Underwater Signal Processing Techniques for Sediment Classification

Nalinee A. Pawar[1], J. S. Rangole[2]

[1]Electronics (Digital System), Vidya Pratisthans College of engineering, Baramati, India

[2]Assistance Professor, Vidya Pratisthans College of engineering, Baramati, Pune, India

Abstract: ***The nature of seafloor/riverfloor affects on some areas such as defense (mine countermeasures), environmental (habitat mapping and protection), economic (fisheries, mining), and maritime (dredging of harbors and channels). To predict the water storage capacity of the river dam, it is essential to know the topography of the seafloor/riverfloor. Collection of samples of seafloor/riverfloor sediment and their characterizations are tedious and time consuming tasks even for a small areas. Thus acoustic remote sensing techniques are useful for rapid seafloor/riverfloor characterization. The main tasks of underwater sediment classification are underwater signal acquisition, feature extraction from underwater signal and classification of underwater signal. This paper reviews and discusses the tasks of underwater sediment classification: underwater signal acquisition techniques, different feature extraction methods and classification techniques used for underwater sediment classification.***

Keywords: SONAR, Single beam sonar, Muiltbeam sonar, Side scan sonar, Model based methods, Empirical based methods

1. Introduction

Knowledge of seabed/riverbed properties, such as grain size, sediment type are required to predict mine burial and to detect ranges of sea nines and to study the effect of benthic habitat on fisheries and other biological species, to determine the effect of proposed offshore waste disposal, to find the sites for drilling platforms, seabed/riverbed communication cables. The detection of probability of ground mines will be highly dependent on acoustic backscattered echo from seabed/riverbed. The nature of seabed/riverbed will be affects on the characteristics of backscattered echo. Collection of samples of seabed/riverbed sediment and their characterizations are tedious and time consuming tasks even for a small area. Thus, the remote sensing techniques are useful for rapid seabed/riverbed characterization in offline and online mode of operation. For a number of years, devices are fitted to ships echosounders and bottom types are inferred from analysis of acoustic returns level and shape. The probability of detection of ground mines are depends on acoustic backscatter from the seafloor. The number of environmental factors affects on mine hunting operations and among these factors most important is the nature of the seafloor. It becomes extremely difficult to detect if a mine becomes buried or partly buried. Acoustic methods are widely used as remote techniques in the field of marine geology, hydrographic, marine engineering and fisheries science to characterize the seafloor sediments[1],[2].

This paper reviews the underwater signal processing techniques required for sediment classification, from underwater data acquisition to classification methods of underwater signal. The rest of paper is organized as follows. Section 2 reviews underwater signal acquisition systems. Section 3 Discusses about various methods of sediment classification from underwater signal Model based methods and Empirical based methods. Section 4 conclusion.

2. Underwater Signal Acquisition

The first step of underwater sediment classification is signal acquisition. The name SONAR(Sound Navigation And Ranging) referred to devices which uses underwater sound for communication or observation. The basic principles of sonar are, to transmit pulse energy into the water medium and receive subsequent returned energy reflected from objects or seabed. Basically the sonar's transmitter generates an acoustic wave that is short electrical pulse centered at particular frequency, length and energy. The transducer transform this electrical signal which is normally a piezo-electric ceramic, into mechanical vibration energy. This vibration is travels into the water as an oscillating pressure, the pulse. This pulse travels through the water until it is scattered or reflected by the seafloor or any object. The energy reflected back, which is in the form of mechanical energy, is converted into electrical energy by the transducer. Then sonar's receiver detected and amplified this energy.

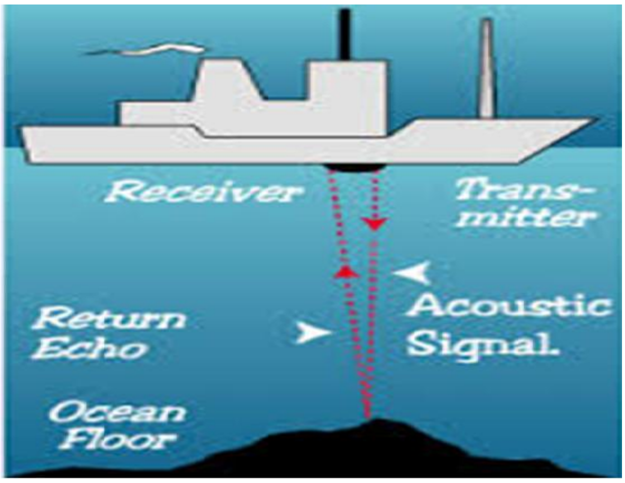

Figure 1: SONAR operation

There are two types of SONAR, Active sonar and Passive sonar. Active sonar transmit and a receive the sound. When the transmitter and receiver are in the same place it is called as monostatic operation. When the transmitter and receiver are placed at different location then it is called as bistatic operation. When more transmitters or more receivers are used, it is called as multistatic operation. Most sonars are used monostatically. Passive sonars only uses the receiver that is it is a "listening" device that record the emitted sounds by objects in water. Such devices can be used to detect sounds emitted by ships, submarines, and marine creatures. There are three acoustic remote sensing techniquese: single beam sonar, multi beam sonar, side scan sonar. The single beam sonar measures the single depth with each ping(acoustic pulse)[3]. In single beam sonar both wide and narrow beam systems includes. The purpose of single beam sonar is to measure the ocean depth one-at-a-time at many locations. The single-beam sonar is simple and inexpensive to build, and easy to use and understand. But the limitation is that it is not suitable for large-scale bathymetric survey.

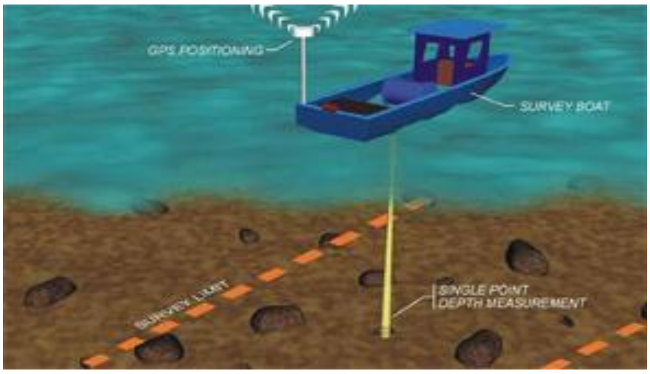

Figure 2: Single beam sonar operation

To produce accurate depth measurements for large seafloor area it is necessary of a large-scale bathymetric survey so that an accurate picture of the geography of the bottom established. Multibeam sonar can map more than one location of the sea floor with a single ping and with higher resolution compared to conventional echo sounders. But the multibeam sonar are more complex, the cost of a multibeam sonar is high than a single-beam sonar.

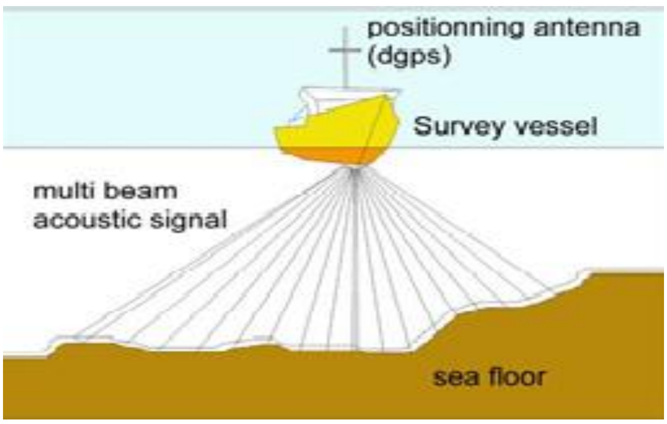

Figure 3: Multibeam Sonar operation

The side-scan sonar is used to provide images which map strength of acoustic back scattering from the seafloor onto a two-dimensional image. Side scan sonar is used to take monochromatic image of ensonified area of a seafloor such that Pixels brightness values are proportional to the strength of acoustic reflection from seafloor/riverfloor within generated acoustic beam. Side scan sonar images are called as sonographs.

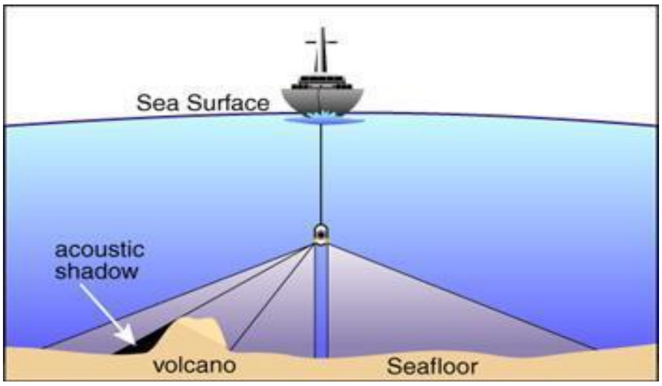

Figure 4: Side scan sonar

3. Classification Methods

The underwater sediment classification methods are divided into Model based methods and Empirical based methods. In model based method echo signal directly translate into the physical properties of sediments. In empirical method some echo features are extracted and correlated with sediment properties. To discriminate between different sediments feature extraction technique is needed. Extracted features from underwater signal will help classifier to classify sediment.

3.1 Model based method

In model based method echo signal directly translate into the physical properties of sediments. In model based method the six input parameters are required: density ratio, sound speed ratio, loss parameter, volume parameter, spectral exponent, spectral strength [4][5][6]. Density ratio is the ratio of sediment mass density to water mass density. Sound speed ratio is the ratio of sediment sound speed to water sound speed. Loss parameter is the ratio of imaginary wave number to real wave number for the sediment. Volume parameter is the ratio of sediment volume scattering cross section to sediment attenuation coefficient. Spectral exponent is the exponent of bottom relief spectrum. spectral strength is the strength of bottom relief spectrum at wave number ,

$$\frac{2\pi}{\lambda} = 1\text{cm}^{-1}$$

The formule of these parameters for different mean grain size are given in [7]. The formula for mean grain size is,

$$M_z = -3.32\ln\left(\frac{d}{d_0}\right) \quad (1)$$

Where d is the grain size or diameter and d0 is a reference length of 1mm.

3.2 Empirical Based Method

In empirical method some echo features are extracted and correlated with sediment properties[8][9][10][11][12]. Some echo features such as echo total energy, maximum amplitude of echo, echo length, echo energy mean, echo energy standard deviation, echo energy skewness are extracted.

Using clustering method such as principal component analysis, K-means clustering, fuzzy C-means(FCM), self organizing map(SOM) these echo features are combined and then each identified cluster is associated with particular sediment type. Also we can use classifier to classify sediment type for example principal component analysis. Some mathematical formule for above features are,

Echo total energy,

$$E = \int_0^{T_0} I(t)\,dt \tag{2}$$

Where T0 is time duration, I (t) is intensity. The echo total energy is an important parameter because it directly relates to roughness of the seabed.

Echo energy skewness,

$$S = \frac{8}{T^3 E \int_0^{T0} I(t)\,(t - t_0)^3 dt} \tag{3}$$

Skewness is measure of asymmetry, the skewness is typically positive for all seafloor echoes.

Echo kurtosis,

$$F = \frac{16}{T^4} \int_0^{T_0} I(t)\,(t - t_0)^4 dt \tag{4}$$

Echo kurtosis measurs the peakedness of shape of echo. An echo shape with less flatness (high kurtosis) has distinct peak near the mean.

4. Conclusion

This paper reviews the different underwater signal acquisition systems. Now days, out of these systems side scan sonar is mostly used because of interest in image processing. Two classification methods are discussed. The empirical based method requires some ground truths and limited to specific area. In model based method some collected samples are required to measure physical properties of sediment.

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