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MEMORANDUM

MULTIPLE VIEW SIDESCAN SONAR

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Multiple view sidescan sonar

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R. Weatherburn
Division Chief

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Multiple view sidescan sonar

B. Stage and B. Zerr

Executive Summary: This memorandum addresses the problem of the detection and classification performance of objects on the sea bed by using a multiple-look sidescan sonar. In particular, it identifies a two-look system as possibly being a good compromise between outright performance and cost/size. The memorandum then demonstrates that the addition of automatic shape classification algorithms could significantly reduce the possibility of misclassifying an actual target as a non-target from 8.7% for a single look to 0.9% for a two-look system, but at the expense of a slight increase in the false contact rate (non-targets classified as targets). Although the two-look sidescan sonar investigated in this memorandum may prove to be beneficial in the traditional route survey role along the routes, its real potential may lie in improving the capability of unmanned underwater vehicles (UUV) to undertake covert area and route surveillance in support of out of area operations.

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Multiple view sidescan sonar

B. Stage and B. Zerr

Abstract: The classification of objects on the seafloor by means of a sonar can be accomplished by viewing the object from different positions. With a conventional sidescan sonar one pass has to be made for every view. The time needed for classification can be reduced by using a sidescan sonar with multiple beams pointing in different directions. This allows multiple views of the object to be acquired in a single pass. The feasibility of the multiple-view concept has been investigated using an experimental sonar with two beams. Results of initial experiments are presented.

Keywords: multiple view - sidescan sonar

Contents

1

Introduction

A technique used to classify objects on the sea floor using hull-mounted or variable depth classification sonars is to examine the object from different positions of the sonar to obtain multiple views. Another technique based on high-resolution sidescan sonar is more efficient in terms of sea floor coverage rate. This characteristic makes the sidescan sonar a well suited tool for route surveillance on known areas and knowledge acquisition on unknown areas. With a sidescan sonar, though, only one view of the seafloor is obtained in each pass. To obtain the same classification performance with a conventional sidescan sonar as with a hull-mounted or variable depth sonar the resolution of the sidescan sonar must be higher or multiple passes over each part of the sea bottom must be made. Here, a solution consisting of a sidescan sonar with multiple beams pointing in different directions to obtain multiple views in a single pass is investigated. The multiple view sidescan concept is illustrated in Fig. 1. A sonar with a number of beams, ranging from two beams to a full sector, is positioned in a side-looking configuration. Each beam produces a sidescan image as the sonar is advanced.

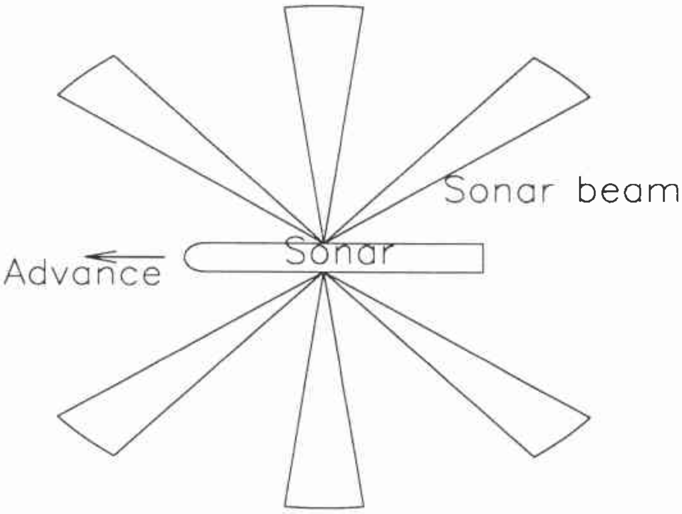

Figure 1 *Concept of multiple view sidescan sonar.*

In the design of a multiple-view sidescan sonar system, the number of beams and the pointing direction of these beams has to be decided upon. It is therefore of interest to know the utility of additional beams in terms of classification performance. In the following, two different methods are used to assess the improvement in classification performance of a multiple-view sidescan sonar. The first method assesses the utility of multiple views by considering the image quality required by a human operator to perform a visual task. The second method investigates by simulation the increase in classification performance when using automatic processing. The automatic processing consists in computer aided detection (CAD) where objects of minelike size are extracted from raw sonar data by analyzing shadow and highlight information, followed by computer aided classification (CAC) where geometrical features on detected objects are used to propose a possible classification to the operator.

2
Image quality

In this section the utility of a multiple-view sidescan sonar system is investigated by considering the image quality required by an operator to perform a visual task.

To classify an object on the sea bottom by means of a sonar system at least two conditions must be fulfilled:

1) Discriminating features of the object shape must be visible from theposition of the sonar.

2) The discriminating features must appear in the sonar image with sufficient clarity.

The visible features of an asymmetric object changes with the viewing position. Therefore, the number of features and the value of these features for discrimination purposes will change with viewing position. Part of an accurate assessment of the utility of a multiple-view system will require geometrical considerations on the visibility of features of the objects concerned. When discriminating between man-made objects with known shape and naturally occurring objects with unknown shape such geometrical considerations require assumptions on the shape of naturally occurring objects.

The problem is simplified by assuming that all objects of interest, both natural and man-made, have discriminating features in any view. When this assumption is correct, a classification can be made provided the object features appear in the sonar image with sufficient clarity. In experiments with electro-optical imaging systems Johnson [1] established an empirical relationship between image quality and the ability of an observer to perform a discrimination task on an image of a complex object. For a range of objects such as tanks, trucks and men the discrimination performance was explained by considering the number of resolved half-periods on a striped test object along the critical dimension, i.e. the smallest linear dimension of the object. The results for four discrimination levels defined by Johnson are shown in Table 1. The mean value and standard deviation are based on the result for the range of objects considered. The standard deviation is approximately 25% of the mean values. This is an indication of the accuracy in prediction that can be achieved without considering the features of the objects in detail. The results apply to the performance of a human observer but can be considered the limiting performance of an automatic classifier.

Table 1 *The Johnson criteria.*

Task	Resolution Cells
Detection	2.0 ± 0.5
Orientation	2.8 ± 0.7
Recognition	8.0 ± 1.6
Identification	12.8 ± 3.0

In a sidescan sonar image the resolution in range and azimuth are usually different. In this case the critical dimension can be interpreted as the dimension in the image of the object with the smallest number of resolution cells. The range resolution is determined by the bandwidth and the azimuth resolution by the aperture. As a large bandwidth is less expensive to achieve than a large aperture the range resolution is often better than the azimuth resolution.

As an example consider a cylindrical object with diameter 0.5 m and length 1.5 m viewed with a sonar system with an azimuth resolution of 0.1 m. The range resolution is assumed so much greater that the smallest number of resolution cells in the image of the cylinder will always be in azimuth. In Fig. 2 the smallest number of resolution cells in the image of the cylinder is plotted against viewing angle. Assume a minimum of 12 resolution cells is required to accomplish a certain discrimination task in an image with a given contrast, at a prescribed level of confidence. With this threshold the result in Fig. 2 indicates the system would have an unsatisfactory performance against the cylinder in 34% of all orientations of the cylinder.

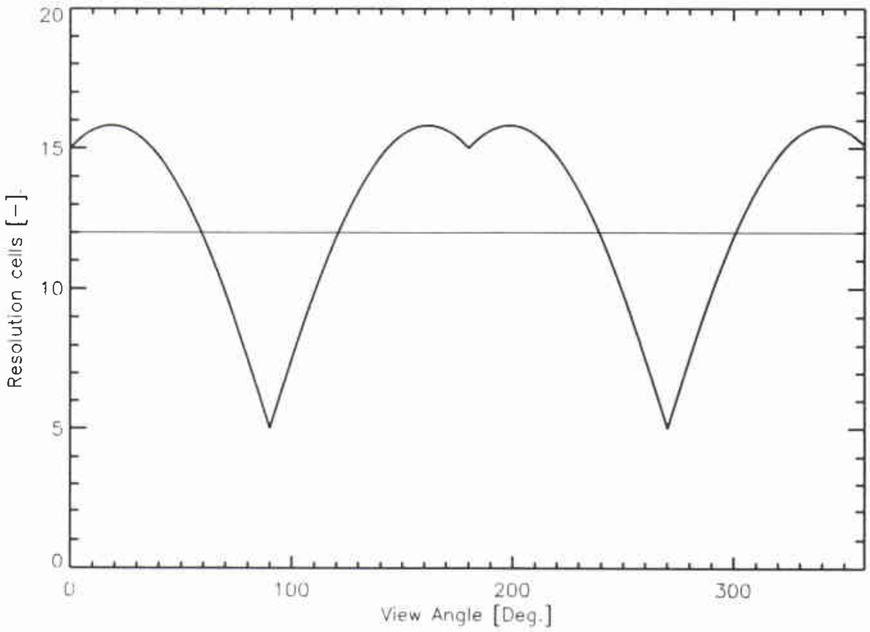

Figure 2 *Resolution cells on cylinder with one beam.*

A second beam placed at an angle to the first could be used to acquire a second view. A criterion to select the angular separation between the two beams is to maximize the minimum number of resolution cells in the critical dimension in any of the two images. This criterion leads to an optimum separation of 90°. A conservative estimate of the utility of a second view can be obtained by assuming the discrimination task will be performed using only the image with the largest critical dimension. The result of taking the maximum number of resolution cells in any of two views of the cylinder with an angular separation of 90° is shown in Fig. 3. In this case the system will have satisfactory performance against the cylinder for all orientations. The average performance of a system with two beams spaced at an angle of 90° thus seems roughly equivalent to the minimum performance of a system with an azimuth resolution that is better by a factor corresponding to the dimension ratio of the target.

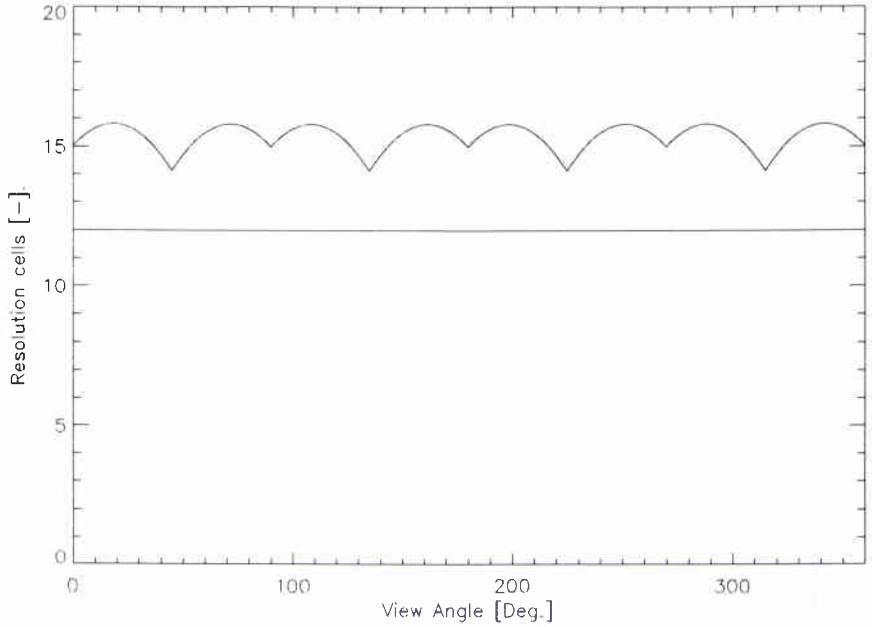

Figure 3 *Resolution cells on cylinder with two beams.*

When placing additional beams, the reduction in broadside coverage as a beam is directed away from broadside has to be taken into account. Here, an angular position with a maximum of ±45° relative to broadside is assumed. As the target orientation is unknown further beams should be placed uniformly within this 90° sector. These additional views will not contribute to any considerable increase in the number of resolution cells in the critical dimension and so the Johnson criteria are not useful for assessing the utility of these. The utility will consist in a mixture of an increased number of visibile features and the equivalent of an increase in image contrast. The increased image contrast could be obtained by averaging images from closely spaced beams where the scene looks nearly the same but the speckle noise in the images is different.

The cost of a system with multiple closely spaced beams arranged in a sector is related to the number of beams. With a fixed number of beams it could be considered whether these beams should be high-resolution beams in a narrow sector or lower-resolution beams in a wide sector. In Fig. 4 the maximum number of resolution cells in one image of the cylinder is shown for 15 different sector sizes and resolutions. The curve marked I corresponds to a 90° sector with a resolution of 0.3 m. The other curves correspond to a decreasing sector size and increased resolution in uniform steps ending with the curve marked II which corresponds to a 20° sector with a resolution of 0.067 m. The performance of the widest sector will be nearly independent of the orientation of the cylinder but a narrower sector will always assure a larger number of resolution cells in any view. As the narrow high-resolution sector has better performance against objects with dimension ratios close to 1, the wider sector is most interesting in applications where the physical size of the aperture is the design limitation.

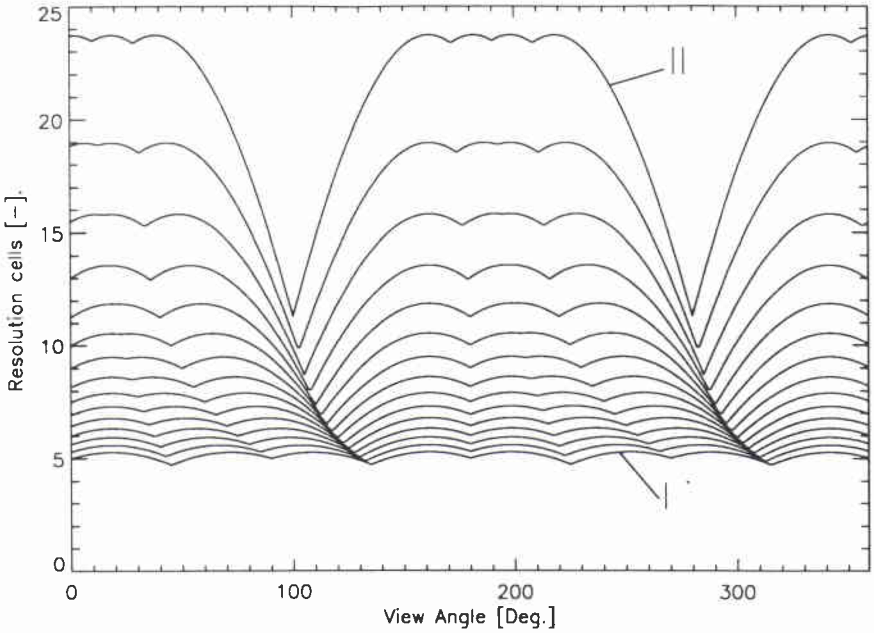

Figure 4 *Resolution cells on cylinder with full sector.*

In order to gain some experience with a multiple-view sidescan sonar an experimental system with two beams has been designed. The system is based on a modified commercial sidescan sonar. One beam is broadside and one beam is pointing 45° forward. The scene in Fig. 5 contains two cylindrical objects with a diameter 0.5 m and length 1.5 m. In addition a bush of *Posidinia oceanica is* seen in the top of the image. The qualitative utility of a two-view system on man-made and natural objects is evident in this image.

Although the nature of the discussion in this section is *quasi*-quantitative it is a way to gain insight in the design of a multiple-view system. The multiple-view sidescan sonar concept seems an attractive solution to increase the classification performance of sidescan sonars. A system with only two beams is an interesting low-cost solution. A system with multiple closely spaced beams arranged in a sidelooking sector is the most effective and will be the choice where size of the aperture rather than cost is the limiting factor.

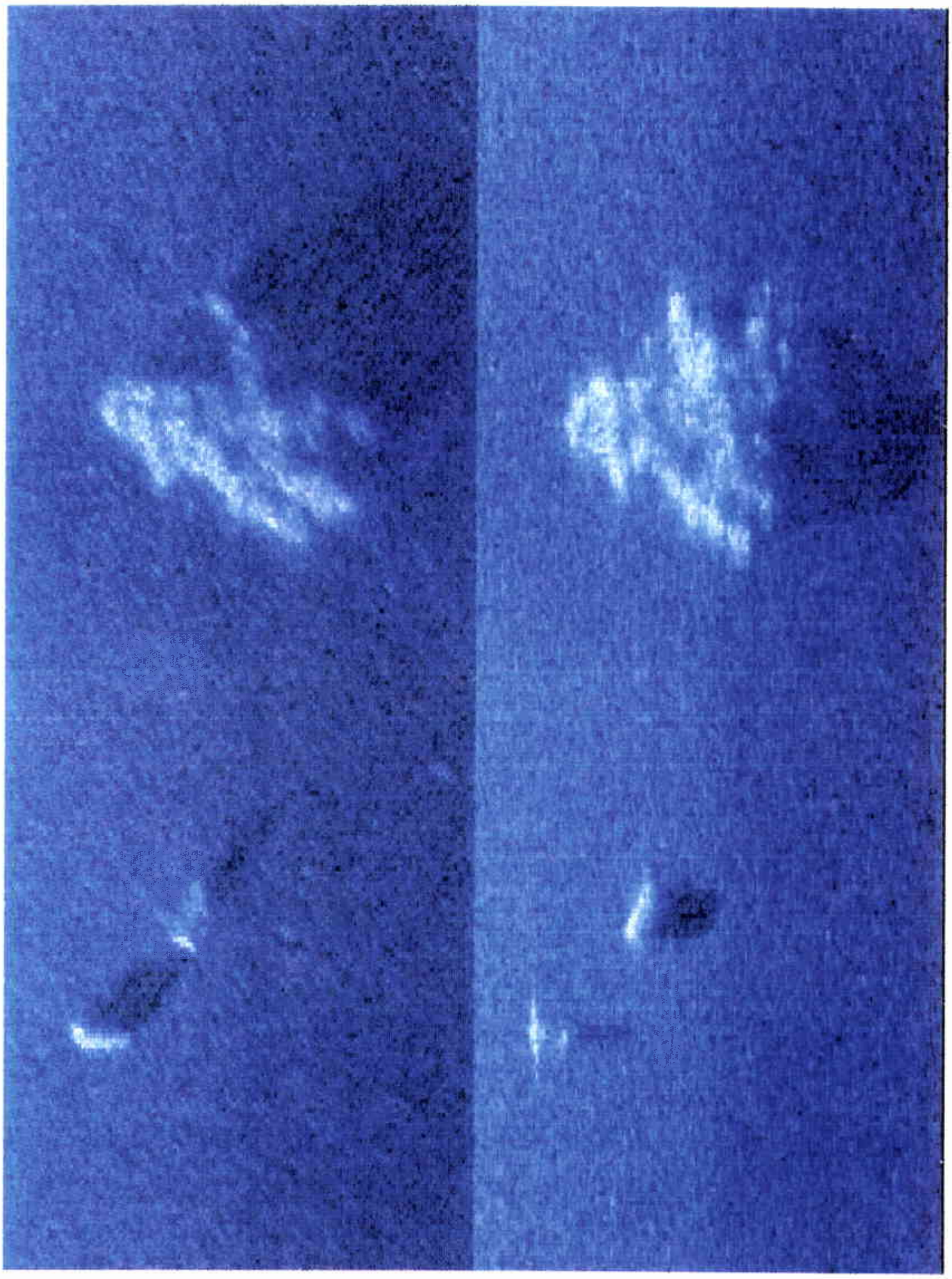

Figure 5 *Two-view image of sea bottom.*

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Automatic processing

The performance of a sonar is not only a function of the basic system parameters, as discussed above, but also the post-detection processing. One technique that can be used, when attempting to recognize objects on the seabed, is some form of automatic shape detection. This section therefore considers the effect on automatic classification performance when using multiple views.

A processing line, chaining computer aided detection (CAD) and computer aided classification (CAC) has been designed to operate on multiple-view sonar data. CAD is achieved by a classical sequence of algorithms [2] performing the following tasks: lowpass-filter-based speckle removal, gray-level normalization, rough-threshold-based segmentation, selection of objects of interest by estimation of shadow dimensions and echo location and, finally, accurate segmentation using either neural networks or Markov random field techniques. Since the increase in performance is expected on classification, three CAC systems are compared to estimate the benefit provided by the multiple-view concept. The first system is a conventional one and uses a single view of the object to classify it. The second system separately classifies each view and determines the final classification by consensus. The third system is based on a joined classification where all the features extracted from different views are merged before being sent to a unique classifier. Results issued by the conventional classification system will be used as a reference when determining the performance gain provided by multiple-view sidescan sonar.

Though highlight information plays an important role in deciding whether an object is natural or artificial, the impact of multiple view on the CAC performance is determined by using solely geometrical features of shadows. The lack of an accurate and complete highlight model, combining various echo sources (specular reflection, diffraction on sharp edges, multiple acoustic paths, etc.), prevents their utilization in the CAC learning phase. So, the CAC makes its classification using the object height profile (OHP).

OHP is a feature that summarizes the geometrical aspect of the object to be classified. OHP, computed on the along-range shadow boundaries, is defined by the following set:

$$OHP = \{OHP_i, i = 1, N\},$$

$$OHP_i = (y_i, h_i), y_i = ya_i - y_c, h_i = \frac{S_i * A_i}{r_i}$$

where N is the number of sonar beams for which the object casts a shadow, and A_i, r_i S_i and ya_i are respectively the sonar altitude, the range distance to the shadow end, the along-range shadow length and the along-track coordinates estimated for the i th beam. Along-track centered coordinates (y_i) result from the translation of absolute along-track coordinates (ya_i) to relative coordinates referenced to the along-track mean coordinate of the object shadow (y_c).

Automatic target classification is based, in most cases, on *a priori* knowledge and is therefore well suited to a supervised approach. The CAC algorithm considered in this memorandum is based on a classical neural network architecture: a multilayer perception trained by back-propagation of the output error. These networks require training on known shapes to perform classification. The input layer of the network receives the OHP while each cell of the output layer is dedicated to a different target classification. In a rough approach, a two-cell output layer is sufficient to separate mine-like and non-mine objects. More output cells allow different target shapes to be separated, such as cylinders, spheres, truncated cones, etc.

Accurate learning requires, for each object, several views taken under different and perfectly controlled viewing conditions. This therefore makes training based on actual data very difficult. Alternatively, one can train the neural network on theoretical OHPs. The advantages of this solution are twofold: first, the good behaviour of neural network on noise corrupted data provides good results on real objects even if the training is based only on simulated ones; second, targets that have not yet been seen by the sonar system can be introduced in the classifier by simulation.

A careful use of optical ray tracing gives the theoretical boundaries of objects shadows. The shadows are then processed to estimate theoretical OHPs. Before learning, these theoretical profiles are degraded to fit the actual resolution of the sonar system. In this study, 0.20 m interbeam spacing, 0.30 m beamwidth and 0.05 m along-range pixel size have been used. The OHP is first convolved with the beam pattern to obtain the along-track resolution. Then, the sonar height resolution is reached by sticking to a discrete height scale computed from the range resolution. Finally, the automatic detection process precision may be introduced by adding zero mean Gaussian noise, with standard deviation corresponding to the shadow boundary detection accuracy.

In this simulation, the multiple views are restricted to two directions of looking (-45° and +45° to the conventional side-scan direction of looking). For the first and second CAC systems, the classification is established via a direct analysis of the neural network output cells. For the third system, an additional consensus algorithm has been defined to merge the results issued by the two networks.

3000 3D objects, divided into four categories (cylinder, sphere, truncated cone and stone), have been simulated: 1000 objects have been used for training purposes and 2000 for testing. A geometrical computation gives the theoretical two-look profiles depending on the look direction and the sonar location. Then, to fit the sonar resolution figures, the actual object profiles results from convolving the theoretical profiles with the along-track beam pattern. The actual along-range resolution is simply obtained by sampling.

The performances of the three CAC systems are summarized in Table 2. As expected, the single-look gives a lower level of good classification and a higher level of missing targets than the two-look. High figures in good classification are mainly due to the fact that the three targets used for training possess very different geometrical features.

The levels of correct classification achieved by CAC2 and CAC3 are so similar that no conclusion can be drawn on determining the best automatic classification algorithm. However, additional tests, with an higher number of target shapes, will be carried out to compare more accurately the CAC2 and CAC3 performances.

Table 2 *CAC results on simulated data.*

CAC Algorithm	CAC 1 Single-look	CAC 2 Separate two-look	CAC 3 Joined two-look
Correct classification (targets and non targets correctly classified)	84.8%	88.3%	89.8%
False alarms (non-targets classified as targets)	5.1%	5.5%	9.3%
Target misclassification (targets classified as non-targets)	8.7%	4.9%	0.9%
Target shape misclassification (targets classified as targets but with a wrong shape)	1.4%	1.3%	0%

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Conclusions

The multiple view-sidescan sonar concept seems an attractive solution to increase the classification performance of sidescan sonars. A system with only two beams is an interesting low-cost solution. A system with multiple closely spaced beams arranged in a sidelooking sector is the most effective and will be the choice where size of the aperture rather than cost is the limiting factor. As expected, the two-look sidescan sonar increases automatic classification performances but more accurate figures will be obtain by both learning more targets and applying CAC algorithms on experimental data.

References

[1] Johnson, J. Analysis of image forming systems. *In*: Proceedings, Image Intensifier Symposium, Fort Belvoir, VA, US Army Engineering R&D Laboratory, October 6-7, 1958: pp. 249-273. [AD 220 160]

[2] Zerr, B., Kernin, J.-P. and Moisan, F. Towards operational mine warfare data processing: how to combine fast processing and accurate results. *In*: UDT 1993. Tunbridge Wells, Kent, 1993: pp. 412-417. [ISBN 0-946821-18-6]

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