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INSTRUMENTS AND METHODS

Sea-floor-mounted rotating side-scan sonar for making time-lapse sonographs

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Abstract—A rotating side-scan sonar system was designed to make time-lapse sonographs of a circular area of the sea floor. To construct the system, the transducers of a commercial side-scan system (frequency 105 kHz; pulse length 0.1 ms; horizontal beam width 1°; vertical beam width 20°; beam depressed 10° with respect to horizontal) were mounted 2 m above the sea floor on a vertical shaft that had a rotation speed of 0.5 rpm.

The radially collected sonar images are recorded linearly on a standard side-scan recorder. To convert the linear record to a radial record, the original moving record is photographed through a slit by a rotating camera, exposing a circular image on film.

Records that are collected with this system offer several advantages over records that are collected with towed systems. Bottom features are presented in nearly true plan geometry, and transducer yaw, pitch, and roll are eliminated. Most importantly, repeated observations can be made from a single point, and bedform movements of <50 cm can be measured. In quiet seas the maximum useful range of the system varies from 30 m (for mapping ripples) to 200 m (for mapping 10-m wavelength sand waves) to 450 m or more (for mapping gravel patches).

INTRODUCTION

THE physical processes that shape the sea floor operate at a wide variety of rates. Catastrophic events can produce rapid changes in sea-floor morphology whereas many other processes, for example, the migration of some large bedforms, operate slowly. To observe such changes of the sea floor, the time interval between observations must be adjusted to be less than the time scale or period of the processes being observed. When attempting to accurately measure rates of change in sea-floor morphology, it is optimal to have the observation point fixed. This is especially true when measuring the migration rates of large bedforms, whose small yearly displacements approach the location error of most navigation systems.

Bedform migration rates have previously been determined by divers making measurements from markers fixed to the sea floor (JONES, KAIN and STRIDE, 1965; SALSMAN, TOLBERT and VILLARS, 1965) or by time-lapse photography (SUMMERS, PALMER and STONE, 1971). These techniques are limited to areas where the water depth and current velocity are not excessive or where visibility is not too low. In areas where these conditions are not met, sea-floor changes can be observed from a fixed point with a stationary sonar transducer, or, as proposed below, with a rotating side-scan sonar system.

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MECHANICAL AND ELECTRONIC DESIGN

To examine bedform migration in San Francisco Bay, where tidal currents are strong and the water is turbid, we developed a sea-floor-mounted rotating side-scan sonar that is capable of making repeated observations from a fixed location (RUBIN, MCCULLOCH and HILL, 1977). The system uses the same electronic equipment as does a normal towed side scan, but the transducers, instead of being towed above the sea floor, rotate around a vertical axis (EDGERTON and WYMAN, 1976). In this respect, rotating side scan resembles radar. In our test system (Fig. 1) the two transducers from a standard side-scan towfish have been mounted on opposite sides of a vertical axle, at a height of 2 m above the base of the supporting tower. The axle and attached transducers are turned at 0.5 rpm by an electric motor fitted with a speed-reducing gear train and emplaced in a watertight box at the base of the tower. We eliminated the need for costly and often electronically noisy slip-ring connections to the transducers by designing the axle and drive train so as to reverse the direction of rotation of successive circular scans. Consequently, the electrical cables to the transducers unwind and wind around the axle with each rotation. Echo pulses returning to the slowly rotating transducers are transmitted through the side-scan towfish cable to a standard side-scan recorder that can be located either on a vessel or onshore.

RESOLUTION, RANGE, AND NOISE

Theoretical resolution in a radial direction on the rotating side-scan records can be no better than the distance that the outgoing pulse travels and returns during a time interval equal to the pulse duration (approximately 8 cm for the standard 0.1 ms pulse). Objects that are spaced more closely can not be resolved because they produce return signals with overlapping arrival times.

In a direction transverse to the sonar beam the near-field resolution is theoretically limited by beam width. In the near field, beam width, and, therefore resolution, approach transducer length (approximately 45 cm). Because of spreading of the sonar beam, the theoretical

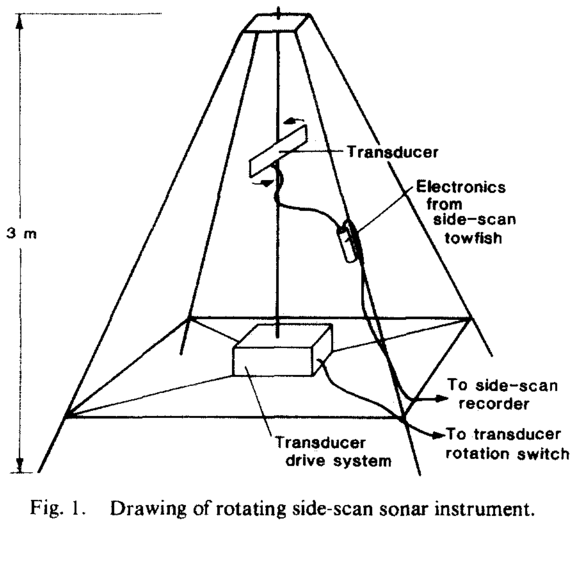

Fig. 1. Drawing of rotating side-scan sonar instrument.

transverse resolution worsens to approximately 5 m as the range increases to 250 m. These theoretical limits are independent of whether the side scan is rotated or towed. However, the yawing, pitching, rolling, and incomplete sea-floor insonification of towed systems produce poorer resolution. In contrast, the rotating transducers do not yaw, pitch, or roll, and they turn so slowly that the entire sea floor is insonified for all scans with maximum ranges <250 m. In practice, the smallest bedforms detected and displayed clearly by the rotating side scan are ripples with wavelengths of approximately 30 cm. In the far field (250 to 500 m) the only features we observed were sharp linear reflectors parallel to sand waves and inferred to be gravel lags in sand-wave troughs. We estimate from the images of these features that the practical transverse resolution at 400 m is 20 to 40 m.

Under favorably quiet sea conditions maximum useful range of the rotating side scan varies from about 30 m (for mapping ripples) to 200 m (for mapping 10-m wavelength sand waves) to 450 m or more (for mapping gravel patches). These ranges of more than 100 m are surprisingly large for the 2-m height of the transducers above the sea floor and apparently result from the following factors: (1) The sonar beam is depressed only 10° below the horizontal plane, and in a horizontal direction the beam is attenuated only by 3 db. Consequently, considerable energy is transmitted toward distant objects. (2) Sand waves like those we observed have large sloping surfaces that face toward transducers and act as reflectors, despite the low mean angle of insonification. Similarly, gravel patches produced detectable reflections, despite the low insonification angle. (3) Background noise is reduced considerably because the major noise sources of towed side-scan sonar are eliminated—water does not stream against the transducers at speeds of several knots, and no turbulent ship wakes, spinning propellors, or noisy engines are nearby. (4) Repeated surveying of a site allows recorder controls (e.g., time-varied gain) to be adjusted for optimum record quality.

We infer that in quiet seas the surprisingly long useful range results because the echo pulses, although weaker than pulses transmitted and received by more elevated transducers, are large with respect to the low-level background noise of the rotating side scan. This appears to be verified by the observation that when seas are rough or current velocities approach side-scan towing speeds, noise becomes comparable to that of towed systems, and the range decreases to several tens of meters, as would be predicted from experience with towed systems.

IMAGE PROCESSING

A standard side-scan recorder prints data received by the transducers as a series of parallel data lines that portray the view normal to the direction of boat travel. When this recorder is used with the rotating side scan, it produces a highly (but systematically) distorted sonogram. Data that were collected along radial lines emanating from the rotating transducers in the center of the observation field are printed by the recorder as a series of parallel lines. Because of this distortion, a linear feature on the sea floor is displayed on the recorder as a curve defined by

$$d \propto \frac{1}{\cos \phi} ,$$

where d is the apparent distance to the linear feature, and ϕ is the angle that the transducers are facing (varying from 0° when viewed normal to the lineation). To remove distortion, the data lines that are printed by the recorder must be redistributed in a radial pattern. Although there are digital methods for storing, enhancing, and redistributing analog data in a radial

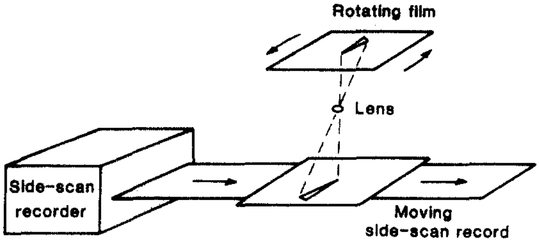

Fig. 2. Diagram illustrating photographic technique for rectifying rotating side-scan images. Original record is pulled behind a slit and photographed by a camera with a rotating film back.

form, we chose to rectify the images photographically. In the photographic rectifier (Fig. 2) the linear side-scan record is exposed to film in a camera through a tapered slit. One end of the slit is positioned at the optic axis of the camera, so that its image lies at the center of the film. The film pack is rotated around the optic axis at a constant speed that is adjusted to make one full rotation in the time it takes for the side-scan record of one transducer rotation to pass beneath the slit. This provides a continuous photograph of the side-scan record on which the linear data are redistribued in a radial format (Fig. 3). We used a standard 4 × 5 in. press camera that has a freely rotating film back. With this device we were able to make real-time rectified images by photographing the original side-scan records as they came off the side-scan recorder. Positive–negative film gave us immediate hard copy and provision for making enlargements later.

ADVANTAGES AND DISADVANTAGES OF ROTATING SIDE-SCAN RELATIVE TO TOWED SIDE SCAN

The most significant advantage of rotating side scan is the ability to accurately resurvey the sea floor from a fixed point. Other advantages are the improved resolution discussed above, and rectified images that are nearly free of distortion. Because the rotation speed of the transducers can be kept extremely uniform, the images lack the kind of distortion that is produced by changes in ship speed in towed side-scan sonar. In addition, the rotating transducers are so close to the sea floor that slant ranges approach actual distances over the sea floor. For example, slant-range distortion is <10% for all but the central 1% of a 100-m diameter circular area.

The main disadvantage of rotating side-scan sonar is that coverage at a single site is limited to a circular area 100 to 500 m in diameter. Also, until self-contained systems are constructed the sea-floor unit must be wired to a recorder, either on a ship or onshore. Finally, rotating side-scan sonar does not provide topographic profiles of bottom features. Consequently, unlike towed side scan, the rotating system cannot detect changes in trough or crest elevation of bedforms that grow or shrink during migration.

ROTATING SIDE-SCAN IMAGES AND TIME-LAPSE RECORDS

The rotating side-scan device was tested in San Francisco Bay at selected sites for periods of several hours and at one site for 8 months. In the short-duration tests the device was wired to a recorder on an anchored vessel, and in the long test it was wired to a recorder onshore.

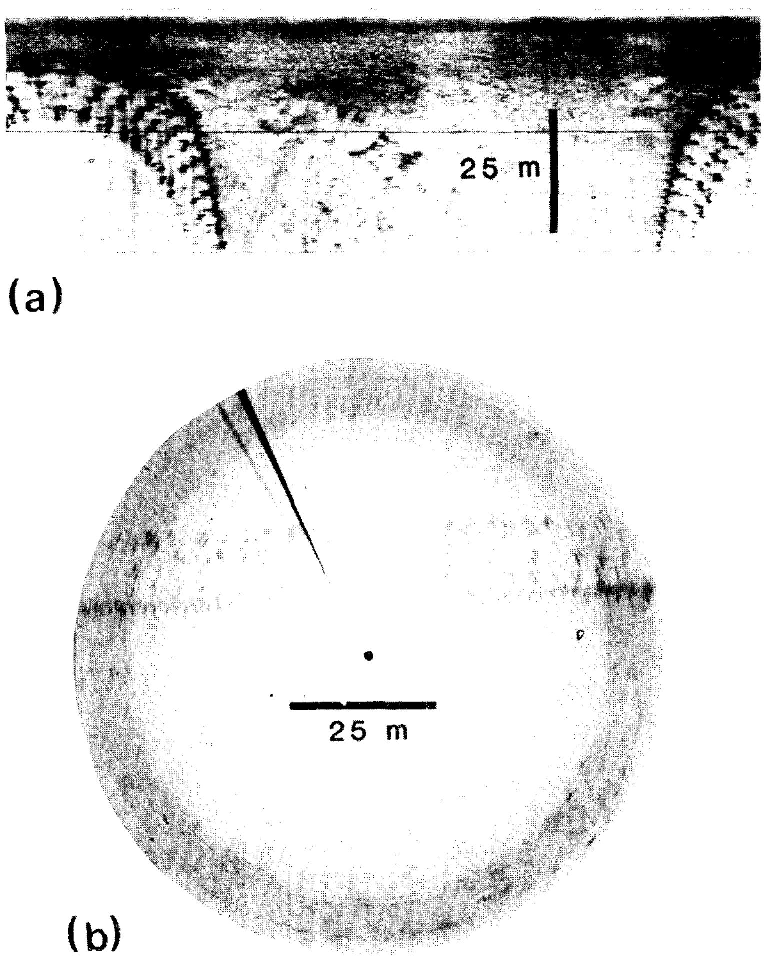

Fig. 3. Rotating side scan records showing the pilings of a straight pier. (a) Image produced by side scan recorder. (b) Image rectified by photographing the record in Fig. 3a with a rotating camera.

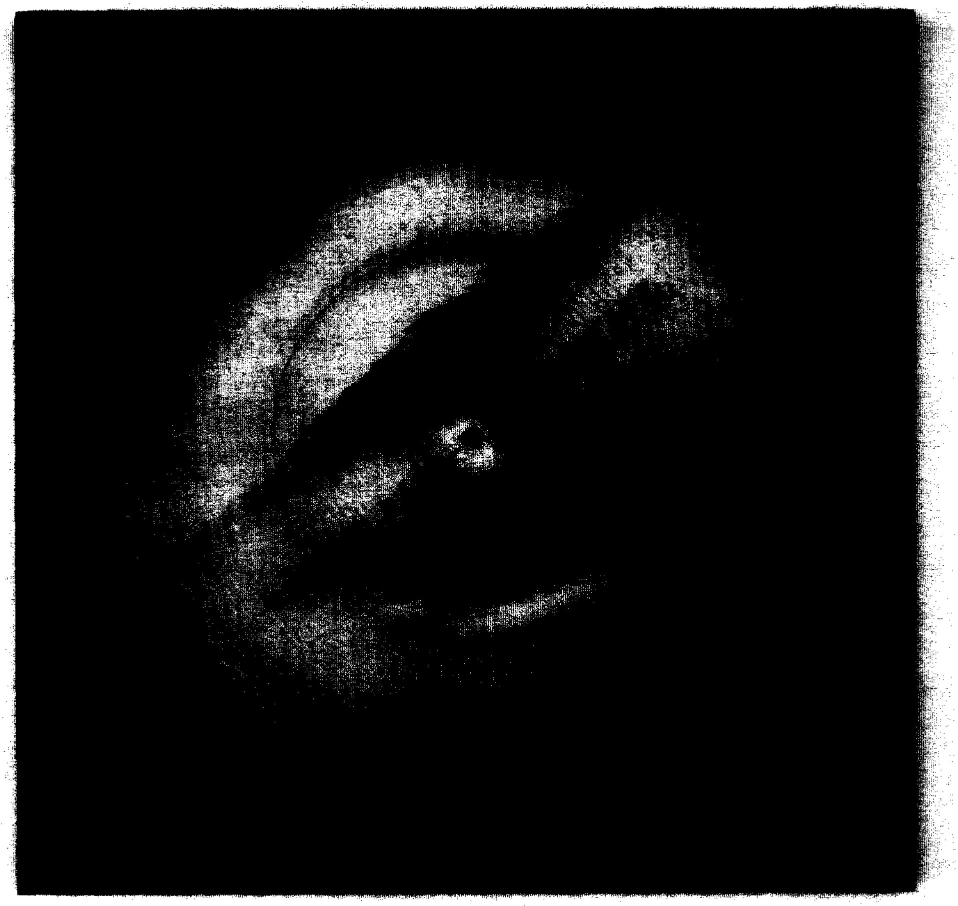

Fig. 4. Rectified rotating side-scan image showing small ripples (wavelengths as small as 30 cm) superimposed on San Francisco Bay sand waves that have wavelengths of approximately 25 m.

An image collected at one of the short-duration test sites (Fig. 4) clearly shows ripples as small as 30 cm in wavelength, and it demonstrates the relatively high resolution of the system. Images collected periodically from the long-duration test site made it possible to measure the migration of sand waves approximately 60 cm high over an 8-month observation period (RUBIN and MCCULLOCH, 1979).

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