Three dimensional acoustic imaging technology of buried object detection

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Abstract. With the development of 21th century seabed imaging sonar technology, more and more attention is paid to buried object detection technology in the world. In this paper, a low frequency and high resolution three-dimensional acoustic imaging of buried object detection method and its application example are given. Compared with the traditional two-dimensional synthetic aperture imaging, the 3D imaging technology not only solves the problem of the aliasing of the seabed formation echo and the sea floor echo, being able to provide the target buried depth, but also the 3D imaging is more helpful to the image recognition. The 3D acoustic imaging method proposed by this paper has already become the development trend of buried object detection technology. We have noticed that, different from the three-dimensional visualization of the target in the water, the three-dimensional visualization of buried objects has a serious formation image occlusion problem. In addition, the three-dimensional imaging needs to be obtained centimeter-level resolution on three dimensions for better image recognition of small buried objects, in which azimuth resolution is the bottleneck.

1 An overview

With the development of 21th century seabed imaging sonar technology, more and more attention is paid to buried object detection technology in the world. The main difficulties of buried object detection technology are: On one hand, the acoustic wave penetration ability of seabed strata and imaging resolution are contradictory by each other, where the high frequency acoustic wave has weak penetration ability and the low frequency acoustic wave has poor imaging resolution. On the other hand, the acoustic characteristics of buried objects are complex, where targets are intergrowth with the seabed.

One of the main application requirements of buried objects detection technology is submarine pipeline and optical cable inspection. Currently underwater imaging technologies such as the artificial diving exploring, multi-beam imaging, side scan sonar imaging, marine magnetometer, subsea profiler and the ROV camera etc. are difficult to give the accurate buried depth and the state of buried pipeline and optical cables.

In addition, in order to cope with underwater surveillance and mine-throwing threats, it is urgent to study high-performance buried-burial detection technology and equipment to realize buried mine and buried sound array detection.

2 The development status of buried objects detection technology

There are three kinds of methods mainly in the current

buried target detection: low frequency synthetic aperture sonar, multi-beam subsea profiler, and multi-beam synthetic aperture sonar.

Fig. 1. 3D-Chirp sonar array and 3D imaging results.

Usually the low frequency synthetic aperture sonar can only detect half buried or shallow buried targets, and can't provide the information of buried depth, such as European Community SAMI SAS, America SSAM and DARPA SAS of, France IMBAT3000 SAS and Britain

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Geo SAS, Norway HISAS1030, New Zealand Kiwi SAS, etc.

Fig. 2. BOSS sonar and buried small target imaging results.

Typical equipment of multi-beam subsea profiler is the UK 3D-Chirp sonar, with the working frequency of 1kHz to 15kHz, two-dimensional receiving array of 2.5m by 2m. 3D-Chirp sonar array and its 3D imaging results are shown in Fig.1. Multi-beam subsea profiler is usually applied in the imaging of stratum structure and the large scale bedrock, it is unable to image for the small buried target.

Fig. 3. SBI sonar equipment and 3D visual detection results.

The BOSS buried target detection sonar developed jointly by Florida Atlantic university, naval surface warfare center, EdgeTech company is a low frequency

two-dimensional focus synthetic aperture sonar system. BOSS sonar for AUV configured has a 2m by 0.2m receiving array, with 40 elements and operating frequency of 3kHz~20kHz. BOSS sonar and buried small target imaging results are shown in Fig.2.

SBI shallow imaging system developed by Canada PanGeo Subsea Company is a multi-beam subsea profiler on the basis of synthetic aperture processing imaging. SBI sonar receiving array is 3.4m width(1.8 meters folded) and 0.8m length (20 cm effective aperture), with 40 elements and operating frequency of 4kHz~14kHz. The sonar equipment and 5m x 5m x 60m underwater 3D visualization of detection results are shown as in Fig.3.

It is seen that due to various constraints, there is a problem of lower efficiency of sweeping the sea and poor three-dimensional imaging resolution in a sort of current advanced buried objects detection equipment, such as United States BOSS sonar and Canada SBI imaging system and so on.

3 Buried objects detection and three-dimensional imaging

Firstly, there is the optimal operating frequency in buried objects detection. Because the stratigraphic absorption loss is proportional to the wavelength, low frequency sound waves are used to solve the acoustic wave penetration ability of large depth seabed strata. Usually, the penetration loss of sediment substrate is $0.3 \sim 0.6\text{dB}/\lambda$. So, in order to obtain larger penetration depth of stratigraphic, the work frequency of the buried objects detection choices in low frequency less than 10 kHz.

Secondly, there is a limitation of observation range in the buried objects detection. Because only the transmission component can be utilized for buried target detection, and the backscattering component be utilized for the seafloor imaging in contrast. The illumination angle should be commonly less than 60° for buried object detection.

Then, there is a necessary condition of buried target detection that the intensity of target echo is greater than the scattering intensity of the same volume stratigraphic. Although the target intensity is usually greater than the scattering intensity of unit volume, but if the resolution cell of imaging sonar is a lot larger than the target volume, it cannot guarantee that the target echo received is greater than reverberation background.

Compared to traditional two-dimensional side scan synthetic aperture sonar imaging, three-dimensional imaging is more favorable for weak buried target detection, when the size of 3D resolution cell is comparable to the target. It can also solve the aliasing problem between seabed echo and strata echo, providing the target buried depth, etc. So 3D imaging is the best choice of the buried objects detection.

Finally, different from the three-dimensional visualization of underwater targets, the three-dimensional visualization of targets in stratigraphic not only has much lower signal-to-reverberation ratio, but also has a serious seabed interface interference. There is

also a serious perspective problem in 3D visualization of stratigraphic targets, where target may be obscured by the image of the surrounding stratum. The underwater target 3D visualization technology cannot be easily transplanted into the 3D visualization of buried object imaging. The related technology research is almost a blank.

4 3D high resolution imaging

The principle of a 3D high resolution buried imaging is shown as in Fig.4, via launching low frequency broadband sound waves to obtain larger strata penetration depth, via broadband pulse compression technology to realize the high resolution in depth direction, via synthetic aperture technique to realize the high resolution in movement direction, via high resolution array processing techniques to realize the high resolution in azimuth direction. In the process of sailing, low-frequency broadband active pulse signal is launched, and the echo of stratigraphic acoustic impedance interface and buried small targets are received to get a two-dimensional image of stratigraphic section. Then a certain width 3D acoustic imaging of stratigraphic is drawn under sweep line by the voyage, in which buried targets information contained.

Fig. 4. 3D high resolution imaging principle.

Generally, sonar imaging resolution with certain aperture is inversely proportional to the wavelength. Here, the challenge of low frequency high resolution in sailing direction can be met via synthetic aperture imaging technology, and the challenge of low frequency high resolution in depth direction latitude can be met through broadband pulse compression technology. However, restricted by acoustic array lateral aperture, and subject to the limit of the low frequency working, the high resolution of azimuth in three-dimensional imaging is a bottleneck problem.

Because the background of buried objects detection is a distribution body target with much more individuals, the background reverberation is a kind of coherent interference. And each target has only once imaging by synthetic aperture processing, it is difficult to estimate the correlation matrix with a single snapshot. We know that the high resolution array processing is a disruptive technology under the condition of single snapshot and coherent interference. 3D imaging equipment until now with the multi-beam technology adopts a routine beamforming without exception.

However, in order to be used further for target recognition, 3D imaging sonar must be optimization

designed, so as to achieve centimeter scale resolution in all three dimensions.

5 Typical application cases

A system prototype of 3D high resolution imaging buried object detection is given in the paper, in which three dimensional acoustic imaging resolution up to $10\text{cm} \times 7.5\text{cm} \times 30\text{cm}$.

The system prototype of buried objects detection was applied to detect a sinking ship on Ningbo golden pond water channel, China, in 2010. Three-dimensional acoustic imaging results of shipwrecks are shown as in Fig.5. A prototype of the suspected target is given by target image analysis.

Fig. 5. 3D acoustic imaging result of sinking ship.

The 3D high resolution buried objects imaging principle prototype was applied for unexploded munitions sweeping outside the port of Qingdao, China, in 2013. 3D imaging result of a suspicious buried bomb is shown as in Fig.6, it is very visual for target discrimination by the 3D high resolution imaging, along with given size, shape and surrounding conditions. Actual bomb size: length 1.2 meters, 0.3 meters in diameter, spindle shape middle fine, both ends big.

Fig. 6. 3D imaging of a suspected buried bomb.

It was used for the routing of seabed oil and gas pipe on Shengsi, the East China Sea. A typical seabed oil and gas pipe 3D visualization result is shown in Fig.7. Buried depth is about 5m.

Fig. 7. A typical seabed oil and gas pipe 3D visualization result.

6 Looking forward

Compared with traditional 2D imaging side scan sonar, 3D high resolution buried objects imaging can obtain three-dimensional stratigraphic image with small target imaging included. And 3D high resolution processing can greatly improve weak target detection and recognition ability in volume reverberation background. It will lead imaging sonar to low frequency, high resolution and 3D imaging development.

References

1. SG Schock, International Journal of the Society for Underwater Technology. **27**, 185-193 (2008)
2. Belkacem A, Besbes K, IEEE Journal of Oceanic Engineering. **31**, 614-627(2006)