PROCEEDINGS of the
23rd International Congress on Acoustics

9 to 13 September 2019 in Aachen, Germany

An effective method for measuring the thickness of Cobalt-rich Manganese Crust based on the neighborhood information and dual-channel information

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ABSTRACT

The thickness of Cobalt-rich Manganese Crusts (CRC) is one of the important information to map and estimate the volumetric distribution of deep-sea mineral. In this paper, we propose an improved method for measuring the thickness of Cobalt-rich Manganese Crust based on the neighborhood information and dual-channel information. The high-frequency signal and low-frequency parametric signal is obtained by feeding the signal received by the transducers centered at the array to two designed filters, respectively. The reflection instant of the top surface is determined by the high-frequency signal, while that of the bottom surface is determined by rule based on the neighborhood information assuming that the CRC has the local thickness invariability. Finally, the demonstration experiment is conducted in the tank to validate the effectiveness of the method.

Keywords: Thickness, Cobalt-rich Manganese Crust, Acoustic

1. INTRODUCTION

Cobalt-Rich manganese crusts(Mn-CRC) are mineral deposits containing valuable metals and can be found on the shoulder of sea-mounts[1]. Mapping and quantitatively estimating the volumetric distribution of these deposits is, therefore, of interest to geologists, oceanographers, and industry[2]. As a key step of the assessment, the measuring of the thickness can be performed by various methods such as bathymetric multibeam, sidescan sonar imaging, and acoustic sub-bottom mapping. However, because Mn-CRC have extremely uneven distribution, thin geometrical features, and being covered with sediment, it still remains a challenging task to collect necessary information to measure the thickness by using traditional acoustic instruments which have low resolution. To complete the task of in-situ thickness measurements of Mn-CRC at depths up to 3000 m, another kind of device, i.e., the acoustic probe developed by the Institute of Industrial Science of the University of Tokyo, can significantly improve the spatial resolution[3,4]. The acoustic probe employs a high-power acoustic pulse, whose sub-surface reflections are recorded [2]. By extracting the reflections from the interfaces above and below the crust layer, the thickness can be determined if the speed of sound through the deposit is known [2]. The thickness measurement has been proven feasible after the laboratory test and sea trial.

Motivated by their device, we built the first generation of the acoustic probe, i.e. Programmable Phased Parametric Array Acoustic Probe 2017 (PPPAAP17), to collect and process the data both for thickness measurement and recognition. Compared with the acoustic probe mentioned above, our device consists of dual-channels, with one channel for the primary signal and the other for the difference signal. The device has a good penetration ability which should be better than 30cm.

In this paper, we mainly focus on the thickness extraction algorithm. Typically, the thickness information is obtained by processing the received signal which is a one-dimensional signal in time-domain that contains complicated context, with the top-bottom peak detection. The reliability of the calculation is affected by noise in the recorded signal arising due to scattering, multi-path reflection, and seafloor features such as local inclusions inside the crust[5]. Considering that the signal quality degraded by the system interference and ambient noise, the inner connection between the large amounts of the recorded data should be exploited. To further improve the robustness of the thickness extraction, we take some improvements into consideration. The processing of the dual-channel signal, i.e., the high-frequency primary signal and the low-frequency parametric signal, are used in different

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way. Specifically, the reflection instant of the top surface is determined by the high-frequency signal in one-dimension field, while that of the bottom surface is determined by the rule based on the neighborhood information in the image field assuming that the CRC has the local thickness invariability.

2. RECEIVER SYSTEM DESCRIPTION

As shown in Fig.1, the receiver system of PPPAAP17 mainly consists of two receiving transducers, a filtering and compensation board, a data collection and controlling board, and the on-line processing unit.

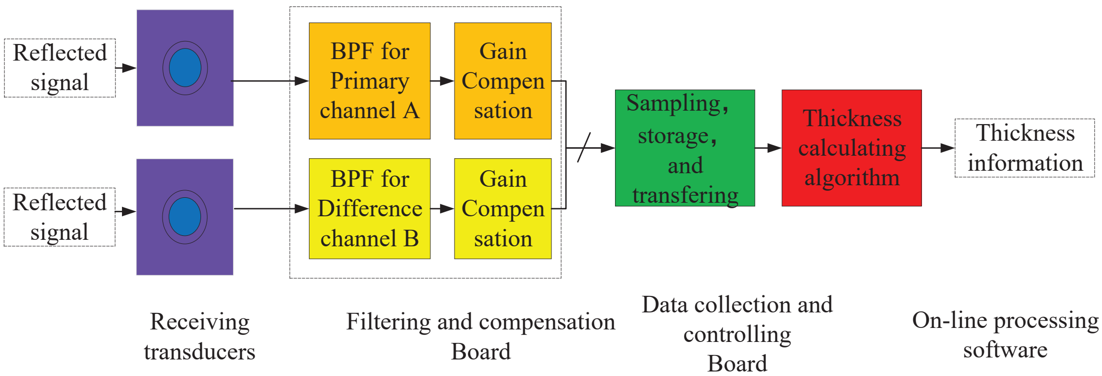

Figure 1 –Receiver System description

When the system works, the reflected signal is received by the two separated transducers, with one fed into the primary channel and the other fed into the difference channel. The high-frequency signal and low-frequency parametric signal is obtained by feeding the signal received by the transducer centered at the array to two designed filters. The two designed filters are used to improve the Signal to Noise Ratio (SNR) of the signal. The gain compensation part can be adjusted by the data collection and controlling board to obtain suitable signal amplitude. The filter and sampling parameters are listed in Tab.1.The sampled data are transferred and stored in real-time way and processed by using the on-line processing software.

Table 1 – Filter and sampling parameters

Parameter	Symbol	Value
Centroid frequency of the primary channel	f_{0H}	1 MHz
Quality factor of the primary channel	Q_H	5
Sampling frequency of the primary channel	f_{sH}	5 MHz
Centroid frequency of the difference channel	f_{0L}	100 KHz
Quality factor of the difference channel	Q_L	5
Sampling frequency of the primary channel	f_{sL}	500 KHz
System transmitting period	T_{work}	20 ms

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3. ALGORITHM

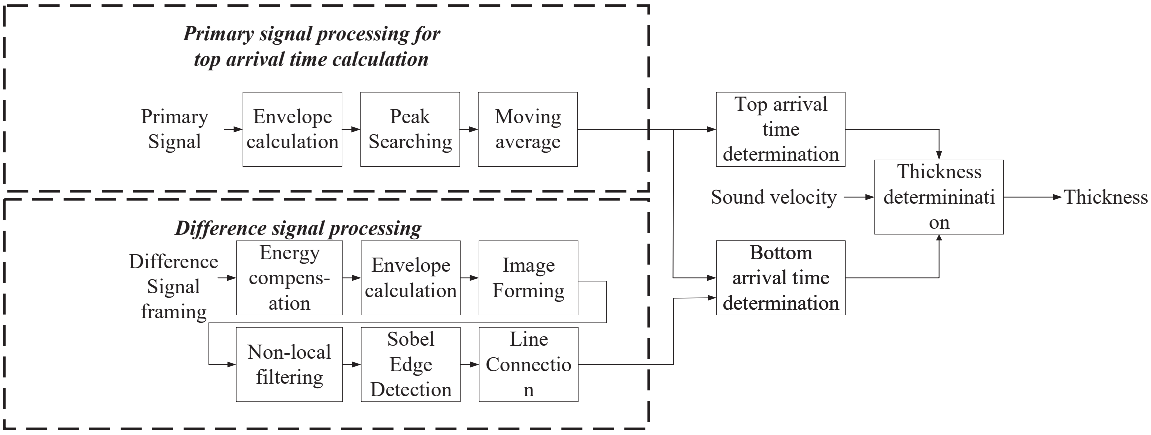


Figure 2 – System composition

The aim of the algorithm is to automatically calculate the thickness of the Cobalt-Rich manganese crusts with the large amounts of the recorded data. Theoretically, the thickness can be simply determined by the time delay between the top and bottom reflection if the sound velocity with the ferro-manganese crusts is assumed to be known. Therefore, the algorithm needs to determine three parameters, i.e., the sound velocity, the top arrival time, and the bottom arrival time.

Generally, the sound velocity of CRCs is not a constant. A feasible way is to measure the values of several samples that are growing a specific area and take the averaged values as the reference velocity. The top arrival time is calculated only using the primary signal. Although the primary signal has a poor penetrating capability for the CRCs, the reflected signal of the top boundary has relatively higher SNR compared with the low frequency signal. Therefore, the top arrival time can be precisely determined by searching the peak of its envelope, which is also a good reference to assist calculating the bottom arrival time. The envelop extraction can be realized by different method, the approximation parameter should be set relatively small to get more accurate peak. After obtaining the peak vector, a moving average filter can be applied to filter the noise, whose window size can be set according to the transmitting period and the speed of the ROV. The filtered peak vector will be simultaneously used to get the top arrival time and serve as the reference to assist the determination of the bottom arrival time.

While the signal of the primary channel is processed in the one-dimension signal field, the data processing of the difference channel is performed in the image field. Because of the travelling attenuation after travelling through the CRCs and affected by the noise, the difference signal is degraded. Fortunately, the results of neighboring measuring can be fully employed to improve the performance considering that during the continuous scan there is some redundant information to denoise the data. The method is listed as follows. Firstly, each difference signal which has filtered by the BPF needs to be corrected for attenuation between the top and coarse bottom boundaries in exponential form[5]. The envelope of each difference signal should be extracted with a relatively large approximation parameter. Afterward, all the envelope signal is assembled as an noisy image which needs to be denoised. Here, we choose the filter of the nonlocal means (NLM) filter[6]. The idea of patch-wise methods, which weights the relative importance of pixels by comparing their patches, offers a new way to reconcile the contradiction between image denoising and texture preservation[7]. Furthermore, a Sobel detector is applied to the denoised image to obtain the possible edges. Broken line connection is also necessary since the edge detection step uses morphological operations. The next step is to determine which line is the bottom arrival time. By the assist of the top arrival time vector, we only keep the edges that have the instant larger than the vector and have the instant smaller than the time of travelling the thickest CRCs (about 35cm). If there only exist unique detected lines, the bottom arrival time vector can be uniquely determined; Otherwise, the progressive probabilistic Hough Transform is necessary to determine the most possible one.

4. EXPERIMENTS

The experiments are carried out on the China Ocean 51th voyage on Aug 5, 2018. The parametric acoustic system is mounted on the hydraulic system of the HAIMA Remotely Operated Vehicle(ROV).

(a) (b)

Figure 3 – The Experimental configuration. (a) The PPPAAP17 mounted on the hydraulic system of the HAIMA ROV (b) The Transmitter transducer array and receiving transducer (Uppper) and the electronic processing unit (Lower)

The parametric acoustic system, PPPAAP17, transmits the signal for a fixed spot every 20ms and it samples and keeps the first 2ms data for each pulse. The Experimental configuration and the array together with the electronic processing unit are shown in Fig.3. The transmitter transducer array and receiving transducer is about 0.3 m away from the seabed at the vertical direction. It can be seen that the primary transducer is slightly higher than the difference transducer, which causes a fixed time delay when receiving acoustic echo signal. The delay value can be calibrated in advance.

The primary data and difference data contain 500 records, which means the measuring time is 10 second. As shown in Fig.4(a), the envelope of the 40^{th} primary signal is calculated with good SNR. The arrival time corresponds with the practical distance of about 0.3m. The averaged peak vector of length of 500 has been presented in Fig.4(b). The smooth filter is designed with the window size of 10.

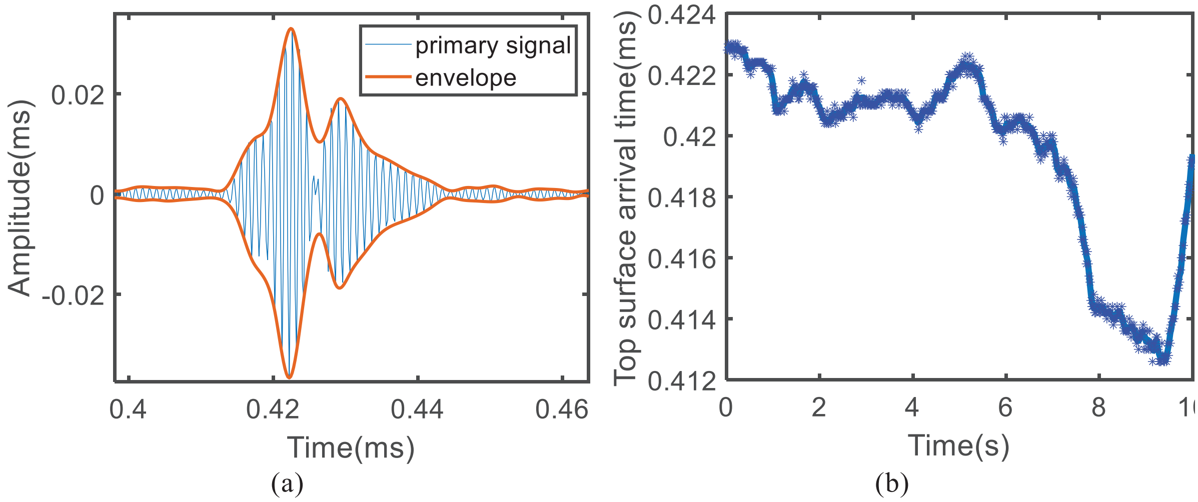


Figure 4 – Primary channel signal and the top arrival time vector. (a) Sampled primary signal (blue)and its envelope(orange) (b) Estimated top surface arrival time before smoothing(blue star) and after smoothing (blue line).

The data processing of the difference channel is performed in the image field. After the energy compensation and envelope calculation operation, the energy of the difference channel forms an image of the size of 500×1000, as shown in Fig.5(a). The NLM filter with the weight block size of 3, the search block size of 7, and the decay factor of 10 is applied to the energy image, whose results are given in Fig.5(b). Comparing these two images, it can be observed that some noise is filtered with the textures kept well.

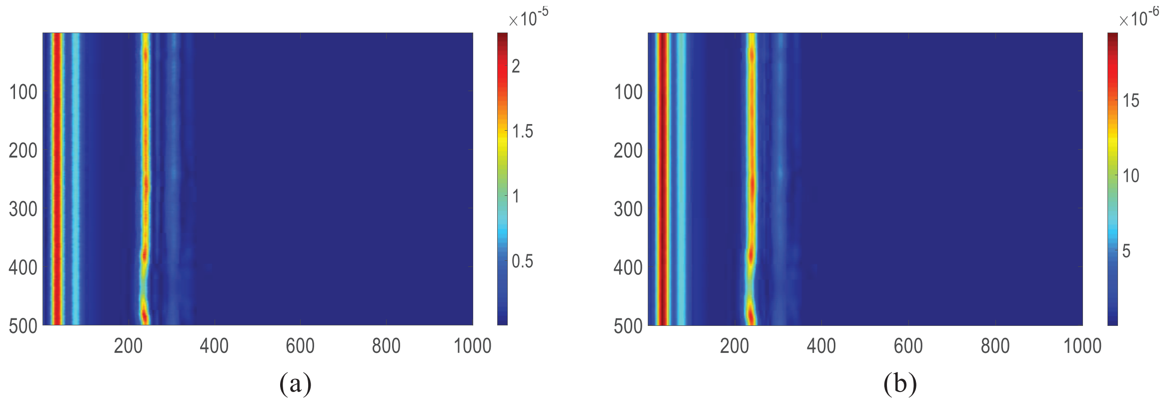
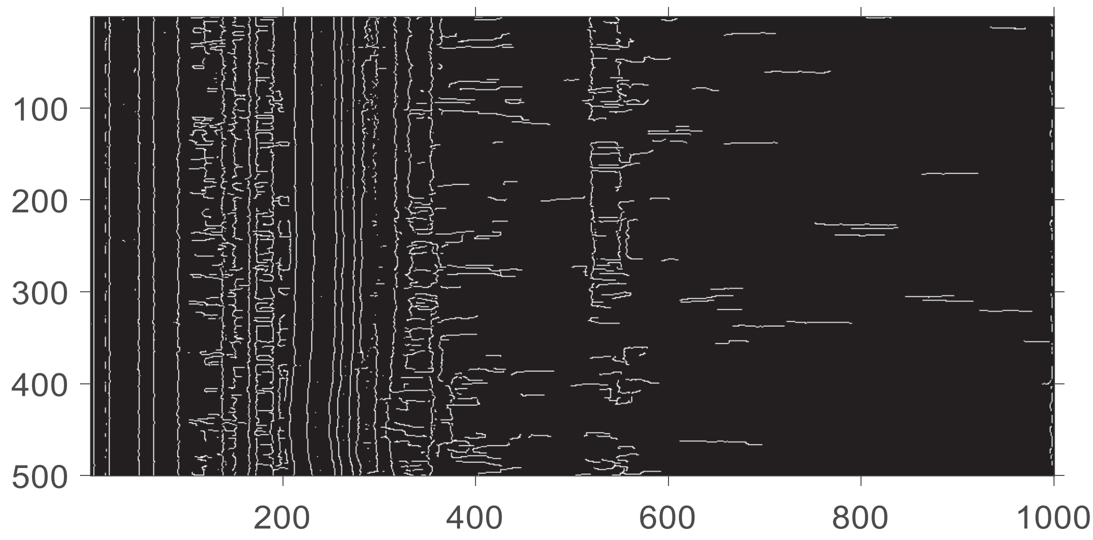
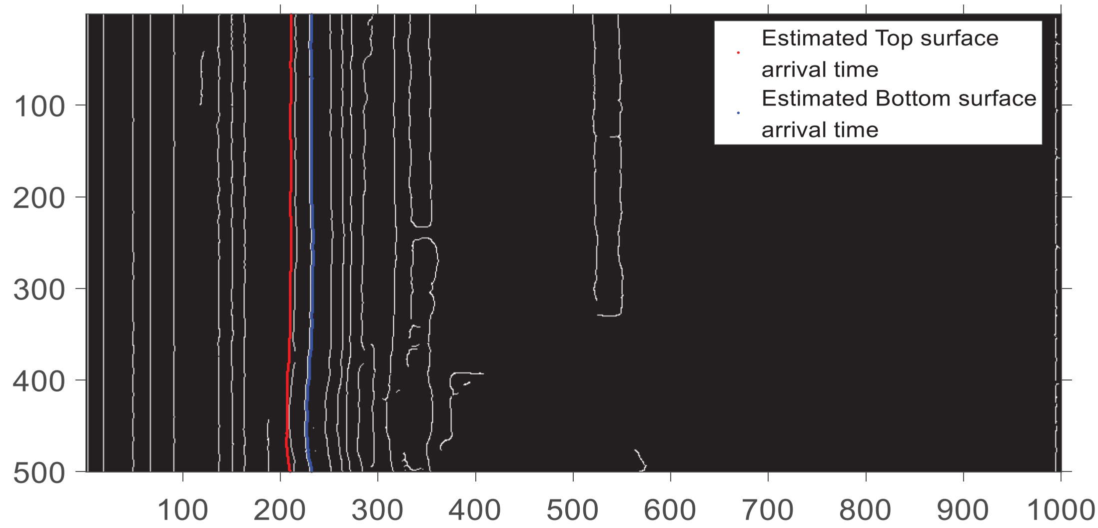


Figure 5– Energy image. (a)The energy image of the difference channel after compensation and envelope extraction (b) The energy image after applying the NLM filter

As shown in Fig.6(a) and Fig.6(b), the Sobel edge detection operator is applied to the energy image without and with NLM, respectively. It can be noticed that after NLM filtering, the inference signal is largely compressed. The averaged top arrival time vector is marked as a red line in Fig6(b). The line at its right side is the difference peak at the top surface, since the setup difference between the primary transducer and the difference transducer. The next step is broken line connection with the morphological operations. Finally, the detected bottom arrival time line is marked with blue.



(a)



(b)

Figure 6 –The detected lines.(a)The image with Sobel edge detection operator with no NLM filtering (b) The image with Sobel edge detection operator with NLM filtering(red: estimated top arrival time, blue: estimated bottom arrival time)

As shown in Fig.7, the estimated thickness is calculated with the mean value of 12.81 cm and the variance of 1.49cm, if the sound velocity within CRCs is assumed to be 2700m/s. The thickness information corresponds with the sample obtained with the shallow drilling system.

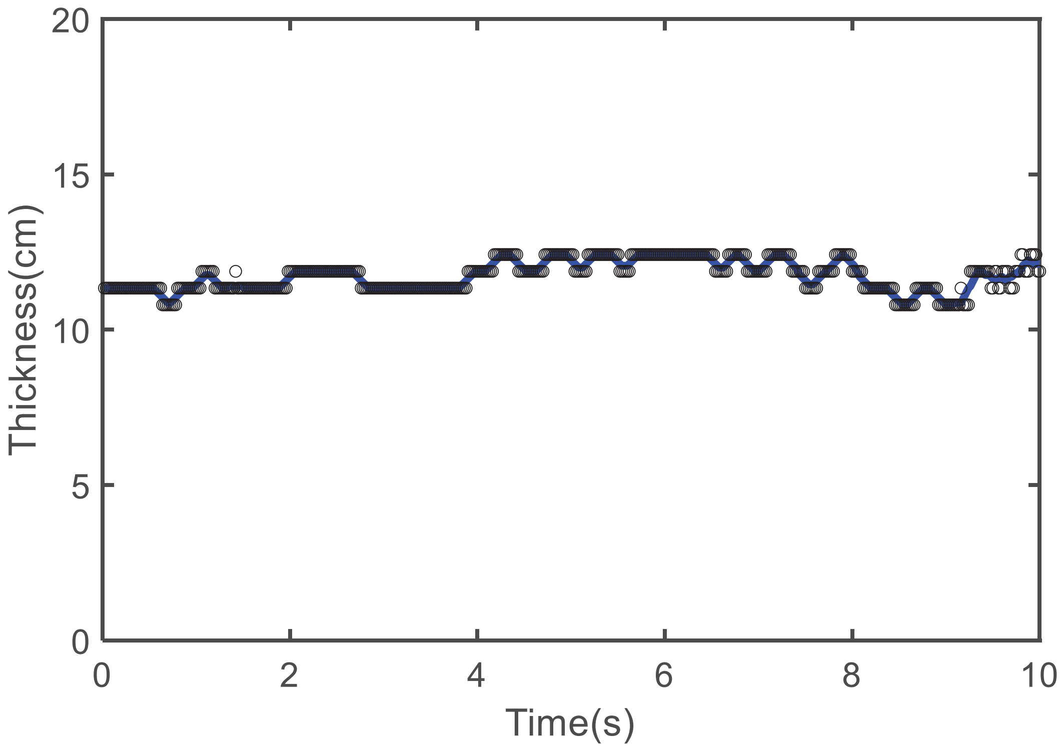


Figure 7– Estimated thickness values

CONCLUSION

In this paper, we briefly introduced the composition of the device and proposed an algorithm to measure the thickness of CRCs using dual-channel information and the context information. Afterward, we applied the algorithm to the real data acquired by the sea trial. The results has demonstrated that the method for measuring the thickness of CRC based on neighborhood information and dual-channel information is effective.

ACKNOWLEDGEMENTS

This work reported herein was funded jointly by National Key R&D Program of China (Grant No. 2016YFC0302000) and the National Natural Science Funds for Young Scholar (Grant No. 61801471). The authors must than and our team members, Zhenya Yang, Weijie Xu, Weicai Zhang, Xiangyang Zhu, Jianhua Fu, Huijun Wang, and Yunfeng Qin.

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