delta y$$

is then

$$G(r/N\Delta x, s/M\Delta y) = G_{r,s} = \sum_{k=0}^{N-1} \sum_{i=0}^{M-1} g_{k,i} \exp\{ -2\pi j(Kr/N + is/M) \} \tag{6}$$

KEYWORDS

AUTOCORRELATION FUNCTIONS
BOTTOM ROUGHNESS
FINE-SCALE ROUGHNESS
PHOTOGRAMMETRY
POWER SPECTRAL DENSITY
PROPAGATION
SCATTERING
SMALL SCALE ROUGHNESS
STEREO CAMERA
UNDERWATER PHOTOGRAPHY

Using the Fast Fourier Transform (FFT) method for evaluation of $G_{r,s}$ requires normally that both N and M be powers of two, and then $G_{r,s}$ becomes evaluated for arguments $r = 0,1,...,N-1$ and $s = 0,1,...,M-1$.

The discrete correlation function evaluated at points $r = p\Delta x$ and $t = q\Delta y$ is

$$C(p\Delta x, q\Delta y) = \sum_{k=0}^{N-1-p} \sum_{i=0}^{M-1-q} g_{k,i} g_{k+p,i+q} \tag{7}$$

In principle, this function can be computed directly following Equation (7), but to save time it is often preferable to compute it by using the FFT, that is:

$$C_{p,q} = \sum_{r=0}^{N-1} \sum_{s=0}^{M-1} G_{r,s}{}^2 \exp\{ -2\pi j (rp/N + sq/M) \} \tag{8}$$

The block diagram in Figure 2 illustrates the method of computation, which is in steps: first the x dependencies are transformed for each y, and then the y dependency is transformed.

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