Literature Study

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1 Sonar

Ocean, which covers more than 70% of the earth, is less detected by human, compared with the Moon or Mars. It is hard to detect seafloor from airplane or satellite since the electromagnetic waves, including lasers and visible light, attenuate rapidly in water. However, acoustic waves can travel over long distances(more than 11km) without attenuating too much. By listening to the echo of acoustic waves, sonar is invented to draw the geometry of the seafloor based on the travelling range and reflection information of acoustic waves [1].

With the developing of several decades, there are several different kinds of sonar including single-beam sonars, multibeam sonars and side-scan sonars. As Figure 1 shows, single-beam sonars use a single beam to detect the depth under the sensor. It is convenient to set and widely used to estimate the depth of seafloor. Multibeam sonars transmit several narrow beams to the seafloor covering larger area then single-beam sonars. With larger covering area, multibeam sonar can provide bathymetry with larger area of seafloor in detail. Sidescan sonars provide detection of the seafloor with high-resolution and much larger range then the sonar mentioned above. The bathymetry is detected by a single beam in each side scanning at one angular dimensions of freedom. And sidescan sonars are usually fixed on a towfish flown closer to the seafloor[1].

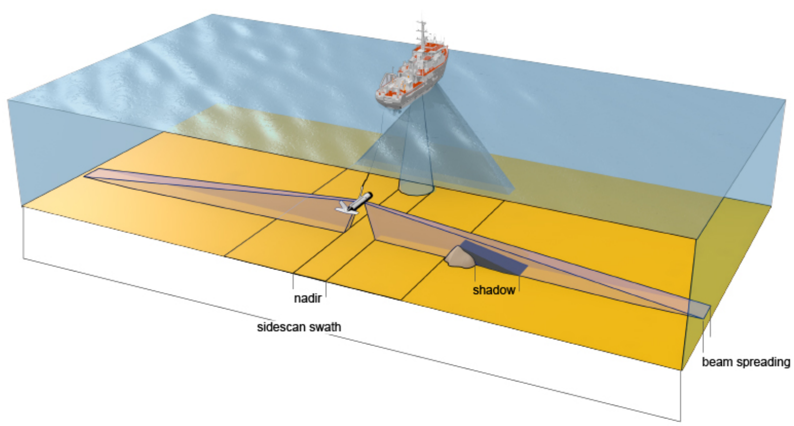

Figure 1: Comparison between sonars, from [2]

2 Acoustic scattering

Figure 2 shows the physical model and definition of sidescan beam. Sidescan sonars will transmit one beam in each side. These beams are narrow along-track to give higher resolution and wide across-track to cover as much range as possible [1]. The distance from the sensor to the seafloor below is called platform altitude. The distance from sonar to seafloor in the direction of peak of beam pattern is called slant range. The incidence angel is the angle between a beam incident on seafloor and the normal. And same definition applies to reflection beam.

The typical beam pattern of sidescan sonar is the shape of lobes. The main lobe is located in the center of beam angle range. And there are two side lobes in the both side of main lobe. They could lead to some unwanted effects which decrease the quality of detection. The shape of the beam patterns shows the transducer sensitivity, or the contour of acoustic amplitude in different directions [3]. Therefore, the intensity of acoustic waves varies when they hit the surface of seafloor, considering the attenuation in different range and beam pattern.

When the acoustic waves hit the surface of seafloor, most of the energy is reflected in the specular direction(the direction of reflection angle). Only small proportion of energy with several magnitude lower intensity will be returned back to sonar, which is called backscatter. Several theories have been proposed to describe the backscatter. The simplest model is the Lambert's law [4], which approximates the backscatter as a linear function of cosine of the incidence angle.

Thus, we can conclude the relation between the source intensity I_s and the backscatter intensity I_b as three individual effects: range C_r, beam angle C_θ and incidence angle C_ϕ.

$$I_b = C_r(r)C_\theta(\theta)C_\phi(\phi)I_s \tag{1}$$

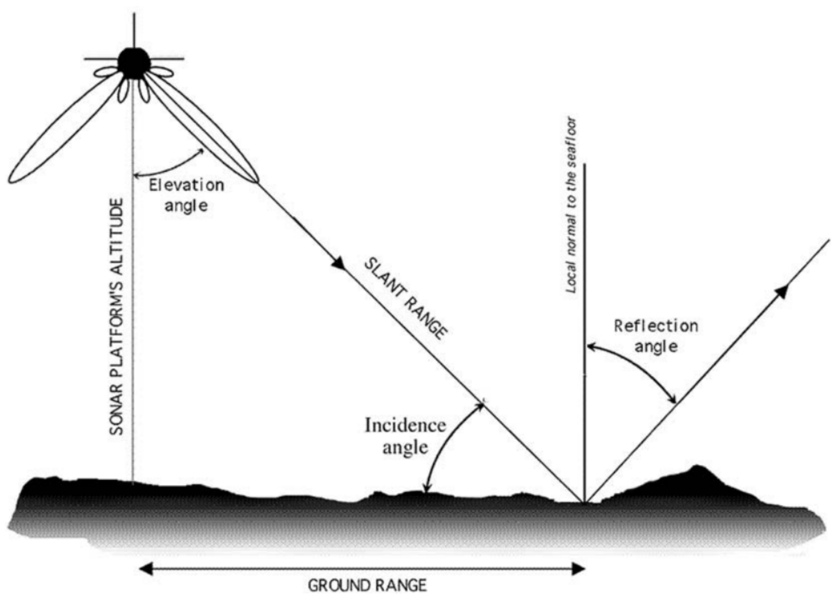

Figure 2: Sidescan sonar beam model, from [1]

3 Gradient Decent

Gradient decent is an optimization algorithm finding the local minimum, which was originally proposed by Cauchy in 1847 [5]. The basic idea is searching in the direction opposite to the gradient with certain step

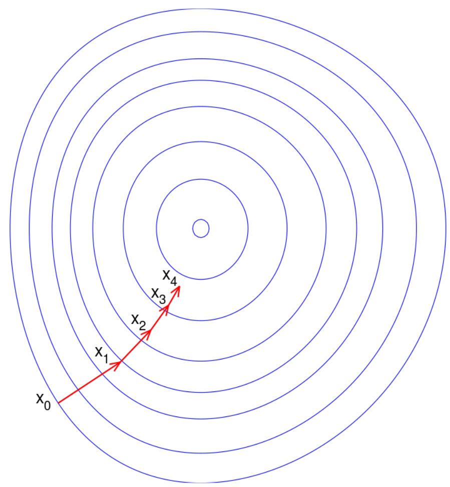

Figure 3: Example of gradient decent

length until the gradient is close to 0. For function with multiple variables $f(\mathbf{x})$, the algorithm could be separated to several steps.

- Set $i = 0$ and initial point $\mathbf{x}^0 = (x_1^0, x_2^0, ..., x_n^0)$
- Compute the gradient of object function $\nabla f_{\mathbf{x}^i}$ at $\mathbf{x}^i$
- update $\mathbf{x}^{i+1}$ with $\mathbf{x}^{i+1} = \mathbf{x}^i - \alpha \nabla f_{\mathbf{x}^i}$, where α is the learning rate
- If $\nabla f_{\mathbf{x}^{i+1}} < threshold$, local minimum is $\mathbf{x}^{i+1}$. Else, repeat last step

In machine learning, the parameters of model is regarded as the variable which gives the best model fitting. And a loss function is applied to calculate the difference between model and real data. Thus, we can find the best fitting model with the parameters giving the local minimum of loss function.

4 Draping

Trace backscatter to the mesh of seafloor to get the geometry information of hit point. Reference to be added.

5 Related works

As sidescan sonar is such an simple, compact and inexpensive type of sensor, many works have been done to model the relation between the sonar scattering intensities and the geometry of the seafloor. Then the model can be used for other purposes including 3D reconstruction and image pre-processing for classification.

3D reconstruction is one of the important part in navigation and augmented reality. And many researches have been focused on the underwater. In [4], backscatter intensity is used to calculate the incidence angel based on the reflection model derived from Lambert's Law. Then seafloor contour is reconstructed using the sensor position, incidence angle and range. Since these parameters is not enough to set a definite patch, global minimization is used to improve the smoothness. Although the 3D map of the seafloor is not that accurate, it considered to include enough altitude information for navigation.

A tine varying gain(TVG) is considered to correct range and beam angle effect properly in [6]. Therefore, the intensity angel is the only factor that lead to the varying of the echo intensity. Based on this assumption and Lambert's Law, a scattering model was build to present sonar intensity with seafloor reflectively, beam-pattern and altitude. With these parameters, a 3D geometry map can be reconstructed. And Least mean-squire was applied to optimize the map by minimizing the error between real image intensity and intensity calculated from model and parameter in map iteratively.

Except for 3D reconstruction, sidescan sonars are also applied to sonar image pre-processing for classification. In [7], flat seafloor assumption was made. Thus, the other geometry information can be derived from the sensor altitude and range. And other parameters(beam angle and incidence angle) effecting sonar intensities are considered as range-dependent in the model proposed. Based on the previous work, [8] [9] proposed a model with separate correction factor of altitude, range and beam angle. And least squares quadratic fit correction was applied to produce image with more stable means and variances across the sonar swath. **check recent research**

Based on the previous research, applications of underwater sonar have been explored. [10] proposed a method using Markov Random Field(MRF) model to classify sidescan image for mining detection. [11] use sidescan correction and classification techniques to create and fuse classified SSS mosaics.

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