

DETECTION OF THE INSONIFICATION AREA OF A MULTIBEAM ECHO-SOUNDER USING A FRONT PROPAGATION

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Abstract

For the execution of its bathymetric surveys, the French Hydrographic and Oceanographic Service of the Navy (**SHOM**) has been operating three MultiBeam Echo-Sounders (MBES) for three years. These systems carry out simultaneous depth measurements along the transversal axis of the ship, decreasing the time for collecting the data.

Planning, managing as well as running a bathymetric campaign rely on a synthetic representation of the area observed by the Echo-Sounder. Representations previously used were only based on an approximation of the covered area obtained by making the assumption that the insonification area of each beam is fixed.

This paper proposes an alternative method for building an insonification area based on a standard operation of mathematical morphology: dilation. The originality of our approach lies in its implementation. A reformulation of the dilation in terms of constant fronts propagation to perform a fixed covered area allows optimization of both time and precision (Euclidean distance). This also gives rise to an efficient implementation of an *adaptive dilation*. This results in a more realistic and accurate representation of the covered area in an acceptable processing time. Used during the planning of the campaign, it allows the simulation of a covered area from a rough Digital Elevation Model and the Echo-Sounder parameters.

1. INTRODUCTION

By providing simultaneous depth measurements, multibeam Echo-Sounders can achieve swath coverage of the sea floor along the survey line with

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higher density and better resolution. For example, the SIMRAD EM12-dual Echo-sounder can cover a swath up to seven times the depth wide.

The area covered by a multibeam Echo-Sounder (*i.e.* limits of the area observed by the Echo-Sounder) depends on the swath width, which is a function of the depth and system opening angle. It also depends on the ship yaw: perturbations of the heading act as a lever and can result in an irregular coverage. In order to carry out a full coverage without "holes", the spacing between the ship lines has to be appropriately chosen. However, as the relief of the sea bottom is usually unknown, a real-time coverage remains necessary. This relies on a synthetic representation of the insonification area. The coverage is described using two contour lines. The first one is outside the data set; the second one is used to delimit the "holes". Both of them are generated for a given control radius that allows the insonification area of each beam to be partially taken into account, which depends, at the same time, on the system and the measured depth. The coverage is currently computed with the assumption of a fixed insonification area for each beam (also called beam footprint). However, beam footprints proportionally increase with depth. Thus, it turns out that the beam footprints are very different from the outer to the central beams of the same system. The covered area of a data set is defined as the sum of the footprints attached to each depth measurement. The processing of the covered area is ideally reduced to a standard morphological operator: a dilation. The originality of the approach described in this article relies on the implementation of this family of operations, which are expressed in terms of uniform fronts propagation (advection).

The first argument explaining this methodological choice lies in the fact that morphological operations are processed by fronts propagation (RAGNEMALM, 1992) allowing the processing time to be optimized. Another advantage, essential for this application, is that it becomes possible to carry out operations of different sizes simultaneously, thus making the **adaptive** covered area.

The **adaptive** covered area is used to optimise the planning management as is the case with the covered area generated by fixing the radius. In the short-term, the running of the bathymetry campaign will make use of it as constraints (*i.e.* prohibiting abusive extrapolations) to elaborate Terrain Elevation Models.

The coverage is also used for the planning of surveys when one has to define the navigation profiles to follow. This step is currently entirely manual; this study provides a mean to automate it. For this reason a second type of covered area has been defined, namely the simulated covered area. Unlike the computed covered area, whose definition is given above, the simulated covered area is attached to a ship line and is defined as the surface area theoretically observed by the sounder along the ship line. Like the computed covered area, the simulated one depends on both the seabed relief and the features of the sounder. The seabed relief is described through a rough Digital Elevation Model generated with available soundings on the area to be surveyed. The features of the sounder are its aperture angle and physical limits.

These two types of covered area are defined in the paragraph below. After briefly introducing the fronts propagation algorithm, its application and then its generalisation to the adaptive covered area case are presented. Finally, the last paragraph focuses on the time and accuracy the technique allows, as well as on the contributions of the adaptive covered area.

2. DEFINITIONS

Two covered area types were defined :

- a *computed* covered area : generated, during the survey, from the acquired soundings (x, y, z) ,
- a *simulated* covered area : generated, during the survey planning, from a coarse seabed modelization.

As illustrated on Figures 2-1 and 2-2, the cover processing is based on a description of both the seabed and the features of the sounder used.

2.1 Computed covered areas

A sounding attached to a beam corresponds to a mean depth computed on its insonification area, namely designated as its footprint, even if it is usually represented by a triplet (x, y, z) .

Two computation modes are considered depending on the retained modelization of the footprints of the beams :

- **fixed** : the insonification area is the same whatever the beam.
- **adaptive** : the insonification area depends on the features of each beam.

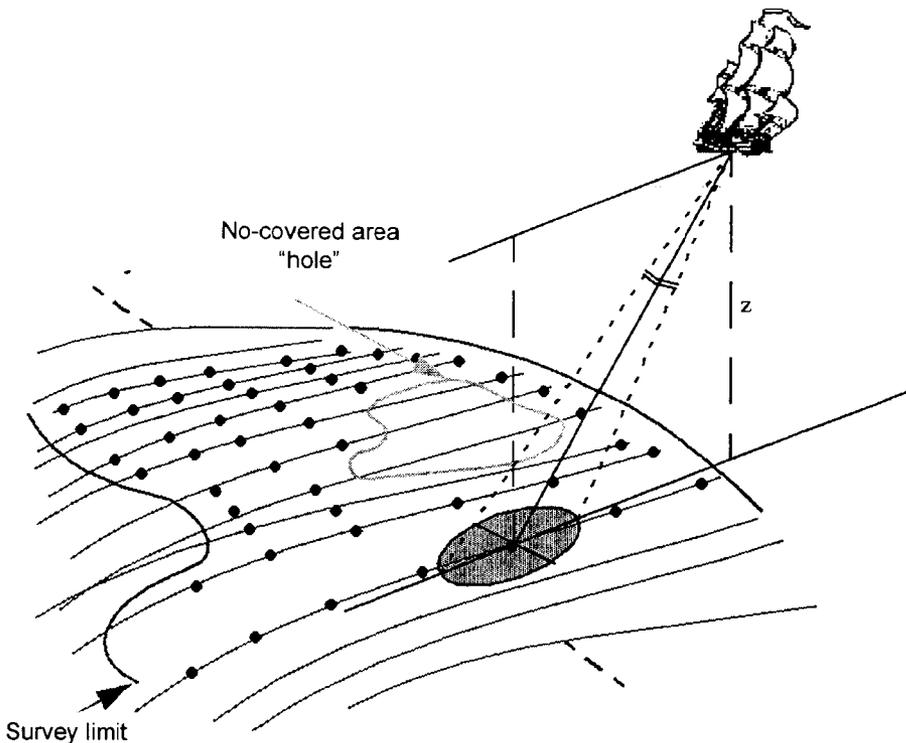


Fig 2-1 – Computed covered area.

In the fixed cover case, a sounding is represented by an insonification area which is the same whatever the beam or its depth measurement. In other words, each sounding of the data set is dilated so as to cover the same area. The retained model is a disc whose radius R can be a priori fixed or obtained from the features of the data set.

The adaptive covered area enables the features of the seabed relief and those of the sounder to be taken into account. It is particularly dedicated to surveys carried out on large areas presenting great relief variations. Moreover, it also allows the footprint deformation of the outer beams to be considered. In order to preserve reasonable processing time, the retained models leave aside the roll and pitch angles of the ship. The effects related to the local slope of the seabed are also supposed to be negligible. Two models are proposed depending on the sounder used.

In the Thomson-Lennermor case, which is a shallow water echo-sounder (i.e. 5m – 300m) with 20 beams of identical lateral and longitudinal opening angles, the deformation of the outer beam footprint is weak. Consequently, the model is the same whatever the beam. It is defined as a disc whose radius depends on the measured depth, on the observed angle, α_i , and on the opening angle of the beam, β_i $R(z, \alpha_i, \beta_i)$.

In the SIMRAD EM12-dual case, which is a deep water echo-sounder (i.e. 200m – 12000m), the opening angle of the 162 beams depends on the operating mode of the system. The deformation of the outer beam has to be modeled as the opening angle can be up to 150°. The footprint of an outer beam will be represented by a set of discs each having a variable radius $\{R(z, \alpha_i, \beta_i)\}_{i=1, N}$. In practice, the modelization of the outer beams footprint is similar to adding virtual soundings to the initial set.

2.2 Simulated covered area

The simulated covered area which is attached to the line R is the theoretical estimation of the area the sounder would cover while following the line R . It is obtained from a description of the seabed features of a coarse Digital Elevation Model (e.g. generated from the soundings provided by the bathymetric data base of the **SHOM**) and the sounder features.

This estimated coverage is used to optimize the planning of a survey. Its accuracy is the one of the Digital Elevation Model used to generate it.

3. FRONTS PROPAGATION PROCESSING

3.1 General principle

In 2D, the temporal evolution of a wave front can be represented by a curve according to its normal directions with a speed that depends on extrinsic or intrinsic front criteria. It becomes an advection process when all of the front points are moving at the same orthogonal speed (JACQ, 1997). A special case of advection process is the linear one thus called because the module of the propagation speed is invariant in time.

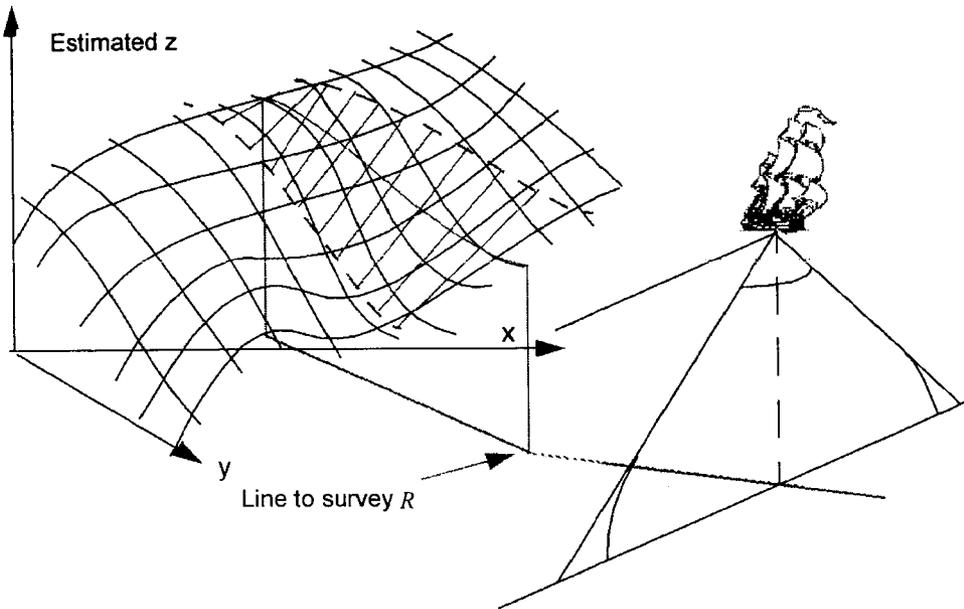


Fig 2-2 – Simulated covered area.

Performing the **dilation** in a binary graph - which is our goal here - corresponds to the simplest algorithmic form of the linear advection. In this way, the temporal evolution of the initial front verifies HUYGENS principle, which says that a front being propagated at a unit speed is, at t time, only made up of points located at distance t from the initial front.

In the graph theory framework, propagating a front with a linear advection is similar to generating a tree structure from the nodes that describe the initial fronts at a uniform cost. A major part of the processing cost of the uniform distance propagation algorithm lies in the search step of the opening node (*i.e.* not visited) having the lowest cost. The list of opening nodes has to be ordered so as to efficiently find this node. As cost values are integers, VERWER in (VERWER 89) suggests the use of a simple bucket sorting technique. Each bucket is associated with a particular cost which is its index. The front propagation starts by storing all of the nodes describing the initial front in bucket 0. As illustrated in Figure 3.1, buckets are inspected, one by one, in ascending order. A bucket inspection comes down to inspect each of the nodes that belong to it. No order is assigned to a node in a bucket. In practice, a bucket is implemented as a linked list, and its scanning order is the same as one of a list management. When a node is inspected, two scenarii can occur :

- The node p is closed, that is to say we have already observed p with a lower cost. In that case, it is simply discarded from the list.
- The node p is opened. In that case, it is marked observed (*i.e.* it is labelled closed). Then, it generates its successors. A successor p' of a node is a node adjacent to p , regarding the neighbourhood defined over the graph

and not marked closed yet. The cost associated to the successor $c(p')$ is the sum of the cost associated to p and the cost of the arc between p and its successor p' . The successor p is thus stored in the bucket $c(p')$.

The checking of the buckets list in ascending order guarantees that the successors of the nodes attached to a bucket always have costs strictly higher to the index of the retrieved bucket (the propagation is entropic).

The resulting distance is non-Euclidean. RAGNEMALM shows in (RAGNEMALM 1992) that this technique can be extended to the Euclidean distance case by indexing the buckets with the square Euclidean distance value, calculated from the position vector (v_i, v_j) connecting the node to the closest one in the initial front.

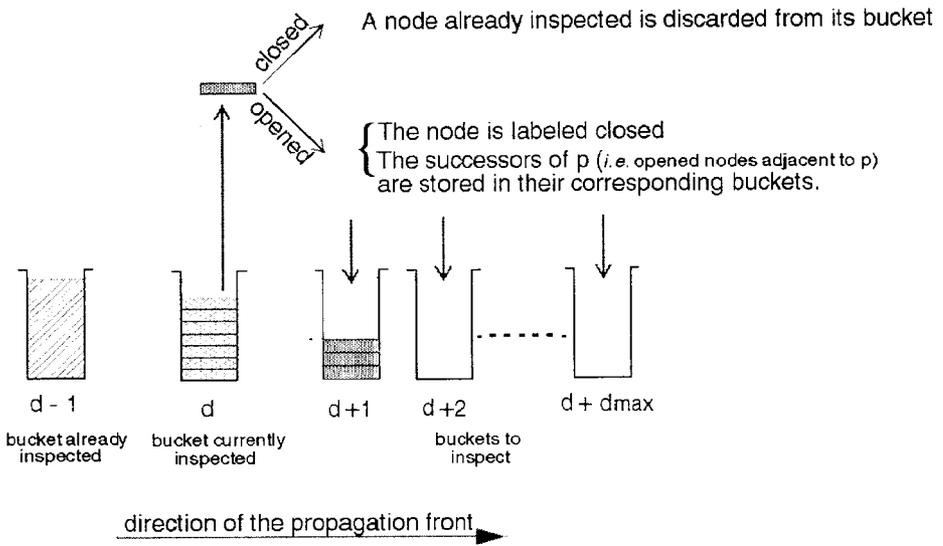


Fig 3-1 – Front propagation with a uniform distance implemented as a buckets list.
- Inspection of bucket d -.

3.2 Application to the cover processing

As previously mentioned, the cover implementation is based on a standard operation in the binary mathematical morphology field : the dilation. As an option, it is possible to propose a post-filtering of the resulting cover while carrying out a closing (i.e. a dilation followed with an erosion of identical size). This operation takes place in the dynamic process of a front propagation. To process an opening of size δ the front has simply to be propagated onto an additional distance δ , and then propagated onto the same distance in the reverse direction. The observed effect is a selective or partial smoothing of the cover limits – gaps are attenuated; In the same way, the “holes” of a smaller or equal size to the closing are filled. These two operations are processed using a front propagation algorithm, with a uniform distance implemented as a buckets list.

Within this framework, the cover process assumes the preliminary generation of a binary image built from the initial set of soundings - a pixel set to 0 will represent an empty cell, whereas a pixel set to 1 will represent a cell with at least one sounding. The pixel size defines the cover accuracy. It is a crucial parameter of the algorithm which is deduced from the dilation size.

Generation of the fixed covered area

The front propagation starts from the cells containing at least one sounding. In the case of a Euclidean distance propagation, each bucket is indexed according to the square distance value of the position vector of its belonging nodes p . The front propagation requires the storage of the coordinates (i, j) of each node as the coordinates (v_i, v_j) of its associated position vector.

Generation of the adaptive covered area

In the adaptive case, the dilation size depends on the features of each sounding. The propagation - with a uniform speed of the several fronts initialised at the same time - generates a uniform dilation of the data set. A simple way to adapt the dilatation size to the features soundings is to generalise the previous algorithm to the case of the uniform propagation of fronts started at different times. As before, the dilation operates on a grid. Each grid cell is then assigned to the maximal depth of its belonging soundings in order to calculate the starting times of the different fronts. The starting times of the fronts attached to each sounding are deduced from the histogram of the depth over the whole grid. The histogram step takes into account both the accuracy of the grid and of the longitudinal opening angle of the beams.

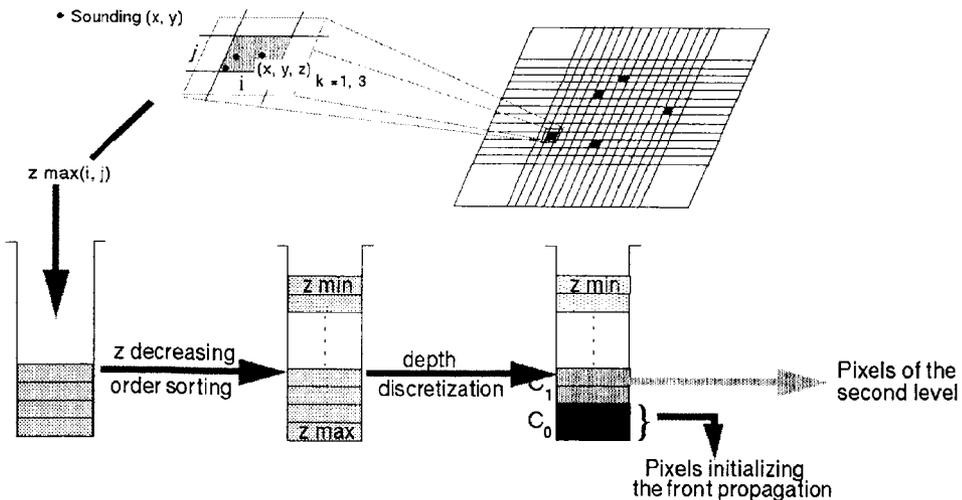


Fig 3-2 (a) – Time delaying process of the different propagation fronts
- in the *adaptive* cover case -

At time t_0 of the adaptive cover starting process, the initial fronts consist of pixels issuing from the maximal depth pixels class z_{max} [Fig 3-2 (a)]. As illustrated in Figure 3-2 (b), the null vector is attached to each of these pixels. At the first step, each pixel - in black - of the initial front generates a set of successors, which are either assigned to bucket $p[1]$ or to bucket $p[2]$. The pixels describing the new fronts have to be placed into the current bucket before the front progresses by generating the successors of the pixels contained. Bucket $p[1]$ also contains the successors of the pixels of bucket $p[0]$ as well as those coming from the class C_1 of the depths histogram. The position vectors of the pixels describing the new front are set to the null vector. As the front propagation is a causal process, the calculation of the index bucket, in which the successors of the pixels will be stored, has to take into account its time delay. From a practical point of view, the initialization time of the front attached to the pixel has to be stored along with its coordinates (i, j) and the coordinates of its position vector (v_i, v_j) .

Generation of the simulated covered area

The front propagation technique used to generate a fixed or adaptive covered area allows an efficient construction of a distance map. Applied to the simulation of the coverage attached to the navigation line R , it consists to propagate a front starting from the pixels of the navigation line R . The front gradually progresses, including the bordered pixels of the built area, as long as they verify the opening constraints the sounder defined.

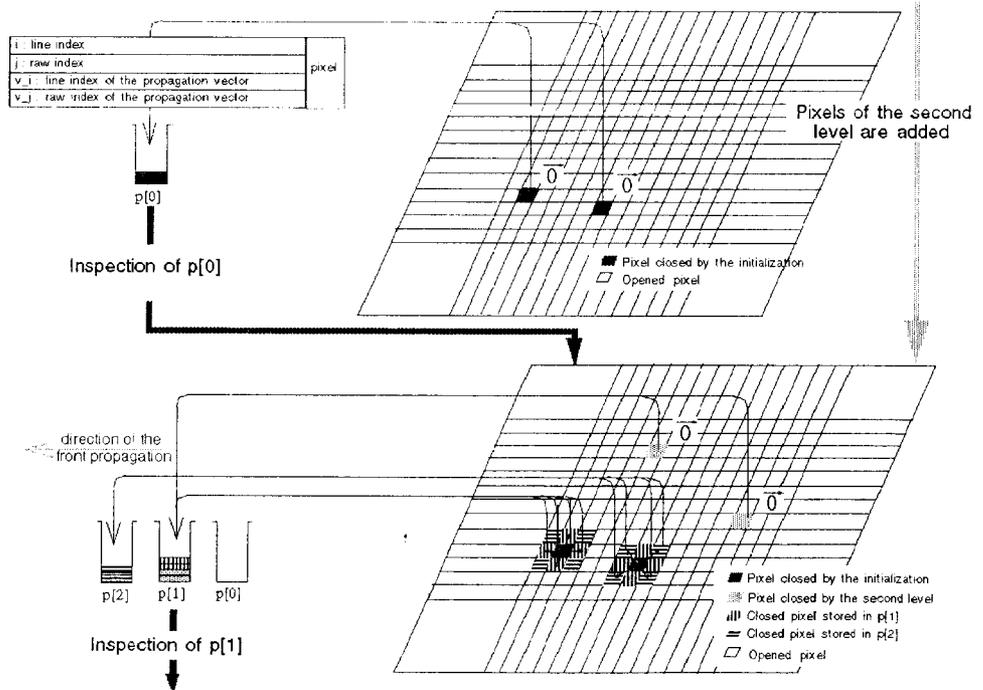


Fig 3-2 (b) – Propagation of the initial front followed by the pixels initialization of the second front.
- adaptive covered area case -

4. APPLICATION

Traditionally, a dilation is achieved by sequentially moving a structuring element (i.e. an image of smaller size) over the whole image. The proposed approach allows the fixed covered area to generate more than one million soundings in less than 3s on a Sun-Ultra Sparc workstation, thus 6 times quicker than the standard technique. This time ratio is given only for information : the spatial configuration of the soundings has to be taken into account in a processing time evaluation. Indeed, Ragnemalm, in (RAGNEMALM, 1992), compared the complexities of each approach. For a $n \times n$ binary image, the complexity of the conventional raster scanning algorithm is in $O(n^2)$. As for the front propagation technique, its complexity only depends on the influenced area of the morphological operation (i.e. the increased surface area resulting from the dilation).

Figure 4(a) underlines the contribution of an adaptive covered area compared to a fixed and a minimal (i.e. fixed covered area whose radius is set from the minimal depth over the data set) ones according their accuracies. Data used for that test comes from the SIMRAD EM -12 echo sounder in 150° operating mode over a flat bottom.

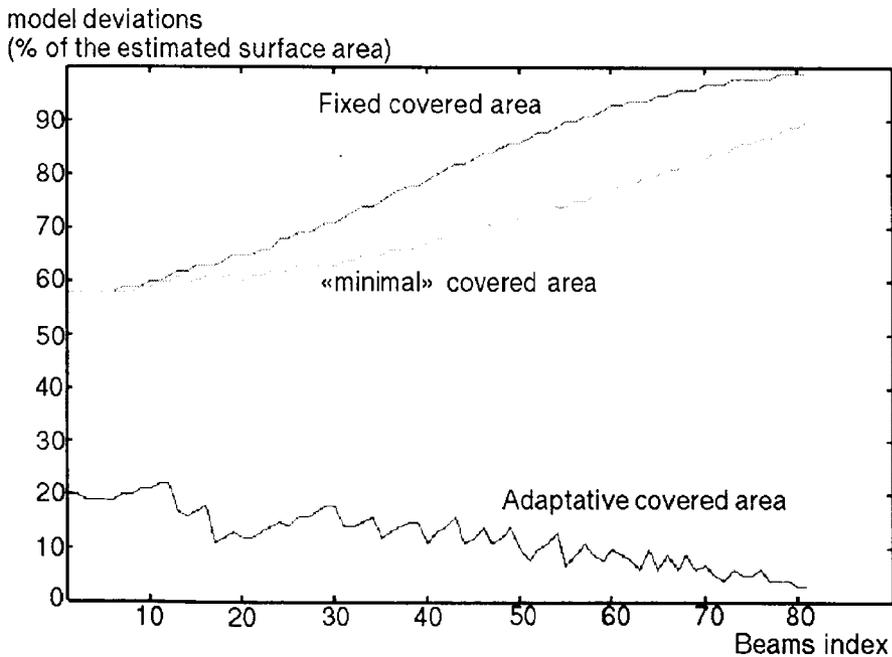


Fig - 4(a) – Surface deviations, in percentage of the estimated area, per beam
- SIMRAD EM12-dual echo sounder.

The adaptive covered area considerably improves the accuracy of the insonification area of a multibeam echo-sounder by taking into account features specific to each sounding. In a sea mount case, as shown in Figure- 4(b), the fixed

covered area introduces a 10% under estimation of the survey limits which appears prejudicial as holes located near a relief increase are filled. This problem cannot be solved with a covered area generated by fixing the disc radius according to the minimal depth. In the presence of a too short erroneous sounding in the data set, the minimal covered area has no meaning at all, as it generates a high density of holes. The density of holes the adaptive covered area generates can be interpreted on the opposite side, and thus used as a survey guide.

Finally, this technique, which is also used in the construction scheme of a hierarchical structure to store the covered area, enables "holes" to be classified and extracted according to some specific criteria (*i.e.* surface area, maximal depth proximity, erroneous soundings rate ...).

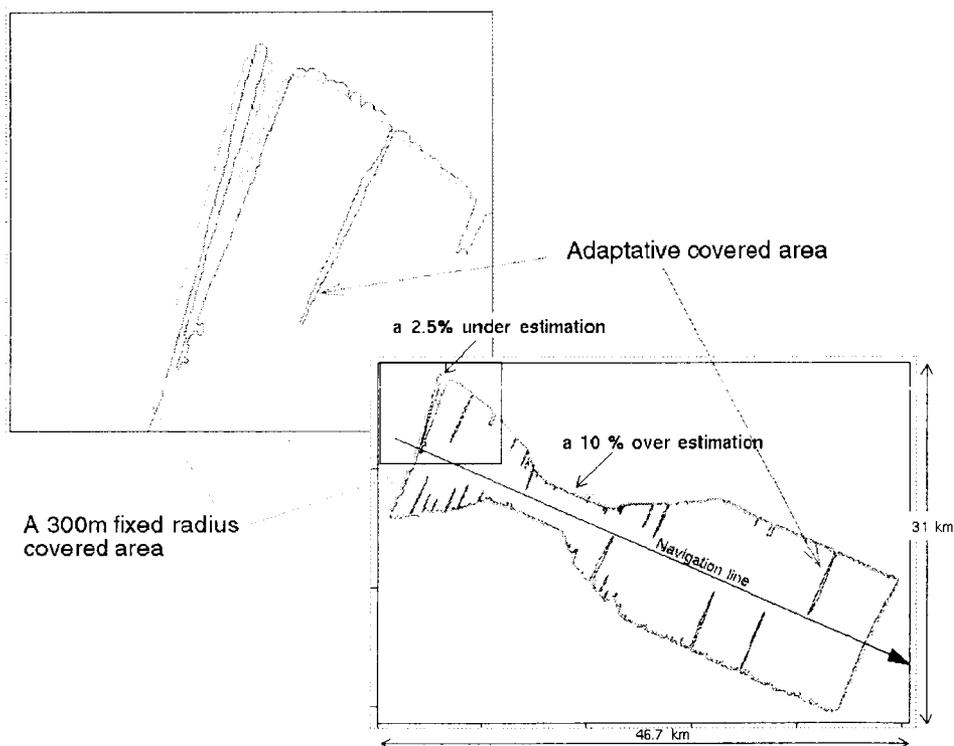


Fig - 4(b) An adaptive covered area compared to a fixed one : example.
To simplify the representation, only the external limits of the survey are drawn.

5. CONCLUSION

Planning, managing as well as running a bathymetric survey rely on a synthetic representation of the insonification area of a multibeam echo-sounder.

This article proposes an alternative construction scheme of a covered area based on a standard operation in mathematical morphology : dilation. The originality of the presented approach lies in its implementation. Using an uniform front propagation technique to process a dilation enables the running time to be optimised while increasing the accuracy. Its generalisation allows an adaptive covered representation to be obtained, according to the relief and features of the echo sounder in realistic processing time.

When used during a survey planning, it also allows the theoretical covered area from a Digital Elevation model and the features of the echo sounder to be simulated.

Finally, the hierarchical description provided is used to classify the doubtful (to some given criteria) areas of a survey. In the short-term, it will be useful to restrict the construction of terrain models.

References

- RAGNEMALM I., Fast Erosion and Dilatation by Contour Processing and Thresholding of Distance Maps. *Pattern Recognition Letters*, Vol. 13, No.3, pp. 161-166, March, 1992.
- JACQ J. J. Eléments de segmentation morphologique, *Rapport interne. Département Image et traitement de l'information de l'Ecole Nationale Supérieure des Télécommunications*, p. 77, December., 1997.
- VERWER B.J.H., VERBEEK P.W., and DEKKER S.T. An efficient Uniform Cost Algorithm Applied to Distance Transforms, *IEEE Trans. on Pattern Analysis and Machine Intelligence*, Vol. 11, No. 4, pp. 425-429, April 1989.
- DEBESE N., Détermination de la zone insonifiée par un sondeur multifaisceaux, *Rapport d'étude du SHOM n°001/99*, February, 1999.