POSSIBILITIES OF DETECTION AND IDENTIFICATION OBJECTS LOCATED ON THE SEA BOTTOM BY MEANS OF A SIMPLE SIDESCAN SONAR

DOROTA ŁUKASZEWICZ, LECH ROWIŃSKI

Faculty of Ocean Engineering & Ship Technology
Gdańsk University of Technology
80-952 Gdańsk, Narutowicza 11/12, Poland

Several underwater tasks require detail visualisation of a water space and bottom features. Search and identification of sea mines or explosives are good examples of such activity. To achieve high capability of detection and correct identification, high accuracy and resolution are required. One of the valuable tools, that can be used for acoustic visualisation are side scan sonars. They are in use since early beginning of underwater activity, but it is only recently that applications of high frequency, high definition sonars are being investigated. First research results show a need regarding better understanding of equipment specification. The aim of a research, reflected in this paper, is to study possibilities of detection and identification of objects located on the sea bottom or slightly buried by means of a side-scaning sonar. The sonar considered is installed on Remotely Operated cable controlled Vehicle (ROV) or Autonomous Underwater Vehicle (AUV) that introduces important limitations to size, weight and power consumption of sonar system. Theoretical evaluation of sonar parameters and definition of information needed for detection and recognition of selected types of object are required for this purpose. For experimental evaluation of theoretical consideration typical industrial equipment has been selected. Tritech International Sea King Side Scan Sonar provides basic facilities. It is modified to allow direct comparison of two images obtained simultaneously from two transducers working at different frequencies.

INTRODUCTION

Sidescan sonars are used in many various research, military and commercial tasks. They are used for hydrographical examinations, pipelines inspection, searches of sea mines, wrecks and other objects (e.g. in underwater archeology) and for ROV navigation. For all these applications it is important to determin information extraction from the sonar image. The main aim is to separate information regarding objects from the whole image. The task is difficult because environment introduces a lot of interferences, disturbances, disfigurements and distortions to an image, with inherently limited resolution and contrast.

A ROV search-identification mission is often executed in this way that potential targets are detected by means of a ship's far-range low-frequency sonar. At next step, a ROV re-acquires and identifies the target. The ROVs are fitted with scanning sonars and TV cameras for this purpose. Scanning sonars serve as navigation tool mainly, while TV camera is a principal identification tool. The practice shows limited usefulness of TV cameras because of very limited visibility in many reservoirs. Due to high water turbidity, visibility often does not exceed 0.3 metre. In such conditions cameras can be useful only for the final classification and identification of the located target. However, such a proximity can be prohibited due to danger of initiating target explosive by influence fuses.

Imaging scanning sonars are extremely effective during target re-acquisition. However experience and practice shows a few limitation. Principal one is drop of resolution with increasing range. It means that it is not possible to classify object while searching for previously detected mine like object. As result, in spite of knowledge about a potential target position, it is sometimes very difficult to find this target and start identification. This situation was often experienced while using the Mine Countermeasure Remotly Operated Underwater Vehicle System “UKWIAL”. In many cases an object had been detected by the imaging sonar, and next it had been lost and it was very difficult to find it again.Reasons can be various. The vehicle could move too high above the bottom or move too fast. In the consequence the sonar overlooks or omits the target between two scans of the interesting fragment of space.Operational result of the problem is longer time required to accomplish the mine counter measure task. For obvious reasons, it can usually not be accepted. One of promising ways to facilitate classification of bottom objects is installation of side scan sonar. While not being a principal sensor for re-acquisition phase, it can give system operator detail image of the surrounding bottom, created during target approach.

Side looking sonar imaging capability can also be utilized during identification phase of mine counter mission, particularly while operating in adverse visibility conditions. Without need for close approach to an object, it can be easily in-sonified from different directions. The idea can be successfully introduced and utilized if a few requirements can be met by potential sonar system. These are:

1) Adequate resolution considered range
2) Near real time image presentation
3) Low cost of ROV installed equipment

Technical constraints are quite obvious for classification and identification tasks. Financial limitation is important due to danger of total destruction of equipment, inherent to considered mission task. In fact introduction of side scan sonar system can rise cost of sonar equipment to more than half of total platform cost.

1. RANGE AND RESOLUTION REQUIREMENT

Resolution is one of the most important parameter of imaging sonar.

Requirements regarding range and resolution depend on mission time constrains and identification needs. Long range or wide swath gives the system high coverage rate. It is however limited by frequency required to achieve required resolution. While both parameters are coupled and develop in opposite directions fair compromise must be achieved while selecting an equipment.

To achieve high probability of correct identification of mine like objects sonar resolution must be related to object size and shape. In a case of “standard” sea mine these can be 1 m long cylinders as well as 1m diameter cones and spheres. In case of “home made” explosives linear size begins at 0,1 m range, while their shape can not be defined before an identification mission begins. Analyse of object geometry shows that to identify such objects spatial resolution of 0,01 m is required. The aim of this study is to evaluate capability to create low cost equipment offering this resolution and a range adequate for counter mine operations.

2. RESOLUTION AND RANGE OF SIDE SCAN SONARS

There are correlations between an altitude of a moving sonar, depression angle of the transducer, a range and sonar speed and sonar image quality. Many sonar system parameters influence quality of sonar data and generated images. Choosing parameters of sonar system for an application, it is necessary to consider existing contradictions in consequences of changes because a change one parameter value can often improve the effect of action in one aspect while worsening the other one in the same time.

For standard long range applications, sonar parameters are well defined and their well understood. For high resolution application phenomena are not understood so well. Recent development of sonar technology makes it possible to built higher frequency sonar with improved resolution, image quality. In consequence, objects detection and classification capability was substantially improved. However, shorter range and longer time of an area coverage are also consequences of the higher frequencies.

Two different resolutions are distinguished:

azimuth resolution $\boldsymbol{\delta_a}$

and resolution in propagation direction $\boldsymbol{\Delta r}$.

By an **azimuth resolution** ($\boldsymbol{\delta_a}$) we generally mean the minimum linear distance between two objects located at the same range, which echoes system (sonar) is able to distinguish.

A **radial azimuth resolution** ($\boldsymbol{\delta_r}$) is the minimal angle between two objects at the same range, which echoes system (sonar) is able to distinguish.

By **resolution in a propagation direction** $\boldsymbol{\Delta r}$ we mean system ability to distinguish echo from two objects located at various ranges.

In the case of single frequency transmit impulse, with rectangular boundary shape and perpendicular reflection, $\boldsymbol{\Delta r}$ is given by: [1]

$$\boldsymbol{\Delta r = c\tau/2}$$

where, $\boldsymbol{\tau}$ - transmitter pulse length and c – sound speed.

Hence, we can improve $\boldsymbol{\Delta r}$ by shortening a transmitter impulse length.

However a transmitter impulse length can not be too short, because transmitter power is directly proportional to a transmitter pulse length.

Transmitter pulse length $\boldsymbol{\tau}$, needs to be longer than a dozen or so wave periods because of conditions required to form directional characteristics and transducers transition states.

For the side scanning sonar case we have to notice, that due to large vertical beam height (about 50˚) the resolution $\boldsymbol{\Delta z}$ is different in various directions:

$$\boldsymbol{\Delta z = c\tau/(2\sin(\varphi))}$$

where

φ - beam centre line angle

The bottom object resolution is lower for the near ranges and small $\boldsymbol{\varphi}$, but is approximately equal $\boldsymbol{\Delta r}$ for the far ranges: $\boldsymbol{\Delta z \approx \Delta r}$

The so called **Rayleigh Criterion** defines dependence between a transducer length (l) and **azimuth resolution** (δ_r) and it says that two objects are distinguished when an angular distance between them is larger than an angular distance between direction of maximum and first zero of a cross section of directional characteristics.
Hence, the **azimuth resolution** of side-scanning sonar is given by: [1]

$$\boldsymbol{\delta_r} = \mathbf{arc\ sin}(\lambda / l)$$

for $l >> \lambda$:

$$\delta_r \approx \lambda / l$$

A far zone (Fraunhofer's zone) **azimuth resolution (δ_a)** depends on distance (R) [1][2]:

$$\boldsymbol{\delta_a = R\,\lambda / l}$$

where,
δ_a - azimuth resolution
R - range in metres
λ - wavelength of signal in metres
l - antenna length in metres
and a zone border is: $r = l^2 / \lambda$
An azimuth resolution improvement in a far zone is possible for a narrower beam width angle.

The azimuth resolution (δ_a) for **near zone** ($r < l^2/\lambda$) is approximately equal a transducer length :

$$\boldsymbol{\delta_a \approx l}$$

In practise, the minimal azimuth resolution $\boldsymbol{\delta_a}$ is limited by a transducer single element dimension l_l of infinite length multi-element transducer:

$$\boldsymbol{\delta_a \geq l_l}$$

It is possible to obtain the azimuth resolution equal l_1, for a transducer length l, for the condition:

$$\boldsymbol{l > R\,\vartheta_{l1} + L}$$

where,
l - total transducer length
l_l - transducer single element dimension
ϑ_{l1} - directional characteristics angle of a transducer single element
L - crosswise dimension of an observed object
R - range

Hence object dimension and maximum range define total transducer length. The azimuth resolution $\boldsymbol{\delta_a}$ defines the transducer single element dimension l_l and transducer single element dimension l_l defines the angle ϑ_{l1}. In practise, the condition is true for small range R only.

It is possible to improve the azimuth resolution by increasing the operating frequency but a consequence is a reduced range because of the greater sound attenuation at higher frequencies.

Making the antenna aperture or transducer single element length larger it is possible to improve the azimuth resolution in a far zone by a narrower beam but dimensions, weight and cost (including cost of larger devices exploatation) are restrictions. Unfortunately it causes increase of the azimuth resolution $\boldsymbol{\delta_a}$ in the near zone [1][2]. Radical improvement in the azimuth resolution can be achieved with multi-element transducers or application of a SAS (Synthetic Aperture Sonar) technology. The SAS technology can give resolution independent of range and frequency equal to one half the size of the receiver element [3]. However both solutions requires much more expensive.

3. RESEARCH

While the equations cited above are very rough approximate, experimental investigation of sonar parameters has been initiated to evaluate of theoretical considerations.
The sonar selected for this purpose is Tritech SeaKing Sidescan Sonar.
The sonar has been modified for the experiment purpose. It is able to operate two different transducers simultaneously.
This unique feature gives possibility to compare data from two transducers operating under the same conditions exactly.
The sonar transducer specification is as follows:

1. 675 kHz transducer active element	
Length:	375 mm
Height:	4.5 mm
Beam pattern @ 3dB:	0,45 deg x 50 deg
Approximate range:	50 – 80 m
2. 935 kHz transducer active element	
Length:	375 mm
Height:	3.0 mm
Beam pattern @ 3dB:	0,3 deg x 35 deg
Approximate range:	30 – 50 m
Maximum range resolution in both cases @ 800 bins per line:	0,01 m for 10 m range 0,05 m for 50 m range
Transmitter source level:	208 dB
Transmitter pulse length:	50 – 200 µs
Receiver sensitivity:	2 mV
Gain control range:	80 dB
Data sampling rates:	5 - 200 µs
Data resolution:	8 bits

For 935 kHz frequency sound wave length is 1,6mm only. For considered range a sonar works in near zone. Limit of far zone for transducer length of $l = 0.375$m and considered frequency is $r = 87$m.

According to the above specification, range resolution of 40 mm can be expected for 50 µs pulse length and 10 – 20 m range. It seems to be quite enough for the tasks considered and typical mine like objects. However, the azimuth resolution, resulting from horizontal beam pattern, is of great question. It can be very difficult to meet mission specification. As indicated in above relationships, its assessment is not straightforward. Beam angle of 0.3º gives linear resolution along track of 0,2 m at 50 m range but in near zone (below 87m) can not be better than transducer length (0,375m).

Another interesting parameter is a length of a path transducer makes along the track. During emission of a of 100 μs length pulse and transducer of speed of 1 m/s of movement along a track gives linear way of 0.1mm approximately. Before the echo returns from 50m range (time of 0,06 seconds), the transducer travels another 60mm. At higher linear speed it can miss the transducer on return. Together with beam width these are factors limiting this speed. Due to factors described above careful adjustment of sonar parameters is required to obtain best results.

The optimum settings of the sonar system will be evaluated in laboratory tank, that allows for fine definition of space geometry and transducer speed. The results will further be verified by imaging of selected, characteristically shaped, objects in real environment. Some unconventional information processing is also planned. Experimental research of real sonar equipment will be supplemented by computer simulations. Comprehensive sound propagation model is being developed, based on ray tracing methods. This would substantially facilitate analyses of experimental result. It will also allow for extension of definition of sonar parameters and imaging capabilities beyond 1 MHz range. The study is expected to indicate solutions that could improve imaging capabilities without radical redesign of sonar hardware and vehicle located signal processing hardware.

REFERENCES

[1] Kilian L., Analiza warunków wykrywania i zdolności rozdzielczej sonaru bocznego, Instytut Telekomunikacji Politechniki Gdańskiej, Gdańsk 1979

[2] Riyait V.S., Lawlor M.A., Comparison of the Mapping Resolution of the ACID Synthetic Aperture Sonar with Existing Sidescan Sonar Systems, IEEE OCEANS'94,III-559-III-564, 1994

[3] Sternlicht D., Pesaturo J.F., Synthetic Aperture Sonar: Frontiers in Underwater Imaging, Sea Technology, p. 27-32, November 2004

[4] Wilcox T.E., Fletcher B., High-Frequency Sonar For Target Re-Acqusition and Identification, Sea Technology, p. 41-45, June 2004,

[5] Alais P., Ollivier F. et al., A high resolution Sidescan Sonar, IEEE OCEANS 94, p.I-340 - I-343, November 1994

[6] Perry S.W., Applications of Image Processing to Mine Warfare Sonar, DSTO Aeronautical and Maritime Research Laboratory, Melbourne Victoria 3001 Aubtralia, February 2000.

[7] Thekkathala J., Spruance J.C., Side-Scan Targets: Image Analysis, Database Management, Sea Technology, p. 57-64, September 1992

[8] Waite A.D., Sonar for practising engineers, John Wiley & Sons Ltd, England, 2002.