Methods of comparative plotting of the ship’s position

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**Abstract**

In recent years the problem of position plotting in navigation has been dominated by satellite systems, the GPS in particular. These systems are used both at sea (maritime navigation) and in the air (aerial navigation) as well as on land (terrestrial navigation). With the application of satellite systems the position can be plotted within very short spaces of time, in the range of a few or a dozen seconds.

Relying exclusively on satellite systems, however, exposes to the danger of losing information in case of average, intentional switch-off, disturbance and possible encoding of information reaching the user. This results in the necessity of having yet another, autonomous system at one’s disposal (independent of external information sources) making possible the plotting of position in an autonomous way.

These requirements are met by methods of comparative navigation. The object of interest of comparative navigation is plotting the ship’s position by comparing a dynamically registered image with a pattern image. The pattern images can be numeric radar charts, sonar or aerial, suitably prepared for comparison with respectively radar, sonar or aerial images. Yet the most frequently registered images at sea will be radar images; the pattern, on the other hand, will be a numeric radar chart generated on the basis of topographic and hydrometeorological data or previous radar observation.

The article presents methods of computer ship’s position plotting by means of comparative methods.
1 Introduction

The main source of image information in comparative navigation at sea is the marine navigational radar compared with the marine radar chart, generated on the basis of topographical data and constituting a layer of the marine numerical chart. Another source of information is the sonar, whose image can be compared with a sonar chart generated on the basis of a sea bottom shape model. Fig. 1 presents a concept of the vessel’s comparative position plotting. This position is plotted on the basis of both overwater (radar) and underwater (sonar) information. Owing to this approach the ship’s plotted position is tied to potential navigational obstacles.

Fig. 1. The concept of comparative position plotting [1].

The so-far applied methods of analytical comparison of digitally recorded radar pictures and the sea chart are based on complex and time-consuming calculation algorithms requiring the computer’s large memory. What is sought for in these algorithms is the part of the chart most similar or least dissimilar to the analyzed radar image. In order to obtain the ship’s position hundreds or even thousands of images are compared. In the course of comparisons particular image elements are analyzed. A number of interesting conclusions relative to
analytical methods have been included in [2], [3], [4]. Among analytical methods the best results were obtained by applying the logical product method [5], which consists in examining the conformity of respective elements of the images compared. Due to the large number of calculations performed while using the analytical methods, the results obtained are likely to become outdated. Therefore, other methods are sought for which could be applied in comparative navigation. The new approach to the problems of plotting the ship's position by comparative methods consists in using artificial intelligence methods, which are artificial neural networks.

There are two basic concepts of the vessel's comparative position plotting using artificial neural networks. The first consists in making use of previously registered images, the second in generating a chart of patterns.

Every time the position plotting algorithm is selected, the problem of image compression or reduction should be considered.

2 Plotting the ship's position using logical product

For images registered in matrix form, as an ordered set of elementary surfaces, their best matching can easily be calculated by applying the logical product method. In the image analyzed pixels corresponding to the coastline, the land pixels and possibly some characteristic points should be sorted out. Before starting to plot the vessel's position by this method, the possibility of reducing the analyzed images should be considered.

One of the simplest methods of decreasing the amount of information indispensable for plotting the ship's position is reduction of the analyzed images (radar image and the numerical marine chart). In the first stage of seeking for the vessel's position reduced images can be compared (e.g. up to 50% or 25%) by reducing the number of pixels in the images. Reducing the number of pixels consists in calculating the value of the 'substitution' pixel on the basis of value of a few (say, four) neighbouring pixels of the analyzed images. In this way we perform a kind of generalization of the analyzed images, losing in accuracy, but considerably accelerating the initial search for the point of best matching. The substitute pixels can be determined according to the following algorithm:

- when there appears a characteristic point in four of the replaced pixels, then the substitute pixel assumes the value of the characteristic point;
- when there appears a coastal point, then the substitute pixel assumes the value of the coastal point;
- when only land points appear then the substitute pixel assumes the land point value;
- when only zeros appear – zero (the sea).

And so, for instance, four pixels corresponding to elementary surfaces with a side of 25m are replaced in the first stage of searching by a pixel with a side of 100m.
Naturally, after determining the initial position of best matching of the images, a search on complete images should be carried out, but only in the closest neighbourhood of the position found.

An algorithm that fully takes into consideration the nature of the radar image is the logical product. As already mentioned, in this algorithm land points, coastline and characteristic points have been sorted out in the analyzed images. According to the above-mentioned assumptions the dependence for determining the image-matching coefficient is as follows:

\[ kw(k,l) = ws \cdot ns(k,l) + wb \cdot nb(k,l) + wl \cdot nl(k,l), \]  

where:

- \( ns(k, l) \) – the sum of characteristic (special) points conformable on the chart and on the radar image;
- \( nb(k, l) \) – the sum of coastline points on the chart conformable with the coast points of the radar image;
- \( nl(k, l) \) – the sum of conformable land points;
- \( w_1, w_b, w_s \) – weight coefficient of the land, coastline and characteristic points.

The weight coefficients should be determined each time for a particular radar image in accordance with the equations:

\[ wl = \frac{SR \cdot ml}{ll}, \quad wb = \frac{SR \cdot mb}{lb}, \quad ws = \frac{SR \cdot ms}{ls}, \]  

where:

\[ SR = ll + lb + ls \]

\( ll, lb, ls \) – the sums of all points of respective kinds on the radar image (when any of the sums equals zero, then the respective weight becomes zero too);

\( ml, mb, ms \) – coefficients determining the proportional share of particular image points.

Numerical experiments have shown that best results are obtained when:

\[ ml = mb = ms = 0.333 \]  

and when

\[ ll, lb, ls \neq 0 \]  

then
that is, the matching of all land points will have the same weight as the matching of all coastal points and of all characteristic points.

The matching of radar images with the sea chart by this method gives very good results in the process of plotting the ship’s position. What may become a problem is only the defining by the operator of, e.g., the characteristic points on the radar image and their accurate marking. The restructuring of radar images before starting the matching process may slightly delay the moment of plotting the ship’s position. A more comprehensive description of the method presented with results of numerical experiments is contained in the monograph ‘Comparative Navigation’ [6].

3 Neural ship’s position plotting using previously registered images

A new approach in comparative navigation is the use of artificial neural networks for plotting the ship’s position. In the positioning process there can be used previously registered images and their positions determined by e.g. the GPS system or by geodetic methods. The registered images correlated with positions constitute the teaching sequence of the artificial neural network. The teaching process is carried out earlier and can last freely any period of time. In the course of using the taught network the dynamic registered images are passed currently to the network input, and the network interpolates the position on the basis of recognized images closest to the analyzed image. A merit of this method is teaching the network by real images with their disturbances and distortions. So, the teaching sequence includes images analogous to those that will be used in practice. The basic problem of this method is the necessity of previous registration of numerous real images in various hydrometeorological conditions.

Analogous to the case of analytic methods the process of positioning is inseparably bound with compression of input data. One of the ways of image reduction is to determine its invariant and then the discrete Fourier transform. As a result of assembling the above transformations we obtain \( n \) – the element vector corresponding to the analyzed image. On the input side, a vector of established number, say 200 of the first transform elements, is the teaching sequence of the artificial neural network, and on the output side the ship’s position is registered at the moment of recording the image. Results of applying the above combination of transformations have been given in [7].

Another approach is the use of artificial neural networks for image compression. The Kohonen network is the one most frequently applied for the purpose. In work [8] an original method of image compression is suggested using the Kohonen network and the General Regression Neural Network (GRNN). In the method presented in work [8] the images are first subjected to the process of segmenting, and then to compression. The process of segmenting
has the task of dividing the logically analyzed area into sub-areas, considerably accelerating their further treatment. Compression by means of neural network consists in assigning a number to each image segment. The assembling of all numbers for each segment of the image gives us a vector that is the compressed form of the image given at the input of the neural network (or group of neural networks). The Kohonen network has a limited set of values, which it is able to return to us; it is a set of indexes or numerical values associated with each neuron. When the network picture appears at the network output, it will return to us the value connected with the neuron most similar to this image. It will make a certain generalization; the more neurons there are in the network, the smaller the generalization, and the compressed image closer to the original.

An alternative is provided by the GRNN network. Instead of the value associated with the most similar neuron we can return the value adequate to the degree of input image similarity to all remembered images in the network – approximate it on the basis of information included in the Kohonen network. The value returned by the GRNN will be closer to the truth than the one from the Kohonen network. In this way, without increasing the amount of information remembered, we obtain a more accurate transformation of the image into its compressed form. When applying this method, the output vector of the Kohonen and GRNN network pair along with the ship’s position registered at the moment recording the image, will constitute the teaching sequence of the neural network that determines the ship’s position.

After compressing the analyzed image a teaching sequence of the neural network designed for plotting the ship’s position is constructed. The task of the network will be to construct a mapping function associating the analyzed picture with the position. Numerical experiments have shown the advantage of the network dedicated to interpolation tasks [9], which is the GRNN. For plotting the ship’s position it is necessary to apply a pair of networks, as each network will determine one of the ship’s position coordinates. After the network teaching process is finished, the currently registered image is passed to the network pair input, and the networks return the interpolated ship’s position coordinates.

4 Neural ship’s position plotting using a generated chart of patterns

Another way of approaching the problem of plotting the ship’s position is making use of a generated map of patterns. It may be a radar, sonar or aerial chart. A map of patterns is generated on the basis of a spatial terrain model and takes into account the specificity of observing the terrain by means of particular measuring instruments (radar, sonar or optoelectronic devices). The pattern method consists in generating images that could be registered from selected vessel positions with assumed distances between successive positions. In this method, no previous registration of real images is required; only in the course of preparing the system for working in a particular water area or terrain is it necessary to generate simulated images. These images are simulated so as if the
vessel was in successive positions in the water area. A data neurobase of its kind is constructed where any obtainable images are remembered.

In the process of preparing the teaching sequence a set of simulated images is prepared and compressed, and next the network is taught in image – position pairs. The network teaching process takes place while the system is prepared for work and is usually not limited temporally. After the network teaching process is finished, as in the method with real images, the current image is passed to the network input, and the network interpolates the ship’s position on the basis of similarity of this image to the patterns contained in the teaching sequence. In the course of the system’s work the response from the network (fixing the ship’s position) is almost instantaneous.

As in the method with real images, the best results were obtained by applying a pair of coupled GRNN networks taught by the teaching sequence after compression by Kohonen network. Each of the GRNN networks determined one of the ship’s position coordinates.

5 Sum-up

The article presents selected methods of comparative ship’s position plotting based on registered images and corresponding patterns. Two of these methods used artificial neural networks. The application of GRNN network pairs, each of them determining one coordinate of the ship’s position, allowed to obtain satisfactory positioning results. Numerical experiments showed considerable resistance of the method to disturbances of registered pictures. The method presented proved its usefulness for working in real time, as the delay time of the system is insignificantly small.

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