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PROBLEMS WITH PRECISE MATCHING RADAR IMAGE TO THE NAUTICAL CHART

ABSTRACT

In ECDIS systems, the radar display is overlapping the chart at the position set out by GPS or other navigational system. In case this information is lost, the radar image is overlapping the point of the reckoned position. The paper presents a different method of integration of the radar image with ECDIS system display. At this stage, using the comparative methods applied in navigation has been suggested. They are associated with methods of digital displays' acquisition and processing.

Keywords:
radar, radar images, comparative navigation.

INTRODUCTION

Contemporary sea navigation is principally based on application of satellite systems for positioning, and electronic charts systems, also radar systems, for safe conducting a vessel along a set trajectory, according to a generally specified course. A navigator's work is reduced to skilled usage of the systems, faultless operation of the equipment which is their element, also cooperative facilities (e.g. AIS). The navigating bridge integrates the above equipment and makes it operating as one unit. Navigational information can be freely transmitted between individual facilities. In this case especially worked out navigational data transmission NMEA standard has been applied. Multifunction indicators are to visualize specific navigational parameters in varied way. While looking at the radar indicator, we find information on a true course, speed and position of a vessel under observation. The information is obtained with a use of gyrocompass, distance recorder and ship's GPS. A majority of present-day radar indicators is capable to cooperate with hydroacoustic systems (echo sounder) and AIS systems (Automatic Ship Identification Systems) as well. The objects visible on display of the radar operated in AIS system don't have to be acquired and traced applying ARPA systems (Automatic Radar Plotting Aid). Radar is the one to take over the data from AIS receiver. Such integration is very advisable as improves safety of navigation. Radar information (the image and data referring to the traced objects) is transmitted to the electronic charts presentation system and navigational ECDIS information. The electronic chart visualizes the ship’s current position and its movement vector. Information concerning its position comes usually from satellite navigation equipment. The most essential issue is setting out the positions precisely. Basing on the displayed on ECDIS navigational data, a navigator undertakes a decision on movement of his own vessel. In case any of information on a vessel’s position, its course or speed get lost, the navigational parameters display shows constant values and the position is set up on the basis of mathematic reckoning.

A position’s error starts growing linearly and is proportional to the reckoning time. Besides, the filters applied for vessel movement vector’s estimation in the integrated navigational systems (Kalman filter) begin to function unstably. It is noticeable within a time of maneuverings. The vessel position according to ECDIS starts to differ increasingly from the true one. It is possible to notice the phenomenon only when the radar display is switched on in ECDIS system. The situation is presented in the figures below.

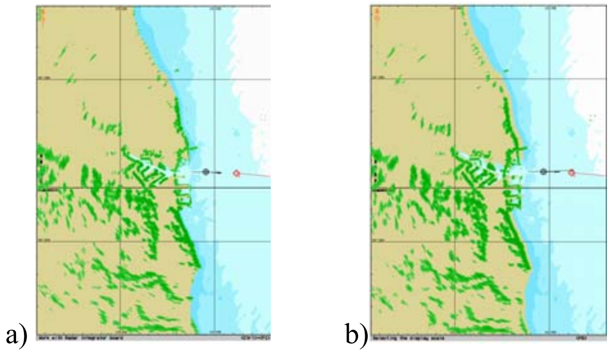

Fig 1. a) radar display plotted on the chart at GPS position; b) radar display plotted on the chart having no information concerning the position under observation

Even with well functioning GPS, while performing fast and considerable maneuverings, a position observed gets dispersed in relation to the true vessel’s position.

A navigator must be aware that his unit is operating improperly. Otherwise he may undertake mistaken decision while performing maneuverings. It may cause a risk to the ship and the whole crew. There already happened events connected with misinterpretation of navigational data transmitted by the system. They resulted in running aground, collisions, damages to ships. In an aspect of lacking in detailed information on a vessel’s position, a solution for the above problem can be the method of precise matching the radar display and the nautical chart’s picture. In ECDIS systems, the radar display is overlapping the chart at the position set out by GPS or other navigational system. In case this information is lost, the radar image is overlapping the point of the reckoned position. The paper presents a different method of integration of the radar image with ECDIS system display. At this stage, using the comparative methods applied in navigation has been suggested. They are associated with methods of digital displays' acquisition and processing. Radar displays and images of nautical charts are compared and a point of the best matching thereof is set out. Adequate algorithms and functions (functions of similarity and functions of proximity) are applied, images match ratios are determined. The methods are well-known and commonly applied in the image understanding techniques. Development of digital displays' processing techniques and computer technology enabled making the methods very precise and fast-acting. Radar display correctly matched to the nautical chart allows getting information on a ship's position. According to the research carried out by the author, the radar display can be matched with the chart with an accuracy ranging from 1 to 5 pixels. It depends on resolution of registered radar displays. Thereby corrected the vessel's position may increase safety of navigation.

SIMILARITY BETWEEN THE RADAR IMAGE AND THE NAUTICAL CHART PICTURE

Every navigator sees a considerable similarity between a radar image display of seashore and its projection in the chart. Radar image is a form of the most exact mapping of a space surrounding a vessel and all objects situated on the surface. It is the two-dimensional projection of the environment, encompassing the ship. Objects reflecting radar beam are represented in a form of echoes on a radar screen, and displayed applying the vessel's polar coordinates system. The vessel's coordinates system is understood as a local system, subject to translocation, performed along with a watercraft being in motion at sea. Accuracy of such representation depends on technical parameters of radar and meteorological conditions, occurring within a water area. The projection close to the one, presented in radar image display, is an azimuthal projection, often applied in cartography. Thus, in the further part of our considerations, the azimuthal projection will be a characterized radar image. It is necessary to point out also a fact of many disfigurements occurrence, all of them characteristic in respect of radar observations specificity. Radio location measurement (survey of distances to objects' bearings) is taken by radar antenna, turning round with a constant speed. Meanwhile the vessel moves towards a direction conforming to the true course. This phenomenon is presented in the figure below.

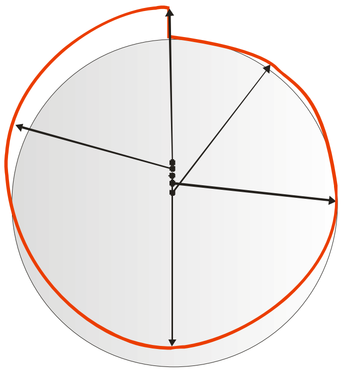

Fig. 2. Disfigurements in the radar image display caused by motion of the proper vessel

The disfigurements appearing upon ship's sailing with low speeds are minor enough to be neglected. If vessel speeds are high, as it happens for rapidly maneuvering Navy vessels, the disfigurements become more important. If rotation of the antenna around its axis takes about 3 sec, then a size of the appeared disfigurements, resulting from the ship's motion, may reach even more than 30 m.

Much more considerable disfigurements occur in case of a survey of bearings taken from objects of the same sizes but located at different distances from the ship. Thus dislocations of the own ship affect to a lesser degree a volume of angular disfigurements, referred to the further located objects. One may conclude that while carrying out observations, the navigator should select the range for the objects under observation to be nearby its maximum values. The above means that while approaching port heads, at a distance of about 2.5 nautical miles, the navigator should reduce the observation range from 6 to 3 nautical miles. The same should take place inside the port; the observations should never be carried out applying the ranges exceeding 1.5 nautical miles etc.

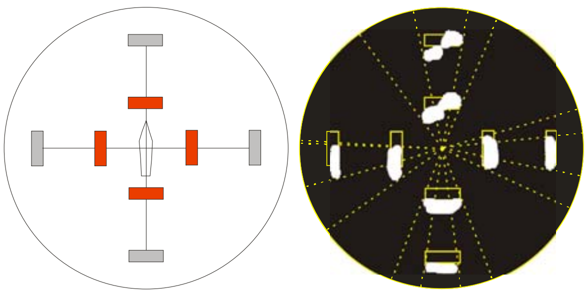

Fig. 3. Geometrical arrangement of the objects immovable in relation to the vessel in motion (chart picture and radar display)

The figure above presents appearance of the radar image, received by the ship in motion. The image has appeared within a time of one rotation of the radar antenna. The noticeable are disfigurements at a distance and considerable angular disfigurements, especially referring to the close objects.

The following group of disfigurements, differentiating the radar image from the chart picture, is the deformations, resulting from a nature of radiolocation radiation. A character and sizes of the point target radar image depend on a time of scanning pulse, a width of direction characteristic and a distance of the image of issue from the radar screen centre. Deformation of the coastline echo configuration and its dislocation in the radar image display, resulting from the mentioned reasons, is presented in the figure of the radar image, recorded in the naval port of Gdynia.

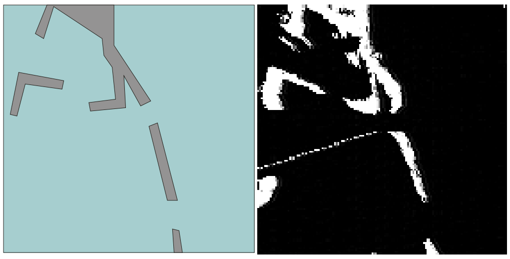

Fig. 4. Port of Gdynia; the chart picture and the real radar image display

The other type of radar image disfigurements is generated in effect of non linearity of the time base pulses and deflective coil structure. Two cases are possible. The first is when a line of time base sawtooth pulse growth is concave; it causes that distances between the constant circles are not equal and they keep growing while approaching the screen's edge. Then 'drawing' of echoes to the display centre occurs. The second case is when a line of sawtooth pulse growth is convex, then, while moving away from the display centre, the distances between the circles keep reducing. Then 'wide-spreading' of echoes, starting from the display centre, takes place [3].

The operators are familiar with disfigurations and disturbances of radar image caused by the highlighted pulse distortions, echoes of sea waves and precipitations. The operators know also how to identify multiple echoes, intermediate echoes, echoes within the side lobes directions, echoes of the previous radar operation cycle and interference distortions. All the above disturbances and disfigurations usually cause no serious problems for appropriate interpretation of the radar image.

The other types of disfigurations result from the radar resolving power. It is subject to analysis in two aspects: as a resolution in range and in angle.

Resolution in range is a minimum distance between two point targets of the same bearing, creating two separate echoes in the display of radar, operating at the short observation range. In [15] there has been specified a dependence between the minimum interval of successive pulses $\Delta l_{\min}$ and a duration time of scanning pulse, for which it is feasible to measure separately the distance:

$$\Delta l_{\min} = t_i \cdot v_p + \phi \tag{1}$$

where:
t_i — scanning pulse duration time;
v_p — spot velocity;
ϕ — spot diameter.

Taking the above into consideration, a minimum distance of resolution in range of two point targets is [15]:

$$\Delta d_{\min} = \frac{c \cdot t_i}{2} + \frac{c \cdot \phi}{2 \cdot v_p} \tag{2}$$

where:
c — velocity of radio waves propagation in atmosphere (about $3 \cdot 10^8$ m/s).

The same for resolution in angle — we have to define a sharpest sight angle of two point targets situated at the same distance from the radar, with their echoes appearing separately on the screen; it can be described with a dependence [15] as follows:

$$\Delta \alpha_{rozr} = \Theta + \frac{\phi}{l_e} = \Theta + \frac{\phi}{M_S \cdot d_1} \tag{3}$$

where:
Θ — width of the directional characteristic;
l_e — distance from the echo to the display centre.

Thus all the above disfigurations, also those resulting from variety of waves propagation conditions as well as hydrometeorological conditions, also the other (described in works [3, 4, 8, 12, 15]), affect the radar image quality and cause, that the image differs from the real picture. All the more it differs from a picture of the nautical chart, which is presented in various projections, not always coincident with the radar image projection.

A map projection type used for the nautical chart purpose, the most often is Mercator's Projection. In this projection there occur considerable distortions, mainly directed towards the north and south, subject to reduction while moving away from the basic parallel. It is noticeable in the small scales charts, encompassing large areas with their extents. The projection distortions resulting from varieties of map projections and radar image have been described in details in [12].

With contemporary techniques and capabilities of the advanced electronic maps systems, transformation from one to the other type of projection is not a big problem. Therefore while comparing radar images and nautical charts, we are capable to carry out transformation of the map picture, its projection, to the representation more similar to the radar image.

One of the solutions suggested in [5] is applying the perspective dynamic azimuthal projection with the positive projection point. The above projection has to be generated dynamically, together with motion of the own, proper vessel. Carrying on navigation (route range) in such a projection is difficult as in this projection the parallels and meridians are not straight lines perpendicular to each other and the loxodromic-line is not a straight line cut-crossing meridians under the same angle. Nevertheless the projection, as based on sight, should provide the navigator with a possibility of comparing thereof with the radar image, identification of objects and targets around the vessel and verification of the position fixing systems indications correctness. It can be achieved through matching precisely the radar image and the chart, also possible adjustment of the faulty position observed.

For this projection a distance adjustment is calculated applying the following dependence:

$$\Delta = d - \frac{k \cdot R \cdot \sin(\frac{d}{R})}{K - R \cdot \cos(\frac{d}{R})}, \tag{4}$$

where:

R — the earth radius;
K — altitude of the projection point, counted from the earth centre;
k — distance between the projection plane and the projection point;
d — radar operating range (distance to the central point of the reference plane).

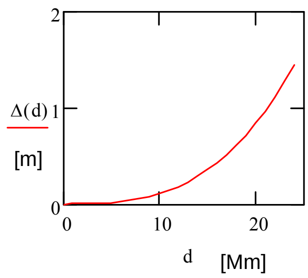

Fig. 5. Adjustment in distance for the perspective azimuthal projection with the positive projection point

An influence of the distance distortions is minor enough to be disregarded for the ranges below 24 nautical miles. It hardly is 1.5 m. Consequently for the nautical charts of 1:50000 scales, a minimum 'spot diameter' is 0.24 mm and coordinates reading accuracy is 12 m. Thus the distortion — both — in the chart and the radar image — is inconsiderable.

REPREZENTATIONS OF IMAGES APPLIED IN THE COMPARATIVE ALGORITHMS

On comparing the radar image and the nautical chart we search for geometrical similarity. We compare with each other raster representations and then this similarity is discoverable. The images differ with colour scheme and sizes. The radar image is an 8 bits bitmap with contours of a coastline, land and singular objects. The chart picture is worked out in the vector technique, with a clearly visible coastline, colour scheme which distinguishes such elements as: land, navigational marking, water areas, navigational lights sectors, fairways, special regions boundaries etc. All these elements contribute to obtain successive electronic map layers, one by one overlapped. Navigational marking, visible in the radar image as radar echoes of characteristic points, is distinguished in the map with a use of graphic symbols, characteristic for specific marks groups. In this case searching for geometrical similarity of the images is useless. Instead, the fact that in this place there is an object visible — both in the radar image and the nautical chart has to be noticed. Thus the images shown in their raster representations, presented as bitmaps, may be subject to comparison at the initial stage, when specifying similarity of the images takes place. In [9] the author has carried out comparison of the images by stages. Firstly, he has searched for matching the characteristic points — the most essential for accurate matching the images; next, the coastline and finally land elements. To the specified image elements he has assigned weighs, which characterize an images matching degree. For exact matching of images much more important is to fit several characteristic points than all radar image points, identified as a land.

The digital representation of the images which specifies a coastline is an outline invariant. It has been described in [6, 7, 12, 13, 14].

The function defining the outline invariant d is formulated as follows:

$$d_i = \begin{cases} A & for\ D^c(NR_k) = \varnothing \\ \min\limits_{P^c \in D^c(NR_k)} \left|P^o P^c\right| & \end{cases}; \tag{5}$$

$$i = 0,1,..,n(360),$$

where:

$D^c(NR_k)$ — set of visible points (pixels) of the image laid within the specific bearing (NR), it means the radar echoes in the defined bearing;

$|P^o P^c|$ — distance of the indicated pixel from the image centre (central point), distance of the radar echo from the antenna;

n — degree of the applied resolution of the radar image invariant;

A — certain assumed distance exceeding the observation range.

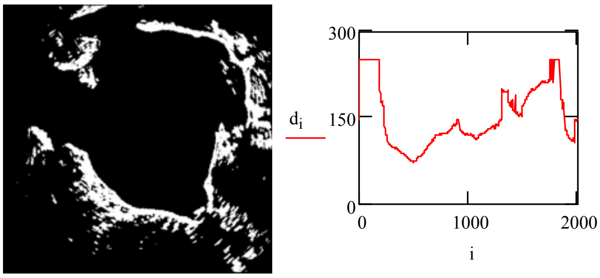

Fig. 6. The radar image and its outline invariant

In brief, the outline invariant presents the line described with polar coordinates (bearings and distances to the coastline points).

Rotation of the radar image is a subsequent element implementing geometrical differences. The radar images are stabilized mainly in relation to the true north. Stabilization is performed owing to the ship compass indications (gyrocompass). Errors of the equipment indications affect rotation of the radar image in relation to its centre.

The image — in frequency domain — is not dependent on rotation. Accordingly, it is necessary to perform the Discrete Fourier Transform (DFT) for the outline invariant. Then the following form is achieved:

$$f_k = \sum_{i=0}^{N-1} d_i \cdot e^{-j \cdot \frac{2 \cdot \pi}{N} \cdot k \cdot i}, \tag{6}$$

where $k = 0, 1, 2, ..., N–1$ is a frequency domain, whereas N depends on a degree of the outline invariant resolution degree n and $N = n \cdot 360$.

The above form of the image has to be treated as a vector of complex numbers of the separated real values and imaginary values (where j is an imaginary number). The transform is of 'non-lossy' type, it means there exist an inverse transform and the obtained image is identical as the original one. The graphical representation of the transform are specific values of DFT ($|f_k|$) modulus, which are characterized with symmetry to $\frac{k}{2}$.

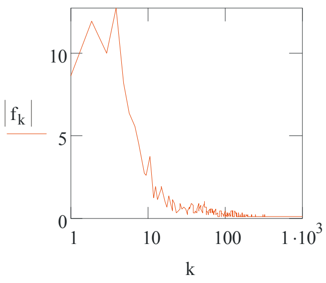

Fig. 7. DFT of the outline invariant

The symmetry phenomenon in frequency representation enables to analyse a half of the image value domain. It is a very desirable feature, as it shortens a time of carrying out calculations and successive transformations. The above feature can be treated as non lossy compression, which eliminates an influence of rotation on the image disfiguration.

Another form of image compression, very often in use, is a projection to OX and OY axes [12, 13]. The elements of raster (pixels) are projected in the directions along the coordinates system's axes and summed. If by $p_{x,y}$ the pixel values of element raster n x n image is designated, then, projecting thereof in columns and rows it is obtained as follows:

$$a_x = \sum_{y=1}^{n} p_{x,y} \text{, dla } x = 1\ldots n;$$

$$a_y = \sum_{x=1}^{n} p_{x,y} \text{, dla } y = 1\ldots n$$

what has been presented in the following diagrams.

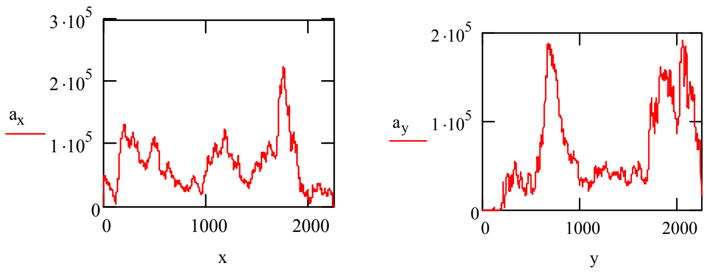

Fig. 8. Projection onto OX and OY axes

The above compression is obviously a lossy one, it means it results in loosing a part of picturesque information and it is not to recover. However, compression considerably reduces the image. A much lower number of information is processed and stored. Such a quality is used in the algorithms of comparison of images, in which artificial intelligence elements are applied. They are, first of all, neural algorithms, in which hundreds, even thousands of image elements are processed simultaneously. Due to complexity of the calculation process and a number of the calculation operations, the images (the radar and chart ones) compression is required. Compression should enable preservation of the most essential qualities of the image. Thus, for example: a feature of 'projection on axes' compression is specifying a total number of elementary echoes on the set up directions. Other compressions mentioned in [12, 15, 16] quote various ways of extracting from images their most essential features, which prove their uniqueness.

ALGORITHMS OF MATCHING UP THE IMAGES

The mentioned above Artificial Neural Networks are one of elements used for identification of images. There is also many classical methods, defined in the literature as analytical methods; in effect they are to match radar images to chart pictures [2, 12, 13, 16].

In [10] there has been contained the classification of the available methods of matching up radar images and chart pictures.

It had been worked out basing on many years of research and experience of the authors. The algorithm of matching up images is the one responsible for the best mutual location of images. Its operation results in determination of the images matching coefficient. It is a measure decisive for right matching all their elements. It is a direct effect of algorithm's operation. The indirect effect is fixing position observed, in which the radar image has been recorded. As a consequence it enables to overlap the chart precisely with the radar image in ECDIS system. Selection of the algorithm is very important and it is up to the navigator's arbitrary decisions (radar observer). One should remember, that the above methods, described in the literature as the comparative navigation methods, are still subject to researches and they are none of elements of ready finished navigational systems. Anyhow, the researches seem to be very promising.

A majority of known algorithms operates on the grounds of the minimum distance methods. They are rooted in the Bayes algorithm of identification and they are the most commonly used and prevalent methods of classification and identification [1, 9, 11]. A majority of these methods is based on application of so-called similarity function. Selection of this function is the most essential matter in the minimum distance methods. It affects the result of matching up images and labour intensity of the whole process of fixing vessel position by observation. These functions can be divided into the functions of distance: Euclid's, Humming's, Czebyszew's, Camberr's, Minkowski's, Pearson's, Mahalanobis's and the other, and the functions of proximity: Tanimoto's, direction cosine, the measure of which is inversely proportional to the distance measure.

A concept of the distance function or the proximity function operating is really simple. There has to be calculated the total distance between the radar image elements and the chart picture elements. When it refers to raster images — a distance between the pixels' values has to be reckoned. As to the outline invariants, a distance between specific discrete values of the functions of radar and chart image is to be calculated. The same is with the other images representations.

Such an algorithm is simple and fast operating. However, a so-called gross error is likely to occur. For two different looking radar images, the set up distance to the chart picture can be identical. It is shown in the Figure below.

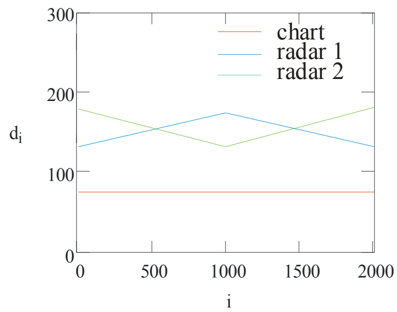

Fig. 9. The situation when a distance between the chart picture and the radar images is equal

Such a situation occurs because a majority of the distance functions is based on so-called Euclid's distance, formulated by the following dependence:

$$D_{C,R}^{Eu} = \sqrt{\sum_{n=1}^{N} (C_n - R_n)^2} \,, \tag{7}$$

where:

C_n, R_n — values of specific chart picture elements and radar image.

Geometry of the image figuration has been complied in other algorithms, so-called correlation algorithms. Correlation coefficients are calculated according to the dependence:

$$\rho_{C,R} = \frac{\sum_{n=1}^{N}(C_n - \mu_C)(R_n - \mu_R)}{\sqrt{(\sum_{n=1}^{N}(C_n - \mu_C)^2)(\sum_{n=1}^{N}(R_n - \mu_R)^2)}}, \quad (8)$$

where:

μ_C, μ_R — arithmetic mean values of chart picture and radar image elements.

It shows a linear dependence in changing values in the comparative images and matches up the images in respect of the coastline configuration. It's a very important quality, but it fails to consider distances between the images. The images of similar forms, but distant from each other, get matched up identically.

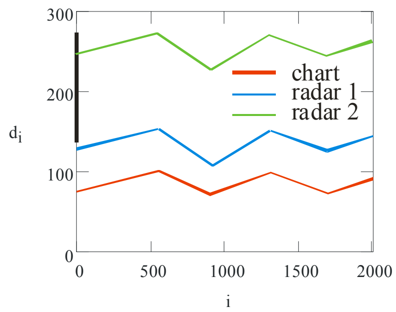

Fig. 10. Situation when the coefficient of radar images and chart pictures correlation is equal

A solution for the above problem is constructing complex algorithms of extended decisive criterion. For example: for the images closest to the radar image there are computed coefficients of correlation, or inversely. It has been suggested in [12].

Neural algorithms operate entirely different. As a result of their operation, a pattern image position is determined. It is possible owing to a process of learning. A specially designed artificial neural network is subject to the process, when it learns to recognize the teaching sequence images. This sequence has to be 'representative', it means to be composed of images, recorded from various positions and in different hydrometeorological conditions. Neural networks, the most often applied in matching up the radar images are: multilayer perceptron (Multilayer Perceptron) and network

GRNN (General Regression Neural Network) [12, 15, 16]. Unlike the minimum distance methods, the neural algorithms approximate the radar image position between these images displaying within the learning process. Besides, it is characteristic for them to operate fast and immediately. Moreover, they demonstrate low robustness to gross errors occurrence.

CONCLUSIONS

The paper presents the main problems of precise matching up the radar images and the nautical chart. The images matching algorithms are based on various forms, representations of the images. A part of them specifies the most essential features of the image. The other ones cause compression of the image.

Each transformation and compression of images is aimed at bringing thereof closer to each other. Distortions and disturbances occurring as a result of these processes have to be eliminated.

Due to simplicity of operation in matching up the images, the distance functions in minimum distance algorithms are generally applied. The radar image position is a position of central chart segment pixel, most matching to the pattern. It results in reducing a position error's value at increasing the image resolution or decreasing the radar operation range. Such operations are carried out in situations of approaching a land.

The researches prove that it is possible to match up the images with accuracy, ranging from one to three pixels [12, 13, 2].

The neural methods, which approximate position, require the learning process (taking several, even a few hundred hours) and compression of images reducing a number of information provided on input. In further operating they are faster and owing thereto, the radar image position is determined immediately. The position's accuracy is comparable to the values obtained in the above mentioned minimum distance algorithms.

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