Wideband signals for Interferometric Sonar systems

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Résumé - Cet article traite du problème de la résolution de portée dans les sonars à phase différentielle. Les techniques de traitement du signal à large bande sont utilisées pour résoudre le problème de compromis entre la portée et la résolution.

L'idée de l'utilisation les formes d'onde large bande est inspirée des mammifères sous-marins qui utilisent des signaux à large bande pour la navigation et la détection des cibles. Le papier s'intéresse en particulier au système sonar à phase différentielle proposé Bathyswath-2 de ITER-Systems. Les expérimentations sont réalisées pour différentes types de formes d'ondes – onde continue, modulation linéaire de fréquence et modulation exponentielle de fréquence. A la réception, le traitement est réalisé par filtrage adapté.

Les résultats sont démontrent les performances d'obtenir une bonne résolution spatiale dans le cas des deux cibles étroites placées dans un réservoir expérimental.

Abstract – Wideband signals are compared with the narrowband continuous wave (CW) pulses to assess the relative merits of signals to improve the range and angle resolution of a phase differential (or Interferometric) sonar system. The idea is inspired by the marine mammals, who use complex wideband signals for navigation and target detection. The idea is to use selected waveforms with phase differential sonar, in this case Bathyswath-2 from ITER-Systems. Experiments are done with different signals e.g. CW (Continuous Wave) pulse with different pulse duration, LFM (Linear frequency modulated) Pulse, EFM (Exponential Frequency Modulated) pulses. For the range calculation, classical Matched Filtering is used. It is suggested that spatial resolution is increased by the use of chirp signals without affecting the range of sonar. Here 28mm tubes are used as a target to compare the range resolution of signals under test. Matched filter technique is used to find out the time of arrival and the delay between multiple sonar arrays; it is widely used in active sonar systems.

Keywords: Active Sonar, Interferometric Sonar, Phase Differential Bathymetric Sonar (PDBS), Bathymetry, Wideband signals, Matched filtering

1 Introduction

In recent years, interferometric and multibeam sonar systems are widely used to explore the seabed. The basic principle behind both kinds of bathymetric sonar systems is measuring the angle of arrival and range of seabed echoes. Phase differential sonars have benefits in shallow water due to long swath range compared to Multibeam echosounders. An interferometer uses angle and amplitude information from the backscattered signals. Most of the current sonar systems use continuous wave (CW) pulses, which gives benefits of simplicity in design with adequate quality bathymetry maps.

The common problem with the CW pulses is high trade-off between range and resolution. By theory a high frequency system gives high resolution but signal loss from absorption is very high, which gives a small range; low frequency signals have a long range but the resolution is comparatively low and the size of the transducers increases.

Wideband signals give high resolution bathymetry with long range. They are widely used in radar systems, but they are less used in sonar, due to high complexity of sound propagation in water.

Here a comparative study is done with different wideband signals and CW pulses.

In this paper we give a basic introduction to interferometry sonar, the major problems with it and the wideband approach to improving them.

1.1 Interferometry

Interferometry, or phase differencing, is a widely used method to measure the angle from sonar transducers to targets. Combined range and angle data is used for create 3-d bathymetry maps. By the name, it describes swath-sounding sonar techniques that use the phase content of the sonar signal to measure the angle of the wavefront returned from a sonar target.

Figure 1, shows the basic setup of interferometry sonar to calculate range & angle from backscattered data. Time since transmit and sound velocity is used to compute the range to the target and phase content of wave fronts is used for angle. Figure 2, shows a cross profile view of backscattered signal from the sea bottom. The blue points represent filtered data and the red points are noise due to different factors e.g. electronics noise, reverberation, multipath etc. On the right of cross profile window you have angle and phase window. The coloured points are the phase difference between different staves pairs. By comparing these stave pair phase differences ambiguity is eliminated and high accuracy is achieved. The white line represents the calculated sine angle.

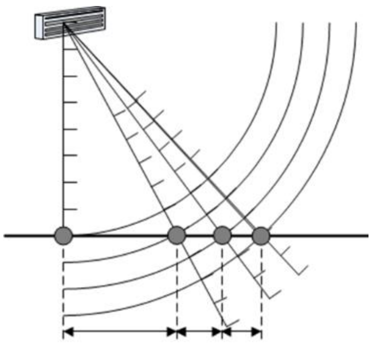


Figure 1 Basic setup of interferometry sonar

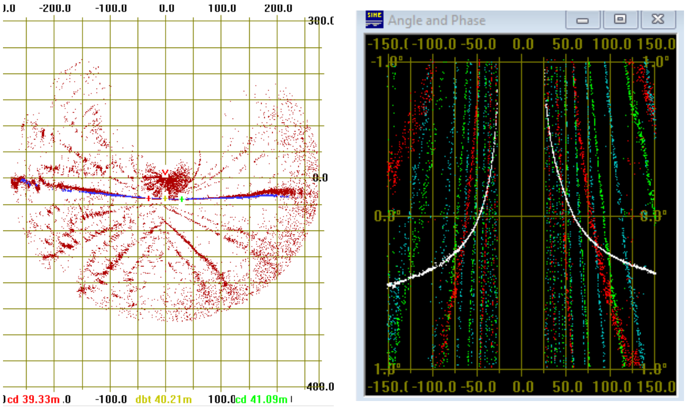


Figure 2 (Left) Cross profile view of backscattered signal, on port and starboard side combined. (Right) Angle and Phase values with respect to range

2 Experiment Setup

A small water tank, size of 1 cubic metre was used for the experiments. A Bathyswath V1 transducer is used for these experiments. It has four receive staves and one transmit stave. The resonant frequency is centred at 468 kHz. The transducer is designed to be mounted at -30 degrees of elevation angle, looking outwards and downwards; this is most common mounting configuration for phase differencing sonars.

A ladder shaped target is placed in front of the transducer face at 60cm distance. This target is made of adjustable cylindrical rungs with 28mm diameter. A minimum separation of 1cm is kept between any two rungs of ladder.

Three different types of pulse signals are used: Exponential Frequency Modulation (EFM), Linear Frequency Modulation (LFM), and Continuous Wave (CW).

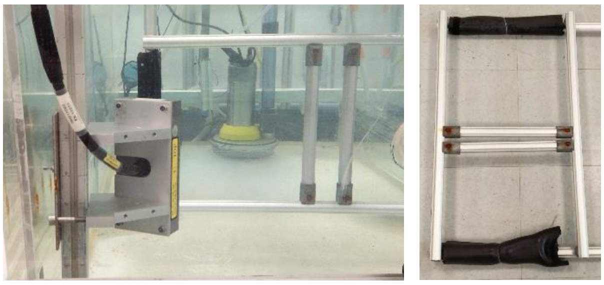


Figure 3: Ladder shaped target and Bathyswath V1 transducer

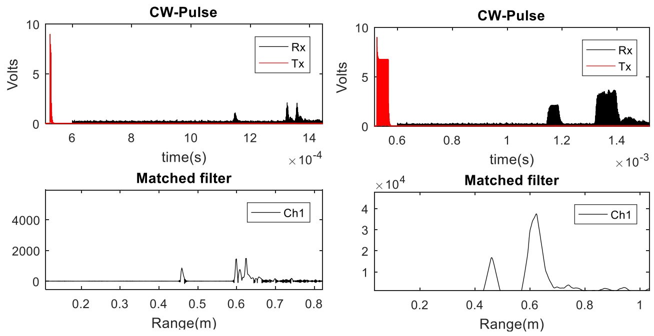
3 Matched filtering

Matched filtering (MF) is widely used to find signal echoes from a noisy signal with high time-of arrival-accuracy. This is accomplished by cross-correlating the received signal with the reference transmitted signal. MF maximizes the signal to noise (SNR) of the detected signal.

For our experiment we used signals from a signal generator as the reference signal for the matched filter. After taking local maxima values, target echoes are easily identified from the received signal.

CW Pulse:

Figure 4 shows a signal of 468 kHz transmitted with 2-cycle duration. The targets are separated by 1 cm. In the figure, the top row represents amplitude envelope of transmitted and received signals and bottom row is the output of matched filter against range. First received echo is from the ladder support and can be ignored. The 2nd and 3rd echoes are the backscattered signal from the ladder rungs. Now we use longer duration pulses, 10 cycles and 20 cycles. After the post processing, we notice that a small 2-cycle pulse can differentiate the target rungs easily but gives low SNR but on the other hand a longer pulse gives a high SNR but the separation between 1st and 2nd rung is difficult. In the case of 20-cycle pulse, there is only one combined echo from both rungs. This shows that we need to trade-off between range and resolution. A 2-cycle pulse can only be used in very shallow water, where the range is limited by other factors.



(A) (B)

Figure 4 CW pulse; Pulse length (left) 2-cycles (right) 20-cycles

LFM Pulse:

The next waveform was a Linear Frequency Modulated pulse. The frequency component of a linear chirp is

$$f(t) = f_0 + kt$$

Where:

f_0– Initial frequency f_1 – Final frequency

k – Rate of frequency change $k = \frac{f_1 - f_0}{T}$

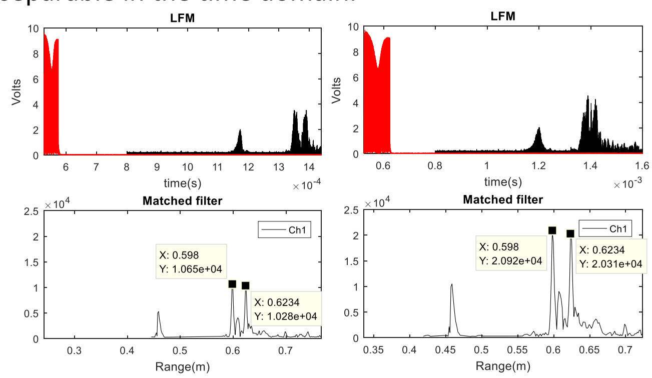
$$x(t) = sin\left(\phi_0 + 2\,\pi\,\left(f_0 t + \frac{k}{2}t^2\right)\right)$$

Where: ϕ_0 = Initial phase

The initial frequency f_0 was 200 kHz and the final frequency f_1 was 700 kHz.

For the first test a pulse of 0.5s seconds was used and for the second time a pulse of 0.7s was used.

From Figure 5, echoes from the ladder rungs are easily separable in the time domain.



(A) (B)

Figure 5 Linear frequency modulated (LFM) pulse; (A) pulse length 0.5 s (B) 0.7 s

EFM Pulse:

In an exponential chirp, the frequency of the signal varies exponentially as a function of time.

$$f(t) = f_0\, k^t$$

Where

f_0 = initial frequency; f_1 = final frequency

k = rate of exponential change in frequency $k = (f_1/f_0)^{1/T}$

$$x(t) = \sin\{\phi_0 + 2\pi f_0 \frac{(k^t - 1)}{\ln(k)}\}$$

The initial and final frequencies are same as used in the LFM waveform.

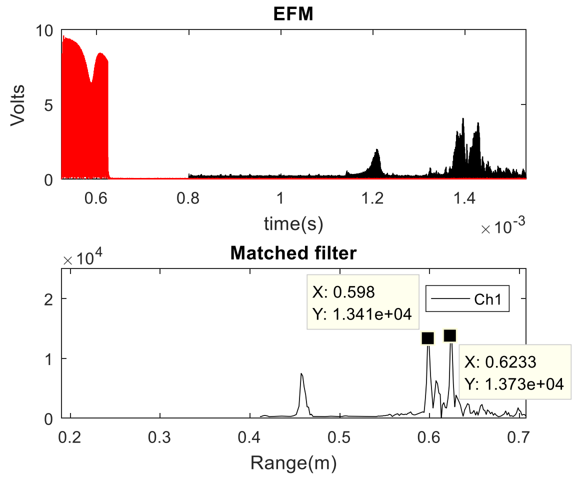


Figure 6 EFM pulse transmitted

From Figure 6, the received echoes from both the rungs are easily separable and the SNR is high compared to the CW pulse with small pulse length. The results are similar to those from the LFM signals. The merits of different wideband signals are selective on the environment, so the next step is to repeat this experiment in different environments. An adaptive selection of signal can be used to get the best results.

4 Conclusion

From the experiments, we show that the resolution of a sonar system can be improved significantly with the use of wideband signals. With the CW pulses the range resolution is directly depends on the pulse length: the smaller the pulse higher the resolution but small duration pulses contain less energy, and so range is limited. With wideband signals, the resolution is unaffected by pulse length. Long wideband pulses give benefits of long range. We also conclude that the results of EFM and LFM pulses are almost same in this case, which gives benefits to LFM signal because of lower complexity in hardware design. Classical Matched filtering technique is used; future experiments will use different filtering techniques. The output of a signal generator was used as the reference signal, but in the real world application it is more complicated to get the reference acoustic signal, so different techniques need to be considered to recover the transmitted reference signal.

Next step will be to see how these wideband techniques affect the angular measurements of interferometry sonar.

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