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Wideband detection and classification of mines in a simulated ship hull scenario

John Fawcett
Richard Fleming

Defence R&D Canada – Atlantic

Technical Memorandum
DRDC Atlantic TM 2007-334
December 2007

Canada

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Abstract

In this experiment we placed a small plastic container with a mixture of rubber epoxy and steel ball bearings on a sheet of fibreglass. The fibreglass sheet was then suspended in the DRDC Atlantic acoustic calibration tank. The sheet was then scanned by a conical beam from the wideband high frequency multi-mode pipe projector (MMPP) and the echo recorded. The goal of the experiment was to determine how easily the attached mine region could be distinguished from the echo of the fibreglass sheet. In addition, we modified the basic “mine” by placing a thin aluminum plate on top of it, a small tungsten carbide sphere on top of this and finally a thick aluminum disc on top of the basic mine shape. These different echos will be used in a computer-classification study.

Résumé

Ce rapport décrit une expérience au cours de laquelle nous avons placé un petit contenant de plastique contenant un mélange d’époxyde-caoutchouc et de billes d’acier, sur une feuille de fibre de verre, par la suite suspendue dans le bassin d’étalonnage acoustique de RDDC Atlantique. Ce montage a été ensuite balayé par le faisceau conique à haute fréquence d’un projecteur à tube multimode dont l’écho a été enregistré. Cette expérience avait pour but d’établir la facilité avec laquelle on pouvait distinguer la « mine » attachée dans l’écho réfléchi par la feuille de fibre de verre. Nous avons, en outre, modifié cette « mine » élémentaire en plaçant une plaque d’aluminium mince devant elle, puis une sphère de carbure de tungstène devant ce montage et, enfin, un disque d’aluminium épais devant la « mine ». Nous utiliserons les échos mesurés lors d’une étude de classification par ordinateur.

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Executive summary

Wideband detection and classification of mines in a simulated ship hull scenario:

J. Fawcett; R. Fleming; DRDC Atlantic TM 2007-334; Defence R&D Canada – Atlantic; December 2007.

Introduction or background: The sonar detection of small mines (or other objects) placed upon a reflective surface such as a ship's hull or a piling is a challenging problem. It may be possible to detect the object with high frequency sonar on the basis of the relative altitude of the object with respect to the background. However, various protuberances, ribs, etc could also cause altitude variations. The approach of this report is to look for distinctive or anomalous spectral signatures as a means of distinguishing mine regions from the background. A simple experiment using a wideband projector is described.

Results: It is shown that various "mine" regions can be successfully classified with respect to a background reflector using the spectral information of the echo from a single sonar ping.

Significance: This experiment indicates the potential of using wideband scattering information, perhaps in conjunction with imaging sonar, as an acoustic tool for identifying mines upon a ship hull, on a pier, or other surfaces.

Future plans: We would like to perform more experiments with different objects and backgrounds, utilizing various projector bandwidths and projector/receiver geometries, etc. in order to quantify the potential of this method. A more controlled version of this experiment with respect to scanning motion is in the planning stage.

Sommaire

Détection en large bande de mines et leur classification dans le cadre d'une simulation de la coque d'un navire

J. Fawcett; R. Fleming, DRDC Atlantic TM 2007-334, R&D pour la défense Canada – Atlantique, décembre 2007.

Introduction : La détection par sonar de petites mines ou d'autres objets placés sur une surface réfléchissante comme la coque d'un navire ou un pilier est un problème difficile. Avec un sonar haute fréquence, il pourrait être possible de détecter un objet à partir de sa « hauteur » par rapport à son fond. Toutefois, diverses protubérances, membrures et autres structures pourraient causer des variations de la hauteur. Dans ce rapport, nous étudions l'utilisation des signatures spectrales distinctes ou anormales pour distinguer les régions de mines du fond sur lequel elles sont placées. Nous décrivons une expérience simple réalisée avec un émetteur à bande large.

Résultats : Nous montrons que l'on peut facilement classer différentes régions de mine relativement à un fond réfléchissant, en exploitant l'information spectrale contenue dans l'écho d'une seule impulsion sonar.

Importance : Cette expérience montre le potentiel de l'utilisation des informations contenues dans une bande large — possiblement de concert avec un sonar imageant — comme outil acoustique pour découvrir des mines sur la coque d'un navire, sur un pilier ou d'autres surfaces.

Recherches futures : Il serait utile, pour optimiser cette méthode, de procéder à d'autres expériences avec différents objets, fonds, largeurs de bande d'émission, et dispositions pour l'émetteur et le récepteur, etc.

Table of contents

Abstract …….. i
Résumé …..... i
Executive summary iii
Sommaire iv
Table of contents v
List of figures vi
1....Introduction 1
2....Experimental Setup 2
3....Experimental Results 4
3.1 Basic mine shape 4
3.2 Basic mine shape with thin aluminum disc 6
3.3 Basic mine shape with thin aluminum disc and small tungsten-carbide sphere on top 8
3.4 Scan of basic mine shape with thick aluminum disc on top 10
4....Classification 13
5....Conclusions 14
References 15
List of symbols/abbreviations/acronyms/initialisms 17
Distribution list 19

List of figures

Figure 1 Drawing of ACT test set-up. 2

Figure 2 HF MMPP endfire transmitting voltage response. 3

Figure 3 Detail of HF MMPP and hydrophone jig. 3

Figure 4 The basic“mine’ shape 4

Figure 5 Reflection time series from scan over fibreglass and “mine” 5

Figure 6 Amplitude of Hilbert Transform of reflected time series from scan of fibreglass and “mine” 5

Figure 7 Representative spectra of pings over the fibreglass (blue, cyan) and pings over the “mine” region (red, black). 6

Figure 8 Thin aluminum disc atop the “mine” shape. 7

Figure 9 Absolute value of Hilbert Transform of time series of scan over fibreglass and “mine” region with thin aluminum disc on top 7

Figure 10 Representative spectra of pings over fibreglass (blue, cyan) and “mine” region (red ,black) with thin aluminum disc on top 8

Figure 11 40 mm tungsten carbide sphere atop “mine” and thin aluminum plate. 9

Figure 12 Absolute value of Hilbert Transform of time series from scan over fibreglass and “mine” region with thin disc and sphere on top. 9

Figure 13 Some representative spectra from pings over the fibreglass (blue, cyan) and “mine” regions (red, black) for the thin disc and sphere on top. 10

Figure 14 Thick aluminum disc atop “mine” and thin aluminum disc. 11

Figure 15 Absolute value of Hilbert Transform of time series for scan over fibreglass and “mine” region with thick aluminum disc on top. 11

Figure 16 Representative spectra from scan over fibreglass (blue, cyan) and “mine” region (red, black) for thick aluminum disc on top. 12

Figure 17 Confusion Matrix resulting from the nearest neighbour classification of the 5 echo classes: (1) fibreglass plate background (2) basic “mine” (3) basic “mine” with thin aluminum disc (4) basic “mine” with thin aluminum disc and sphere on top and (5) basic “mine” with thin and thick aluminum discs on top. 13

1 Introduction

The detection of mines or explosive devices planted on a ship's hull or on a piling is currently a research topic of much interest. High frequency sonars may provide a rough image of the area of interest or a bathymetric sonar may be able to resolve the height difference caused by an object placed on a surface. However, on the basis of geometric measurements alone, it is anticipated that there is potential for many false alarms. The approach of this report is to investigate whether it is possible to reliably distinguish echos of interest from background echos in the case of a wideband incident pulse.

The projector that is used has been described in previous reports [1], [2]. A compensated "Sinc" pulse with a flat spectrum in the frequency interval [17-57] kHz is used to ensonify a fibreglass sheet. A small simulated mine was constructed and attached to the fibreglass sheet. The projector/hydrophone complex was manually rotated over the fibreglass sheet and at some instances the projector and hydrophone were almost directly over the attached "mine".

The set of time series which were recorded clearly show that the backscattered echo from the basic "mine" region (which is a combination of scattering from the object itself and the fibreglass backing) is diminished with respect to the background amplitude. In particular, the diminished amplitude is most strongly evidenced in the higher frequencies of the echo. Other modifications of the target region were considered, each giving rise to a distinctive echo structure. Examples of the echos will be shown both in the temporal and frequency domains.

Finally, echos from each target class and the background echos will be used to train an automated classifier and the resulting Confusion matrix obtained with this classifier will be shown.

2 Experimental Setup

DRDC Atlantic's acoustic calibration tank (ACT) was equipped with a suspended 5.91 mm thick fiberglass panel in order to provide a simulated submerged boat hull upon which a simulated "mine" and a series of other reflectors could be attached. A jig was fashioned to permit rotation of a coaxial hydrophone/projector assembly through 360 degrees over the fibreglass panel/"mine" target (see Figure 1).

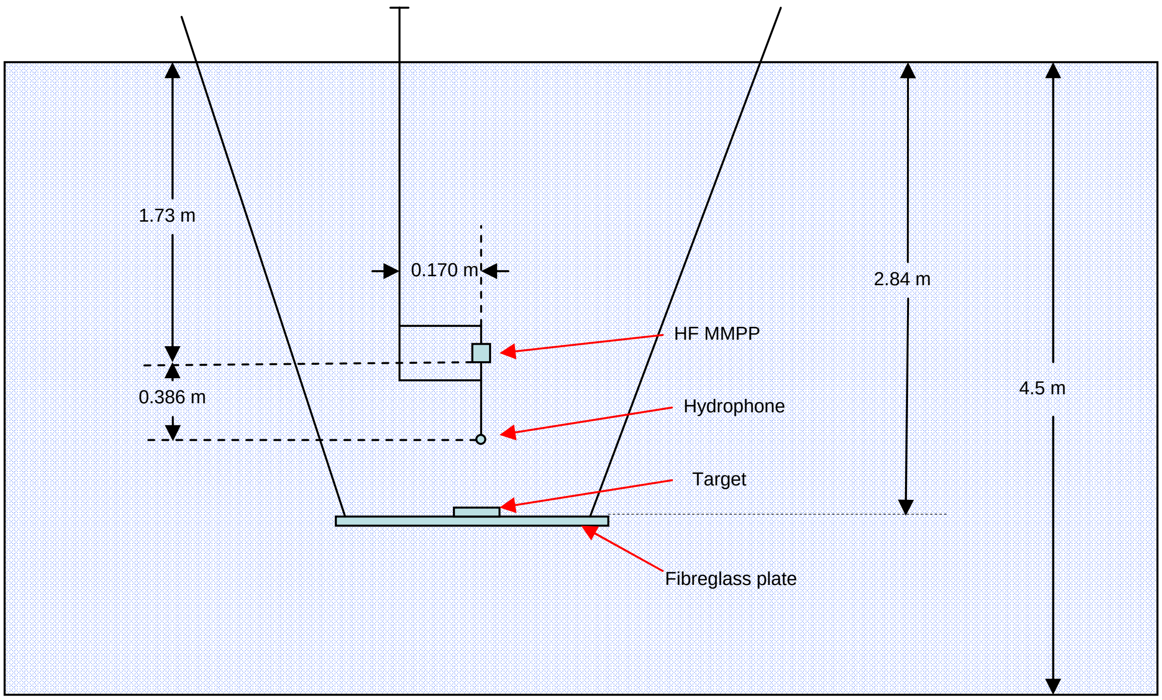

Figure 1 Drawing of ACT test set-up.

A high frequency multi-mode pipe projector (HF MMPP) was employed in endfire configuration to provide wideband acoustic energy (see Figure 2 endfire transmitting voltage response of HF MMPP). A B&K 8100 hydrophone (serial number 539) is mounted by a fibreglass rod below the HF MMPP.

Sinc pulses were generated using a LabView™ virtual instrument called the Pulse Echo Recorder which was developed at DRDC Atlantic [1]. These sinc pulses were subsequently spectrally corrected to provide a nearly flat output sinc spectrum. The sinc was amplified by an Instruments Incorporated Model L-2 amplifier. Drive voltage was on the order of 47 Vrms resulting in a post-spectral correction source level of 112 dB re 1μPa @ 1m/root-Hz.

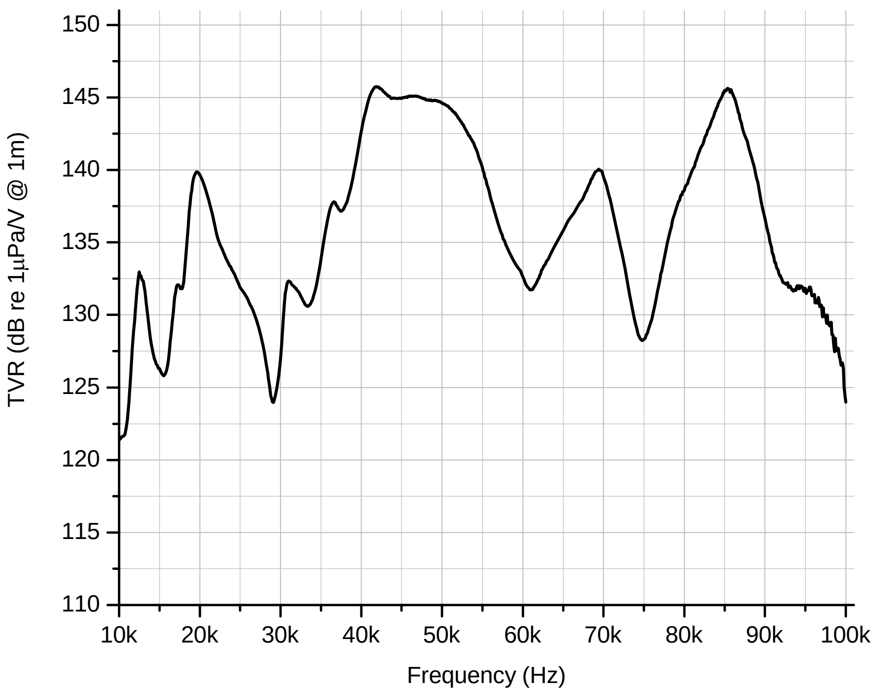

Figure 2 HF MMPP endfire transmitting voltage response.

Figure 3 Detail of HF MMPP and hydrophone jig.

3 Experimental Results

3.1 Basic mine shape

The basic "mine" shape is composed of a matrix 150 ml of Loctite™ Rapid Rubber Repair compound loaded with 400 g of 3.7 mm diameter steel ball bearings. This composite was allowed to cure in a plastic mould. The "mine" shape was removed from the mould and affixed with 5-minute epoxy to the fibreglass sheet (see Figure 4). The "mine" shape is 10 cm in diameter and 2.5 cm in height.

In Figure 5 we show the echo time series received (a section of the larger recorded time series) as a function of the ping number. The mine region corresponds to approximately Ping 31 to Ping 47. This region is even more evident in Figure 6 where the absolute value of the Hilbert Transform of the time series is shown. In Figure 7 we show the spectrum of 4 representative pings, 2 corresponding to reflections away from the "mine" region and 2 in the mine region. The differences are quite noticeable. The mine region has a "notch" in its spectrum at about 40 kHz and the two sets of spectra appear to diverge at about 35 kHz.

Figure 4 The basic "mine" shape

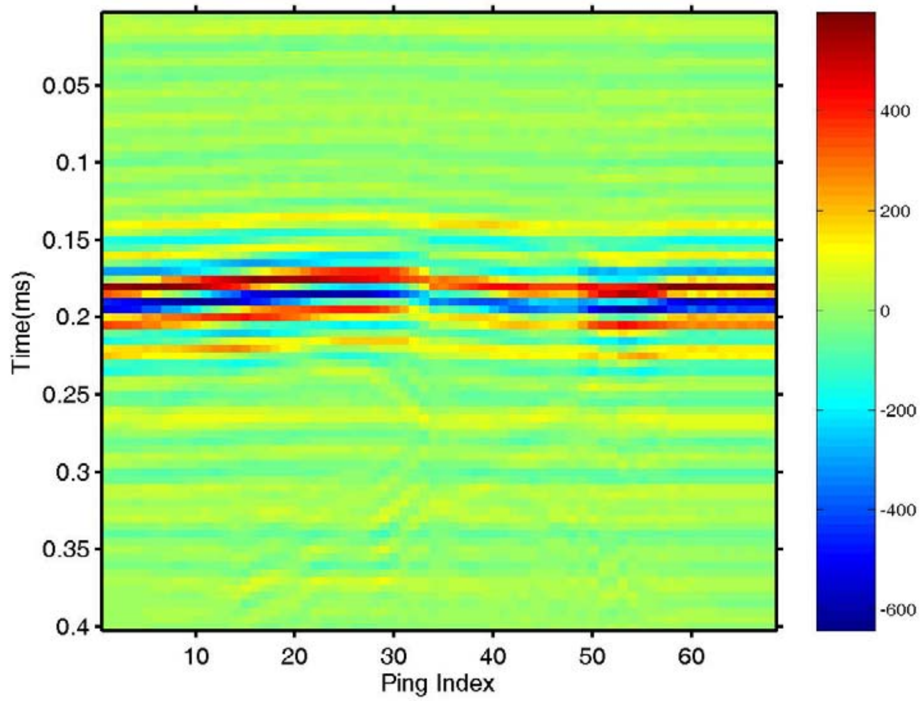

Figure 5 Reflection time series from scan over fibreglass and "mine"

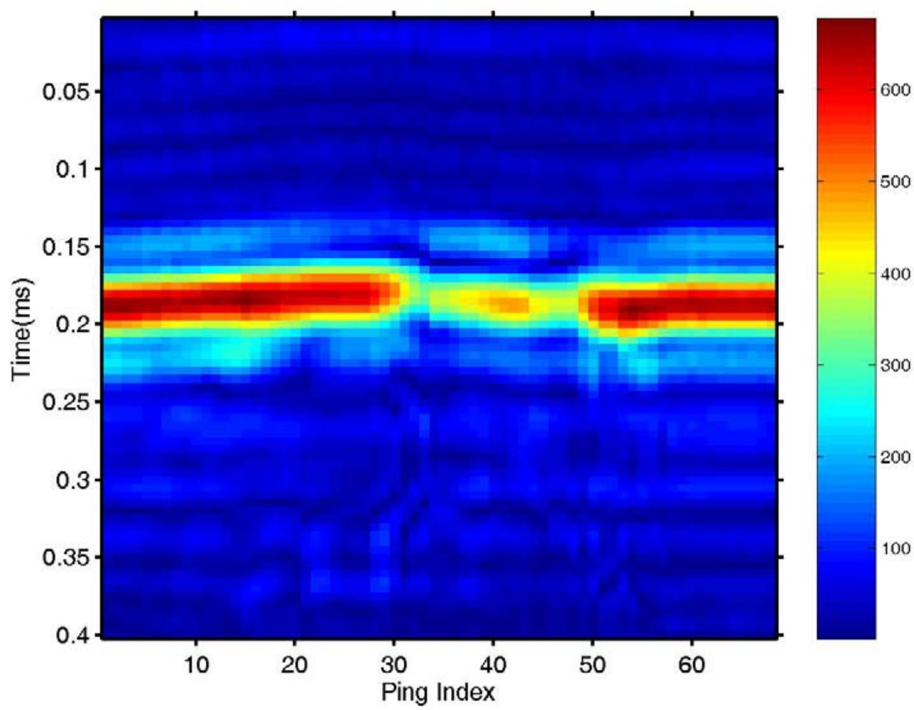

Figure 6 Amplitude of Hilbert Transform of reflected time series from scan of fibreglass and "mine"

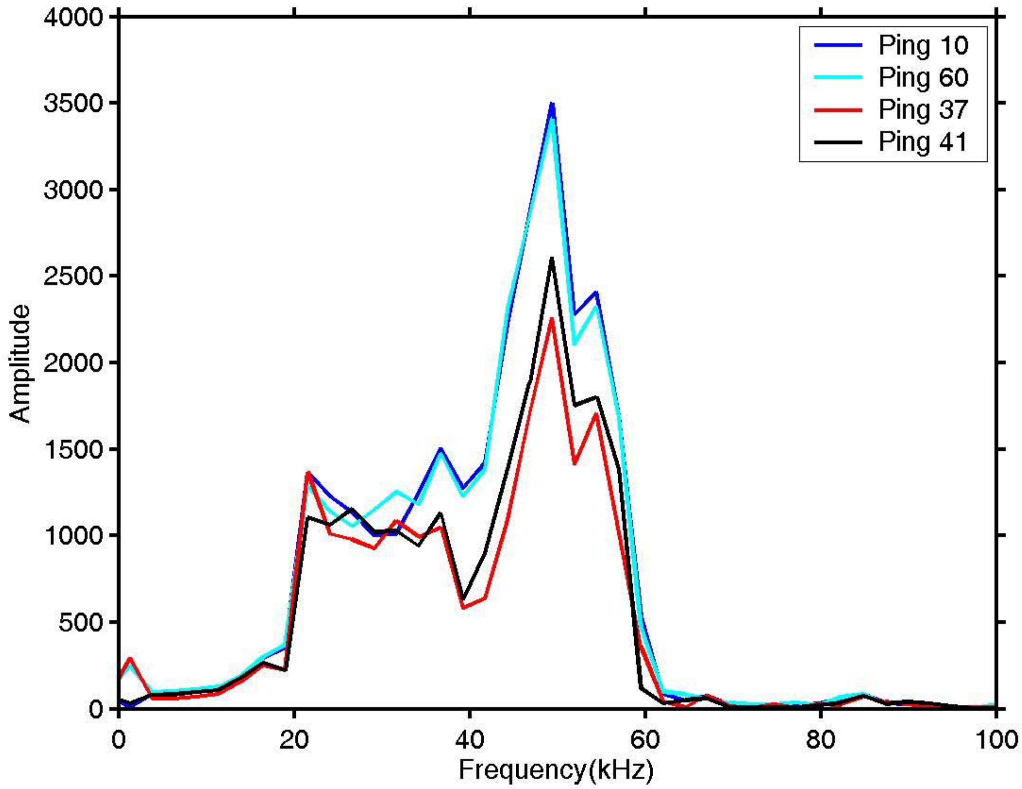

Figure 7 Representative spectra of pings over the fibreglass (blue, cyan) and pings over the "mine" region (red, black).

3.2 Basic mine shape with thin aluminum disc

A thin aluminum disc (1.2 mm thick and 77 mm in diameter) was then placed upon the top of the "mine" (see Figure 8). The scattered time series and spectra are summarized in Figures 9-10. The gain was changed during the recording so that the absolute levels have changed from the first scan. Once again, the "mine" region can be detected on the basis of the decrease of the amplitude. The spectra corresponding to pings over the "mine" region (Figure 10) are almost flat as a function of frequency.

Figure 8 Thin aluminum disc atop the "mine" shape.

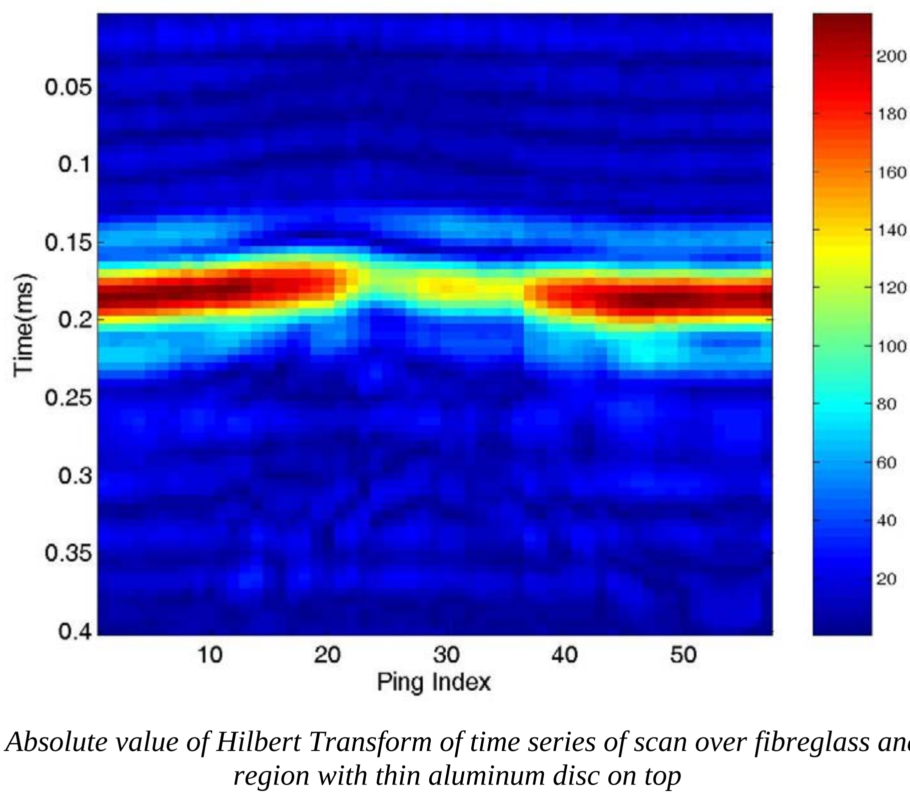

Figure 9 Absolute value of Hilbert Transform of time series of scan over fibreglass and "mine" region with thin aluminum disc on top

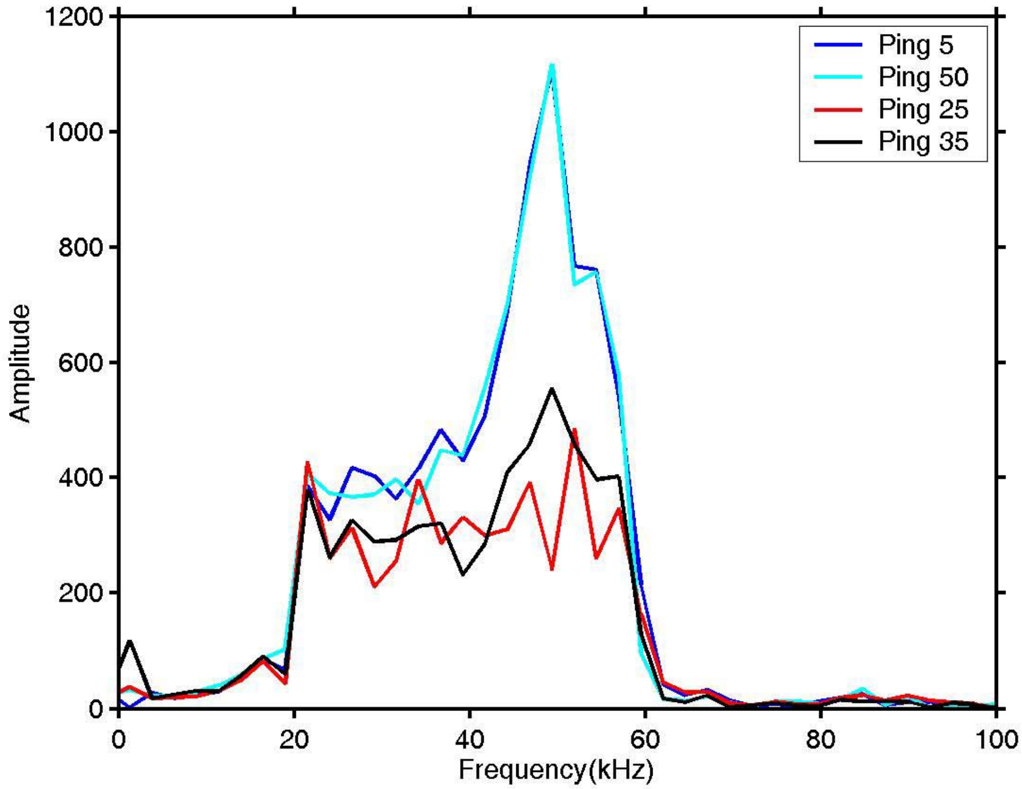

Figure 10 Representative spectra of pings over fibreglass (blue, cyan) and "mine" region (red, black) with thin aluminum disc on top

3.3 Basic mine shape with thin aluminum disc and small tungsten-carbide sphere on top

For the scan in this case, a small tungsten carbide sphere (40 mm in diameter) was placed on top of the thin disc and "mine"(see Figure 11). The absolute value of the Hilbert Transform and the representative spectra is shown in Figures 12 and 13. Notice the enhancement of the high-frequency backscatter relative to the no sphere case (Figure 10). Thus the spectra in Figure 13 are beginning to resemble those from the basic mine scan in figure 7.

Figure 11 40 mm tungsten carbide sphere atop "mine" and thin aluminum plate.

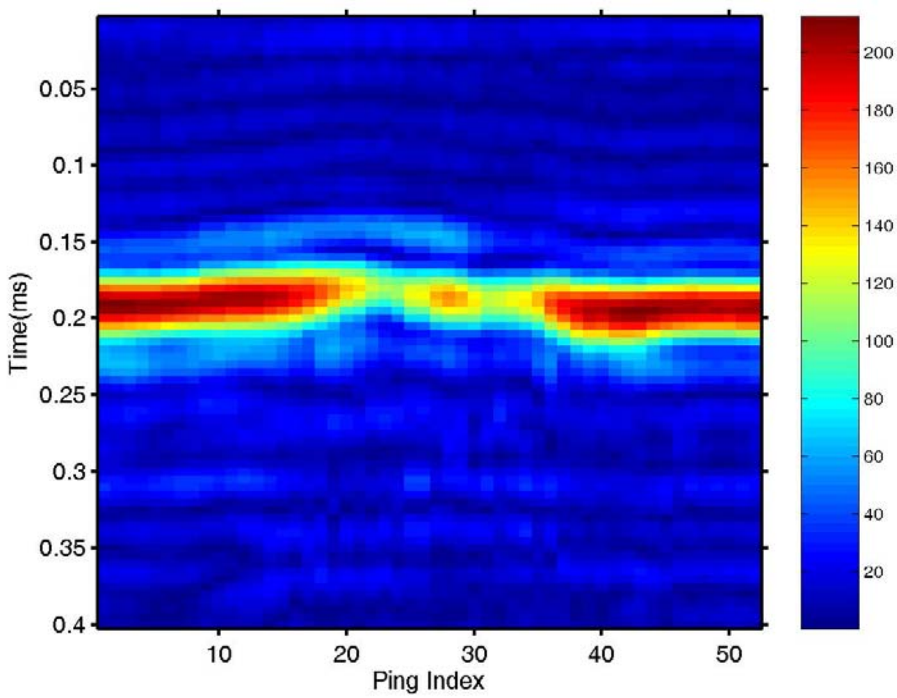

Figure 12 Absolute value of Hilbert Transform of time series from scan over fibreglass and "mine" region with thin disc and sphere on top.

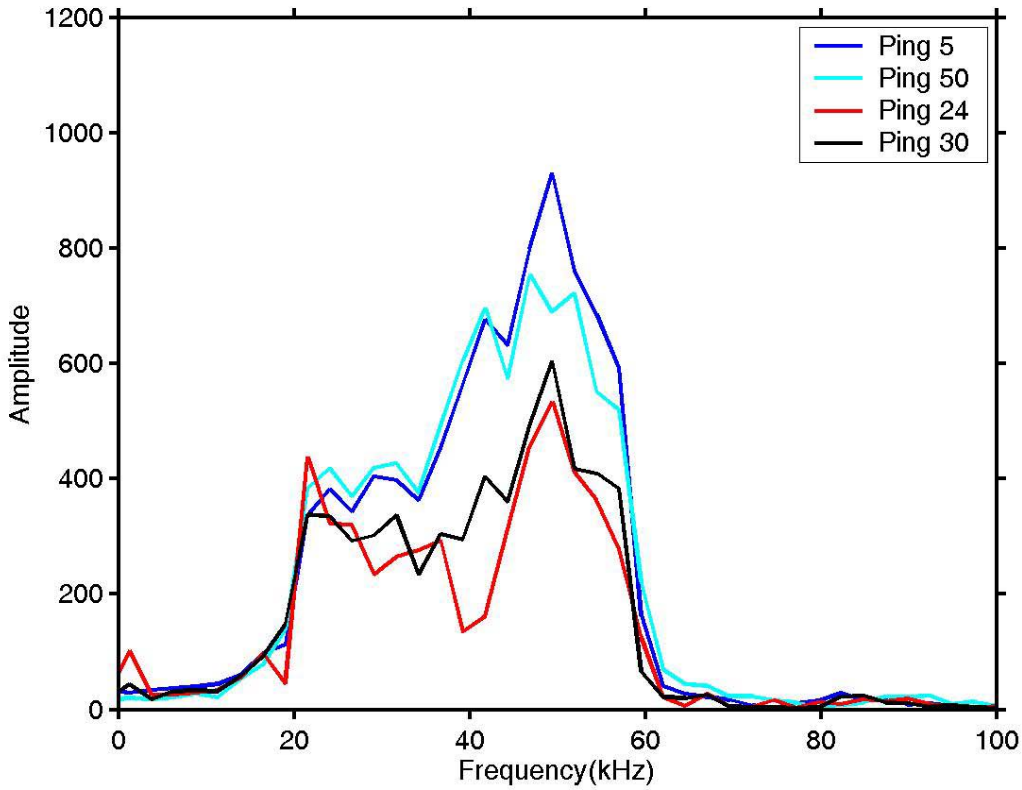

Figure 13 Some representative spectra from pings over the fibreglass (blue, cyan) and "mine" regions (red, black) for the thin disc and sphere on top.

3.4 Scan of basic mine shape with thick aluminum disc on top

In this case a thick aluminum disc (16.4 mm thick) with a larger diameter (153 mm) than the "mine" shape was placed on top (no sphere in this case) (see Figure 14). As can be seen in Figure 15, this feature causes significant scattering relative to the background levels. This is the only case where the scattering feature on the fibreglass gives a stronger echo than the background fibreglass echo. The spatial extent of the scattering also seems to be larger in this case, likely due to diffraction of energy from the edges/sides of the aluminum disc. It is also interesting to see that there is a region where the disc, to a large extent, shadows energy from reaching the "mine" and a region (near ping 25) where energy seems to get behind the plate (this may be due to a small tilt in the overall structure). This is also manifested in the spectra of Figure 16 where the 2 spectra for the "mine" region are quite different from one another

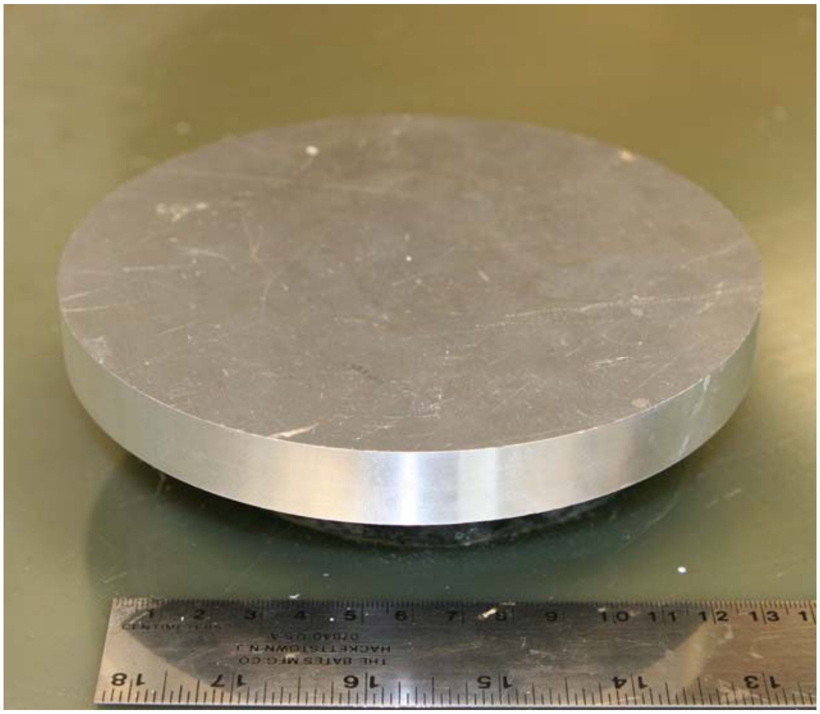

Figure 14 Thick aluminum disc atop "mine" and thin aluminum disc.

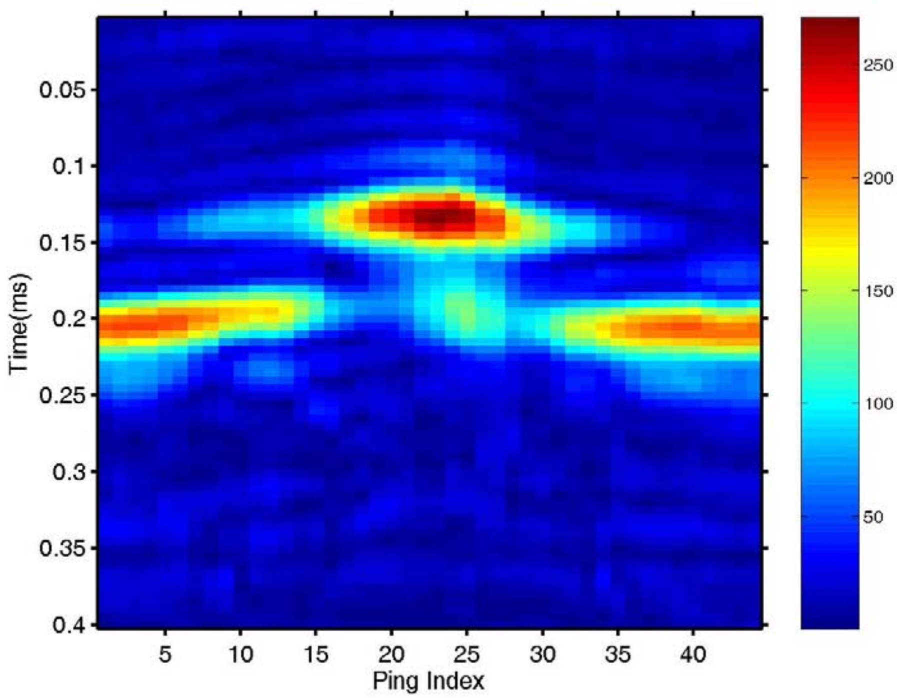

Figure 15 Absolute value of Hilbert Transform of time series for scan over fibreglass and "mine" region with thick aluminum disc on top.

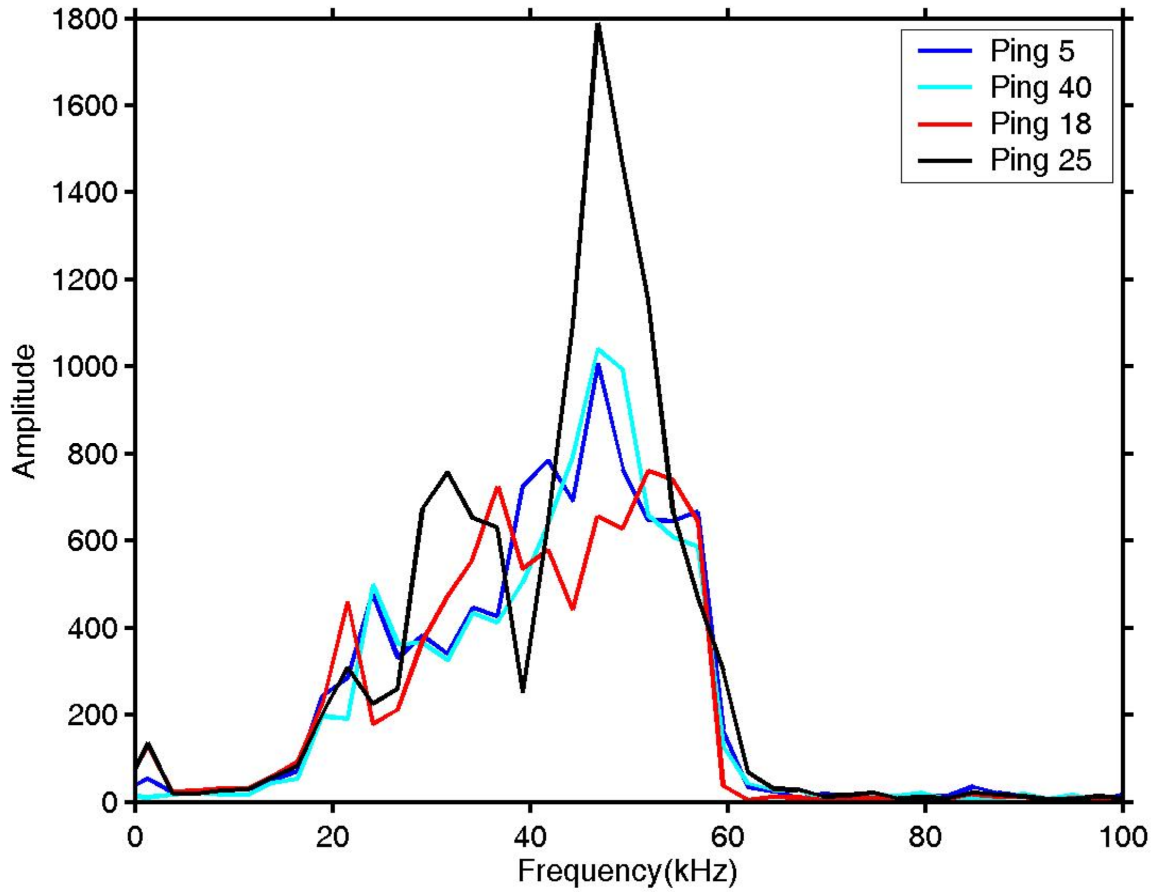

Figure 16 Representative spectra from scan over fibreglass (blue, cyan) and "mine" region (red, black) for thick aluminum disc on top.

4 Classification

We have shown that the spectra of the recorded echos are quite different for the 5 different classes: (1) fibreglass plate background (2) basic “mine” (3) basic “mine” with thin aluminum disc (4) basic “mine” with thin aluminum disc and sphere on top and (5) basic “mine” with thin and thick aluminum discs on top. In this classification study, for each of the scans we extract a number of pings corresponding to the background (a total of 70), 13 for the basic “mine”, 9 for the basic “mine” and small disc, 10 for the mine, disc, and sphere, and 12 for the mine and thick disc. A 80-point window containing the reflection is extracted and the 40 absolute values of the Fourier Spectra, corresponding to 0-100 kHz (although, in fact, our signals are only in the band 17-57 kHz) are used as features. The spectra for each scan are normalized by the mean maximum value of the spectra for just the fibreglass area. We randomly divide the spectra of each class into 2 for training and testing and use a nearest-neighbour classifier, where the distance between feature vectors is the Euclidean distance.

A Confusion Matrix is constructed for the testing set and this matrix is compiled over 601 random partitionings of training and testing. The (j, k) element of the Confusion Matrix represents the percentage of times Class j is classed as Class k. The resulting Confusion Matrix is shown in Fig.17. As can be seen, the classes are well identified with only a little “confusion” between the classes. There is some misidentification of the mine with the thick aluminum disc as the background echo. This is likely due to the pings towards the edge of the “mine” region. It is important to recall that the features considered here are simply the absolute values of backscattered spectra. The difference in the arrival time of the echo is not considered.

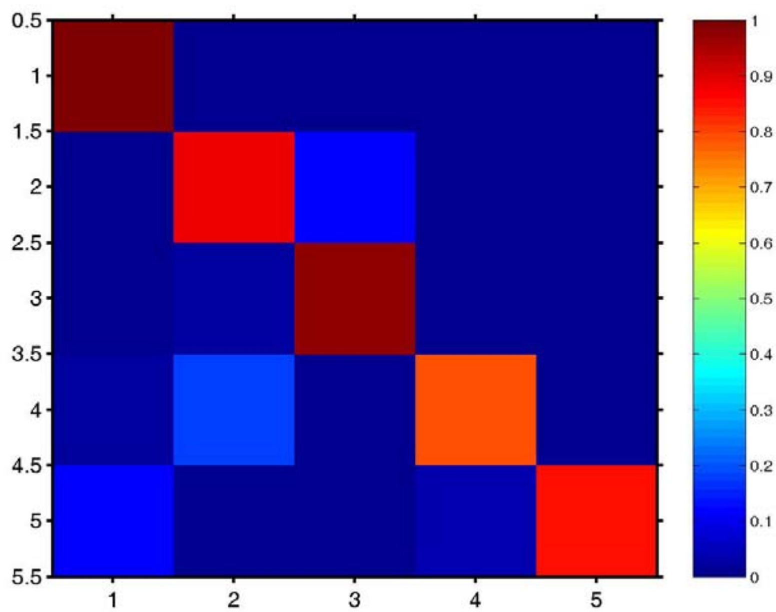

Figure 17 Confusion Matrix resulting from the nearest neighbour classification of the 5 echo classes: (1) fibreglass plate background (2) basic “mine” (3) basic “mine” with thin aluminum disc (4) basic “mine” with thin aluminum disc and sphere on top and (5) basic “mine” with thin and thick aluminum discs on top.

5 Conclusions

We have performed a simple simulation of a mine-shape placed upon a background reflector, in this case a sheet of fibreglass. This structure was then scanned with a broadband acoustic projector ([17 57] kHz). The details of the spectrum of the recorded echo were sufficient to accurately classify the different types of mine regions and the background echos, on the basis of single pings, in a high percentage of cases. This appears to be a promising approach in the acoustic identification of spectrally anomalous regions with respect to background echos.

The configuration of this experiment was short range. In future, it would be interesting to consider larger offsets of the projector from the scattering surface. The setup used here was quite simplistic: a single small high frequency MMPP projector and a single hydrophone. It would be interesting to consider extending the bandwidth of the system considered and the use of a linear or planar array of receivers for beamforming the received signals.

References

[1] J. Fawcett, J. Sildam, T. Miller, R. Fleming and M. Trevorrow, Broadband Synthesis with the High Frequency Multi-Mode Pipe Projector, DRDC Atlantic Technical Memorandum, TM 2005-022, (2005).

[2] R. Fleming and J. Fawcett, Wideband detection and classification of mines in a simulated ship hull scenario, DRDC Atlantic Technical Memorandum, TM 2007-293, (2007).

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List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
R&D	Research & Development
MMPP	Multi-mode pipe projector
HF MMPP	High frequency multi-mode pipe projector
ACB	Acoustic calibration barge
kHz	kilohertz
RHIB	Rigid hull inflatable boat

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MMPP mine detection broadband

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