A SIMULATION STUDY OF 3D IMAGE GENERATION USING FAN-BEAM SONARS

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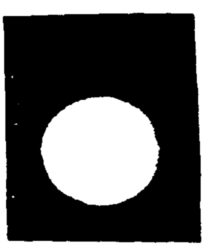
INTRODUCTION

Sector-scanning sonars are finding increasing use in a number of undersea scenarios. These sonars perform rapid scanning of a given sector by a vertical fan-beam having narrow horizontal beamwidth.[1] The range resolution of these sonars is on the order of a few centimetres, with maximum ranges of a few hundred metres depending on the frequency of operation (100 kHz - 2 MHz).[2] This paper presents results on 3D reconstruction of objects from their acoustic images. The acoustic images used in this paper are obtained by simulation using a high-resolution imaging sonar model. We also present some results on object classification.

THE FAN-BEAM SONAR MODEL

A HIgh-Resolution Imaging Sonar Model (HIRISM) has been recently developed[3] that generates "realistic" acoustic images of 3D objects against a backscattering sea-floor. The model's parameters are interactively selected by the user. Fig. 1 shows simulated visual images of a suspended sphere and a cylinder. Fig. 2 shows the simulated composite B-scan acoustic image of the sphere that clearly shows the formation of the acoustic shadow on the sea-bottom.



(a)

(b)

Fig. 1. Visual images. (a) Sphere, (b) Cylinder.

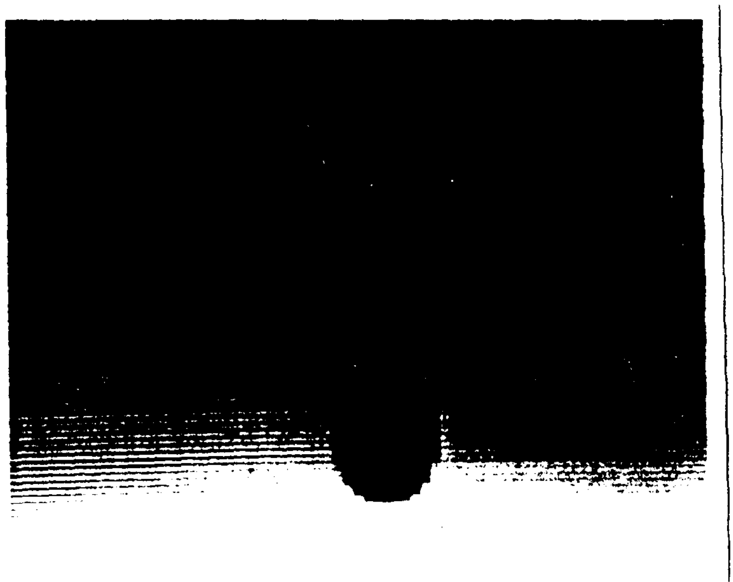


Fig.2. B-scan image of sphere suspended above the sea-bottom.

EXTRACTION OF 3-D INFORMATION

This section discusses some approaches that provide valuable information about the 3D structure of an object.

Silhouettes

Sonar operators develop object-identification skills based on "shadows". We have developed a display format that provides a "true" silhouette of the shadow-forming object as viewed from the sonar location. The silhouette is generated by a deterministic non-linear transformation of the range axis in the conventional B-scan image. The transformation is given below:

$$MR = H / GR \qquad (1)$$

where,
MR is the modified range axis,
H is the sonar height, and
GR is the ground range.

Application of this transformation results in a new shadow whose outline matches with the perspective outline of the object. An example of such a transformation on the sphere's image is shown in Fig. 3. The potential of such a display technique both for operator-based and machine-based object recognition is obvious.

3-d wire-frame images

The 2D B-scan images can also provide us information on the confining volume of the visible portion of the object. This information is not explicit but has to be derived from both the echo and shadow extents of the object. The steps that need to be taken include segmentation of the acoustic image into three regions, namely; object echo, object shadow, and the bottom. The geometrical relationships between the echo and shadow regions are then applied for obtaining both vertical and depth information about the object.

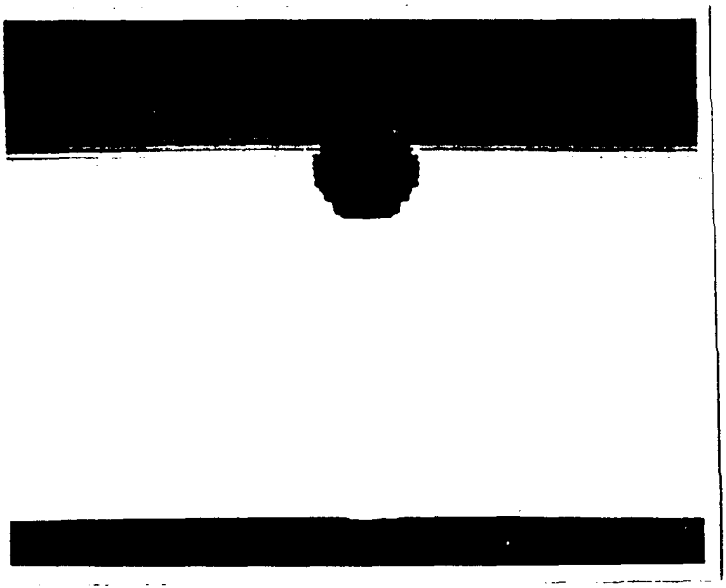


Fig. 3. Transformed image of Fig. 2. showing silhouette of sphere.

<u>Segmentation</u>: We perform adaptive dual-thresholding of the B-scan image on a range-cell basis to label the three regions. Those pixels that exceed the upper threshold are labelled as echo/object points, while those that lie between this and the lower threshold are labelled as bottom points. All other points, ie., those that lie below the lower threshold are labelled as shadow points.

<u>Confining volume:</u> The shadow extent in a particular bearing is translated into vertical angular extent for objects with distinct echo and shadow regions as per equations:

$$\phi u = \mathrm{Sin}^{-1}(H/Rmax) \qquad (2)$$

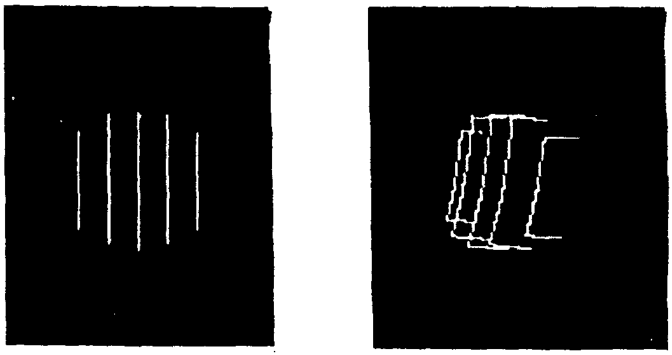
$$\phi l = \mathrm{Sin}^{-1}(H/Rmin) \qquad (3)$$

where,

H is the sonar height,
Rmax is the far-range of the shadow, and
Rmin is the near-range of the shadow.

These angles are referenced below the horizon. The visible surface of the object can be assumed to be confined within the range and vertical extents as derived above. This confining volume may be regarded as a stack (in bearing) of vertical circular sectors lying within the minimum and maximum range radii of the echo.

The 3D information derived above is presented on a display in a form suited to human interpretation, namely, a perspective wire-frame image. This presentation is a fundamental break from the earlier presentations of acoustic images from sector-scanning sonars. We have developed a technique that can artificially view the wire-frame of the confining volume by means of a hypothetical camera from various vantage locations to heighten the depth perspective. Examples of such images are shown in Fig. 4.



(a) (b)

Fig. 4. Wire-frame images of a sphere's confining volume.
(a) Front view, (b) rotated view.

Shape from echo intensity

The confining volume as derived above represents the volumetric limits of the object, and not its shape. In the case of sonar where we have speckled images, we propose spatial superposition of acoustic images from multi-frequency transmissions to reduce speckle and increase reliability of echo-intensity based shape derivation.

Let us consider a facet of length W, vertical projection H, and horizontal projection ΔR (range resolution of the sonar), presenting an angle of incidence θ with respect to a horizontal sonar beam. The reflected signal amplitude is given as:

$$Vr \propto 2.W. \frac{\mathrm{Sin}(\pi/\lambda.2W.\mathrm{Sin}\theta)}{\pi/\lambda.2.W.\mathrm{Sin}\theta} \qquad (4)$$

When this facet is repeatedly excited with slightly different frequencies, the facet's response varies as Sin (x)/x. In the region of small values of the parameter (π/λ.2W Sin θ), the average reflected amplitude or echo is proportional to W/ΔR. Under the condition that $\Delta R<H$, ie., the range cell is much smaller than the vertical extent of the facet, the echo level is proportional to H/ΔR.

The echo intensity in a given bearing is summed over all range cells. This represents the confining vertical angular limits of the object in that bearing. We then distribute the angular extent in range in proportion to the individual echo intensities, thus obtaining a profile in range. This range profile represents the shape of the visible portion of the object in the given bearing slice. Application of this technique can be made in a straight-forward manner for certain poses of objects, eg., when the objects present a symmetrical cross-section to the sonar beams. Examples of wire-frame images for such cases are shown in Figure 5.

OBJECT CLASSIFICATION

The segmented image provides information of the range extent of the echo and its shadow. Some parameters that can be derived from this information are; (i) thickness of the object in each bearing, (ii) near-end outline, and (iii) far-end outline.

(a) (b)

Fig. 5. Wire-frame images of echo-derived shapes. (a) Sphere, (b) cylinder.

These parameters are used to distinguish between spheres and cylinders. We have carried out a number of (simulated) experiments on object identification based on thickness and far-end outline, for a variety of scenarios, such as, (i) sphere at different heights above the bottom, including partial submergence, and (ii) cylinder at various orientations with respect to the sonar. Results (a sample given in Table 1) have been obtained that indicate that it is possible to identify the objects in these cases with a high degree of confidence.

CONCLUSION

This paper has attempted to present generation of 3D images from 2D sonar images. The acoustically-derived 3D information from a 2D sonar has been used both for 3D wire-frame modeling as well as for object classification. Preliminary results show the feasibility of such an approach for view-independent automatic object classification.

Table 1. 2-stage automatic object classification results*

No.	Object scene	Initial guess	Final estimate
1.	Sphere: 25 cm radius, centre at 100 cm above bottom	Not sphere	Sphere
2.	as above, but centre at 10 cm above sea bottom	Not sphere	Sphere
3.	Cylinder: 25 cm radius, 100 cm length, 60^{o} orientation	Cylinder	Cylinder
4.	as above, but 30^{o} orientation	Cylinder	Cylinder

*Sonar parameters used: Beamwidth = 1^{o}, range cell = 15 cm, wavelength = 6 cm, distance of object = 400 cm.

Acknowledgement

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