# DYNAMIC SHIP POSITIONING BASED ON HYDROACOUSTIC SYSTEMS

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*The Article describes the concept for development of a dynamic ship positioning system based on the information provided by hydroacoustic systems.*

*It is the first presentation for the wide audience of a modern method for determination of position using modern measuring and processing technology where the hydroacoustic wave is the carrier of information.*

## INTRODUCTION

The carrying out of the navigation process including the determination of ship's position is dominated by satellite systems, mainly GPS. However, basing solely on these systems involves the risk of possible information loss in case of a break-down, inclusion of noise or coding of information reaching to the users up to a complete system turn down. It turns out that there is a necessity for availability of other autonomous systems allowing determination of position. This is mainly associated with the navigation of underwater vehicles conducting work not only in open waters but also in waters under ice cover. Also, for inland shipping, taking advantage of bathymetric information is an attractive alternative for the GPS system. Especially that the execution of bathymetric navigation is connected directly with the sea bottom which is a primary requirement for shipping in shallow waters. In the course of last years it has been observed that there are more navigational failures caused by contact with the bottom or other underwater obstacles than by contact with other ships.

It may be forecasted that the navigation of units along maritime tracks and especially during the phase of moving of the ships out of the inland waters using the bathymetric navigation connected with the local reference system, as is the shape of the bottom, will satisfy the constraints of positioning precisions. At the same time it will enhance the maritime safety.

## 1. CIRCULATION OF INFORMATION IN BATHYMETRIC NAVIGATION

The concept of comparative navigation forms a foundation of development of positioning system using the hydroacoustic systems. It is based on the possibility of localization using the information of the sea bottom shape.

Until recently, the bathymetric information, and more precisely the depth was used in navigation only as one of the general methods for control of the position. If a ship was crossing on her course a specific isobath, the echo sounder should yield a corresponding depth change. Now, having at the disposal the modern measuring and processing technology the new possibilities of positioning are emerging. These methods are necessary especially for the execution of navigation by autonomous, crew-less, underwater vehicles, but may be also used for surface vessels navigating along water tracks. Bathymetric navigation, as it was already mentioned, relies on comparing the bottom image obtained during the movement of a ship with the archived image or an image generated dynamically. The necessary condition for such a system is the possession of a credible bottom spatial model as the reference frame. A unit, during her movement at sea, conducts measurements by an echo sounder (singe or multi-beam) – and we obtain the 3D shape of a profile or a strip which is subject to the comparison with the reference model or by the side scan sonar – we obtain 2D bottom image without depth information. The position determination algorithms depending on the measuring system are presented on figure 1 and 2.

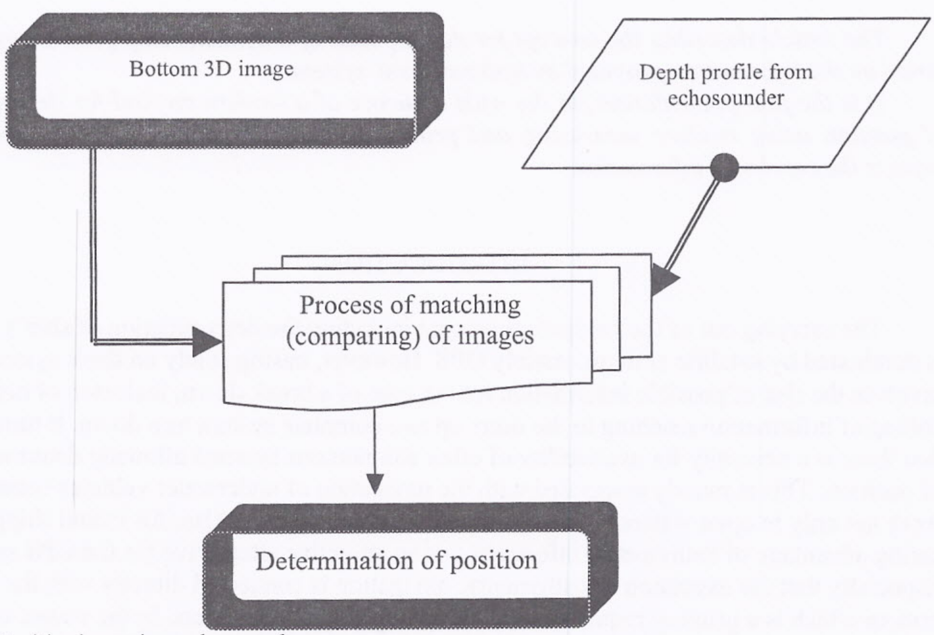


Fig. 1. Positioning using echosounder

When on the output of the system is the 3D image it is sufficient to carry out the image matching (comparison) process. In case of the side scan sonar, for the comparison it is necessary to first build (generate) a sonar image basing on the possessed 3D model. This results from the fact that the sea bottom shape remains relatively constant but sonar image at the same location changes depending on the sonar parameters, depth of the transducers and temporal hydrological conditions in the area. This leads to the necessity of obtaining of many reference images for a given area which includes these types of objects. Having the depth measurements it is possible to create a simulated sonar image practically for any theoretical positions of a sonar. Thanks to that, the basis may be formed for characteristic reference images of sea bottom that may also include navigational points. These points may be not only the fragments of a natural bottom but also artificial objects, positioned on purpose as a result of human activity at sea. Characteristic objects that may have any significance for bathymetric navigation can be divided into two types: objects with clearly defined shape that should allow for a precise determination of localization in reference to these objects and objects with some repetitive features in a given area (reflection coefficient, texture, etc.) that would approximate the localization. Taking that into account the problem of using of the object recognition for position determination comes down to the solution of two problems that will be realized in the framework of this project:

- Detection, localization in image, and recognition of objects with a definite shape, which will also be associated with the improvement of a method for creation of simulated sonar image, so far that it will be useful as a reference image for a direct comparison and as part of the reference image database for method requiring a teaching phase. The main problem in recognition of these type of objects, which will be solved in the project, will be the elimination of influence of high changeability of acoustic shadow on the recognition results.

- Determination of object type, of a shape difficult to isolate, namely all kinds of geological forms located at sea bottom and approximate determination of sea bottom type, which may have significant importance during the determination of object localization.

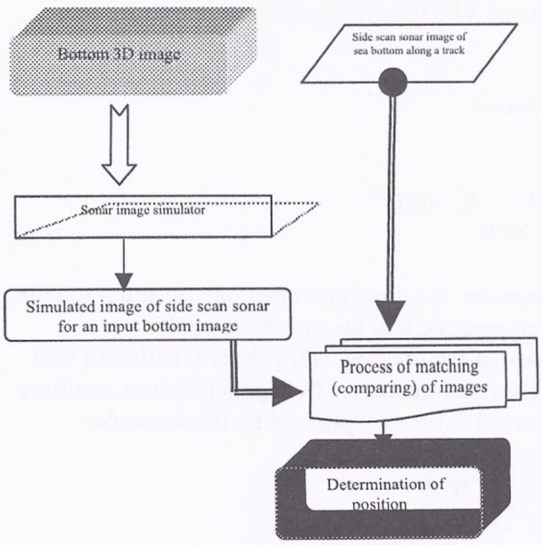


Fig. 2. Positioning using side scan sonar

## 2. DYNAMIC POSITIONING SYSTEM

Realization of the concept of bathymetric navigation yields a series of problems. The basic ones are:

1. Creation of a credible spatial bottom image.
2. Development of a sonar image simulator.
3. Choosing of algorithms for realization of image comparison process

- Bottom spatial modeling

In the initial phase of research the bottom spatial modeling should be established by the geostatic Kriging method. This method is used to express trends included in the measuring samples. The essence of the process is based on the estimation of an average value of random field by linear combination of known field values in finite number of observation points. This method was created on the basis of mathematical theorem of, so called, regionalized variable. Here, the semivariogram found its application, being a function depicting the spatial changeability of a random field. In Kriging, it is important to determine the magnitude of a radius of the junction vicinity, the number of sectors in vicinity and the maximum and minimum number of points taken into account in each sector. This gives extremely good possibilities for the generation of contour maps where the Kriging method found its wide application.

Surface interpolation using this method is conducted in two phases:

- First phase, creation of a proper semivariogram
- Second phase, surface interpolation

In order to determine the set of weight functions used for the estimation of values at unknown points in space a semivariogram is used which determines how fast the values of measuring points change in a specific direction. Although, there are many methods for the estimation of semivariogram parameters, because of the statistical character of such relation no fully normalized model has been worked out. The following are the example known semivariogram models:

| | |
|---|---|
| Exponential | $\gamma(h) = C[h^n]$, where $0<n<2$ |
| Linear | $\gamma(h) = C(h)$ |
| Gauss | $\gamma(h) = C[1 - e^{-h^2}]$ |
| Quadratic | $\gamma(h) = \{C[2h-h^2] \quad h<1; \quad C \quad h\geq 1\}$ |
| Logarithmic | $\gamma(h) - C[\log_e(h)] \qquad h>0$ |

From the above models of semivariograms, the most universal one for interpolation of surface shape is the linear model, therefore in practice it is the one most used.

Interpolation, namely the second phase of the method, is the determination of best weight coefficients for all samples. During the determination of weights relations resulting from a semivariogram are used. The interpolated value is expressed by the folrmula:

$$z = \sum_{i=1}^{n} w_i z_i$$

where:

$$\sum_{i=1}^{n} w_i = 1$$

z – interpolated value
$w_i$ – weight of i-th measuring point
$z_i$ – value at i-th measuring point

The weight coefficients of consecutive measuring points are obtained by a solution of an equation set (Magnuszewski, 1999):

$$w_1\gamma(h_{11})) + w_2\gamma(h_{12}) + \ldots + w_n\gamma(h_{1n}) + \lambda = \gamma(h_{1p})$$
$$w_1\gamma(h_{21}) + w_2\gamma(h_{22}) + \ldots + w_n\gamma(h_{2n}) + \lambda = \gamma(h_{2p})$$
$$w_1\gamma(h_{31}) + w_2\gamma(h_{32}) + \ldots + w_n\gamma(h_{3n}) + \lambda = \gamma(h_{3p})$$

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$$w_1\gamma(h_{n1}) + w_2\gamma(h_{n2}) + \ldots + w_n\gamma(h_{mn}) + \lambda = \gamma(h_{np})$$
$$w_1 + w_2 + \ldots + w_n + 0 = 1$$

where:

$\gamma(h_{ij})$ – semivariance in function of distance between samples i and j.
$\gamma(h_{ip})$- semivariance in function of distance between point i and a point of interpolated value

In the process of interpolation it is possible to use a larger number of measuring points located within the range of reaction radius and an optimum estimate is calculated from the formula:

$$z = w_1 z_1 + w_2 z_2 + \ldots w_n z_n$$

where:

$w_i$ – weight coefficients depending on semivariance (their sum must be equal 1)

Kriging is, along R.Hardy's method, the most optimal method for modeling of terrain surface. It should be however remembered that the semivariogram equation must be determined in a proper way, ie. closely reflect the spatial structure of data.

- Sonar image simulator

The following are the goals required from a sonar image simulator:

1. Simulation of realistic, basic parameters of water environment:
    a. Temporal depth of water,
    b. Spatial shape of the sea bottom,
    c. Speed of sound wave in water,
    d. Salinity, temperature,
    e. Bottom type, etc.
2. Generation of disturbed (randomized) environmental parameters:

   a. Uniform or normal disturbance distribution,
   b. Singular "fat" disturbances,
   c. Correlated mutually disturbances, etc.
3. Simulation of ideal work of hydroacoustic equipment:
   a. Intensity of signal,
   b. Signal power,
   c. Range,
   d. Beam width along planes,
   e. Location of a transducer, etc.
4. Generation of disturbed (randomized) working parameters of hydroacoustic equipment – random with small amplitudes, possibility of omission
5. Processing of measurements – deterministic values of parameters in input block of a receiver.
6. Generation of disturbed values in input block of a receiver:
   a. Uniform and normal distribution of disturbances;
   b. Singular "fat" disturbances,
   c. Correlated mutually disturbances, etc.
7. Creation of test scenarios – work verification of simulator.
8. Graphical processing; user-operator system panel; data registration

- Comparative algorithms

Realization of the process of comparing (matching) of two 3D images of sea bottom is possible with the application of distance comparative algorithms.

Comparing of sonar images is a process much more complicated, and therefore it is a problem suitable for artificial neural networks.

## 3. SUMMARY

The proposition of application of an echo sounder and side scan sonar for the realization of navigation process in respect to a reference system, namely the sea bottom forms a new and unique approach to the problem of underwater positioning.

The constant observation of sea bottom by hydroacoustic systems allows, with application of proper algorithms, determination of vessel position in real time with an adequate precision.

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