OCEANIC ACOUSTIC TECHNIQUES FOR STUDYING TERRESTRIAL EROSION AND SEDIMENT TRANSPORT

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Abstract. Sediment transport studies and associated technologies were initiated by scientists within the area of hydrologic sciences more than 50 years ago. However, technological advances and the need for similar studies in oceanic and coastal environments has led to the development of a number of new sophisticated techniques for studying sediment transport processes remotely using either acoustic or optical techniques. In this presentation, a review of the acoustic techniques used by the Coastal Processes and Sediment Dynamics (CPSD) Laboratory at the University of South Carolina is presented.

Two examples of acoustic measurements are shown that include: (i) acoustic imaging of the sea bed using stationary rotating sonar; and (ii) acoustic backscatterance of the water column for estimating sediment resuspension from the seabed. These techniques have been developed primarily for use in the coastal ocean; it is envisaged that their adoption for engineering studies and monitoring in the terrestrial environment (e.g., scouring processes around bridges, etc.) by state and federal agencies can be a significant step toward improving safety and monitoring or our infrastructures.

INTRODUCTION

Acoustic imaging of the sea bed has long being used for mapping sedimentary provinces in the coastal ocean. Herein, we present a miniature rotating sonar that has been robustly used to map and identify wave-generated ripples in the ocean bed. An adaptation of this method can be used for the monitoring of scouring and erosion processes in rivers and in particular at the foundation of bridges during high discharge periods when the actual erosion occurs. The system can be used to provide scour information in real time. The use of acoustic imaging provides the advantage that it can operate at periods of high discharge that coincide with those of high sediment concentration and turbidity that makes optical methods inadequate.

Acoustic images of the scoured bed can be combined with acoustic backscatterance signals from within the water column that can be used to provide data on amount and size of sediment in suspension.

In this contribution two systems routinely used at the Coastal Processes and Sediment Dynamics Laboratory, at the Department of Earth and Ocean Sciences of the University of South Carolina are presented.

BED MONITORING SYSTEM

Side scan sonars have been extensively used to acoustically map the sea bed for a variety of activities ranging from mapping benthic habitats (e.g., Cochrane et al., 2008), to evaluation of sedimentary resources and underwater archaeology (e.g., Mindell and Croff, 2000). These types of surveys are usually carried out from a moving vessel and when combined with a navigational system provide large spatial geo-referenced coverage. However, they are limited in capturing temporal variability and thus not suitable for application in rapidly changing process studies.

The implementation of a stationary sonar system provides limited spatial coverage, on the order of a few meters, but can be utilized at high temporal scales thus providing information of rapidly changing processes such as changes of bathymetry in response to an energetic event.

![Figure 1. Schematic diagram of the control mechanism of the sonar (adapted from Voulgaris and Morin, 2008).](image-url)
A digital rotating imaging system operating at 2.25MHz (Imagenex Model 881) has been used to monitor sea bed evolution over the period of a year at the outer continental shelf off the coast of Georgia. The sensor has a tilted transducer head that rotates around its axis through a mechanical motor, providing an acoustic image in the vicinity of the installation location. It was installed 60 cm above the seabed, at a water depth of 26 m. The seabed at the deployment site consists of medium to coarse sand with a mean diameter of 0.450mm. The sonar was cantilevered from a 3m long stainless steel pipe jetted into the sea bed. The unit was offset by 25cm from the vertical pipe and the head tilt was set 9° from the vertical providing an adequately high grazing angle for backscatterance by the sea bed.

Logging, power control, and data transmission control are provided by a PC computer. In our application the computer was housed on a platform tower that owned by the US Navy. Underwater data transmission and power are provided by a 1,500m long, 7 conductor armored cable (Rochester Stock Type 7-H-422A, 18x18 Armor) deployed from the tower to the sonar location. System software responsible for sonar control and data logging was developed in house in C+ and utilizes two serial ports for controlling power and data logging. One serial port is used to control the power through a TTL relay while the other is used for the 2-way data communication with the sonar head unit. Because of the long distance, RS485 protocol is used for communication and data transfer, then converted back to RS232 at the base station. A schematic of the control hardware and wiring on the tower is shown in Fig. 1.

The software is controlled by a text file that can be altered remotely from shore; it contains all instrument configuration parameters controlling the operation of the sonar. Overall the configuration file contains information on: (i) starting date and time; (ii) interval between successive data collection periods; (iii) number of images to be collected within a sampling period; (iv) range of image; (v) amplification gain and TVG; (vi) attenuation due to water absorption; (vii) sonar head starting angle and sector to cover; (viii) angular resolution; (ix) sonar pulse duration; (x) data points to be collected along a radial (resolution); (xi) serial ports to be used for data communication and for power control; and (xii) path to data storage directory.

Figure 2. Examples of acoustic images of the sea bed showing different types bedforms generated by the oscillatory motion of the surface ocean waves.
An example of the type of data collected by this method is shown in Figure 2. There, a number of acoustic images of the sea bed covering an area with a radius of 6 m (113 m²) are shown. Each image corresponds to different wave and current conditions (not shown) that have mobilized the sediment covering the sea bed. The ripples shown are in response to different surface waves and associated oscillatory motion that organize the sea bed sediments. Such images have been analyzed quantitatively using 2-D spectral analysis (Voulgaris and Morin, 2008) to obtain scales of ripple wavelengths and sizes of erosional features. It is proposed that the deployment of a system like this at the footings of bridges or other underwater structures can reveal information of scouring extent and depth under different river flows. This information can be part of routine monitoring of a structure or part of evaluating the performance of different designs.

ACOUSTIC BACKSCATTERANCE SYSTEM

In a similar manner as presented in the preceding section, acoustic imaging of the water column can also provide us with information on the amount of sediment (D) present in the water column. For incoherent scattering (i.e., scattered phase is random and uniformly distributed over $2\pi$) the recorded root-mean-square voltage (V) from a suspension of spheres insonified with a piston source transducer can be written as (Thorne and Hanes, 2002):

$$V(r) = \frac{K_s K_T}{r \psi(r)} \cdot e^{-2r \alpha_w} \cdot C(r)^{1/2} \cdot e^{-2r \int_0^r \alpha_s C(r) dr}$$  \hspace{1cm} (1)

where, $K_s = \frac{<f_m>}{(\rho_s <\alpha_s>)^{1/2}}$ is a term that represents the sediment backscatter properties (i.e., sediment radius $\alpha_s$, sediment density $\rho_s$, and backscatter function ($f_m$)); brackets denote mean so that $<\alpha_s>$ represents the mean particle radius and $<f_m>$ is the backscatter function weighted by the total number of sizes of particles. $\alpha_w$ is the water attenuation parameter, $r$ is the range from the transducer face, $C$ is the sediment concentration and $\psi$ is the nearfield function of the transducer. At this juncture it should be noted that the backscatter function depends on acoustic frequency and size of particle, so that simultaneous analysis of data from multiple frequencies allows us to estimate the size of the sediment in suspension in the water column.

The term $K_T$ also called the system parameter depends on the electronic and acoustic transducer characteristics, such as receiver sensitivity, voltage transfer function of the system, pulse duration and the radius of the piston transducer. This parameter is considered a constant and is derived for each transducer / frequency through an elaborate calibration procedure in a specially designed...
same studies. Processes for different designs. The water acoustic foundation of bridges or for evaluation of scouring in real time to provide warning for scouring around the river scouring processes. The imaging system can be used for these sedimentary processes. It is the shown to be a very useful tool for the study of sediment processes. A review of acoustic measurements of small-scale sediment processes. Continental Shelf Research, 22:603-632. Voulgaris, G., M.P. Wilkin and M B. Collins, 1995. The In Situ Acoustic Measurements of Shingle Movement under Waves and Currents: Instrument (TOSCA) development and preliminary results. Continental Shelf Research, 15(10):1195-1211.

AKNOWLEDGEMENTS

I would like to acknowledge Dr. J.P. Morin, Mr. T. Nelson and Mr. N. Kumar for their invaluable assistance provided at various stages of this work including data collection to code development.

Funding for the work presented in this contribution has been provided by grants from the National Science Foundation (Awards OCE-0451989 and OCE-0535893) and as part of a cooperative agreement between the U.S. Geological Survey and the University of South Carolina as part of the Carolina Coastal Change Processes project.

LITERATURE CITED


