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# RADAR IMAGE CHARACTERISTIC POINTS IDENTIFICATION

**ABSTRACT**

The article undertakes an issue of building an autonomous coastal positioning system that would work on the basis of information included in a radar image. Prior researches have led to working out the method of extracting characteristic points from the radar image – peninsulas, buoys etc. Currently the algorithm of identification of such points, that is assigning an identity (a position) to each of them, will be illustrated. The proposed solution is based on comparison of a relative bearing and distances fixed for pattern points (from a chart) and for points extracted from the radar image.

## INTRODUCTION

There are a lot of autonomous coastal positioning systems conceptions that take advantage of information included within the radar image. The simplest of them is creating a database of pattern radar images registered for known positions and subsequently during working on the sea comparing the recorded radar image with images saved within the database. The pattern image the most resemble the recorded image fixes the ships position.

Other approaches make use of neural approximators such as multilayered perceptron, radial networks – RBFNN, HRBFNN, GRNN or fuzzy NN. Each network is learned with an application of feature vectors that represent the radar image or an image prepared from an electronic chart both generated for known, training positions. Suitably prepared network is able to fix vessel position.

The solution that differs conceptually from methods presented above is an idea of automation of classical radar navigation methods. The system that would implement such approach should perform exactly the same steps as a navigator who uses radar to fix position that is it should determine characteristic points on the radar image, identify them assigning the identity (an accurate position) and subsequently calculating bearing and distance to selected points it should fix the vessel position, certainly on the basis of formulas and equations known from the classical radar navigation.

The current article illustrates one element of the overall proposed system that is the method of characteristic points identification, based on the comparison bearing and distances vectors fixed for pattern points (from the chart) and for points extracted from the radar image.

## OUTLINE OF THE COASTAL POSITIONING SYSTEM

Functioning of the proposed system has been yet presented in [4]. The system should contain following elements: the subsystem responsible for registering radar images in a digital form, eliminating echoes coming from moving objects subsystem, characteristic points extraction subsystem, the subsystem of characteristic points identification and finally the fixing position subsystem. The moving objects echoes elimination subsystem could work on the basis of information obtained from ARPA or take advantage of image filtration methods. The characteristic points extraction subsystem is described in [4]. Briefly, it uses second derivate of a radar image invariant estimator to determine characteristic points. The identification characteristic points subsystem is a content of the current article. The latter subsystem works on the basis of previously selected and identified reference points with determined likely position and with the help of the traditional radar navigation.

## THE CHARACTERISTIC POINTS IDENTIFICATION SUBSYSTEM

The subsystem could work on the strength of comparison of „contour" invariants generated for pattern points located on the chart and characteristic points from the radar image. This idea is described and tested in another article. Another possibility is the application of information about bearing and distances between individual pattern points and radar image points. This approach will be presented in the currant article.

Let $P^W$ be the set of $K$ characteristic pattern points of the considered sea area. A mutual location of every two pattern characteristic points $p_i^W, p_j^W$ is determined by the bearing $NR_{ij}^W$ from the point $p_i^W$ to the point $p_j^W$, the bearing $NR_{ji}^W$ from the point $p_j^W$ to the point $p_i^W$ and the distance $d_{ij}^W = d_{ji}^W$ between points.

The above situation could be presented in the form of a directed graph $G^W$, in which characteristic points from $P^W$ constitute vertexes whereas edges are described by bearing and distance.

The graph $G^W$ could be defined with the help of three matrixes: $\mathbf{M}^W = \left[m_{ij}^W\right]_{K\times K}$, $\mathbf{D}^W = \left[d_{ij}^W\right]_{K\times K}$ and $\mathbf{NR}^W = \left[NR_{ij}^W\right]_{K\times K}$. $\mathbf{NR}^W$ and $\mathbf{D}^W$ are respectively bearing and distances matrixes. $\mathbf{M}^W$ is the neighborhood matrix of graph $G^W$ that determine which connections between points occur and which do not.

From the given pattern point, we can see merely a part of remain points – only that points, which distance to considered point is not larger then a range of radar observation $R$. Relations between individual characteristic points for fixed $R$ we can describe in the form of a subgraph $G^W{}_R$ of the graph $G^W$. There is a connection in $G^W{}_R$ from the point $p_i^W$ to the point $p_j^W$ if the distance between these points is not larger then $R$. $\mathbf{M}_R^W = \left[m_{ij}^{W,R}\right]_{K\times K}$ is a neighborhood matrix of the graph $G^W{}_R$. Every pattern point $p_i^W$ for the given range $R$ could be described in the form of a subgraph $G^{W,i}{}_R$ of the graph $G^W{}_R$. A set of characteristic points, distant from $i^{\text{th}}$ point not further then $R$ and $i^{\text{th}}$ point constitute a set of vertexes $P_R^{W,i} \subset P^W$ of the subgraph $G^{W,i}{}_R$. Connections in direction from $i^{\text{th}}$ point to remain points from the set $P_R^{W,i}$ are edges of the subgraph $G^{W,i}{}_R$.

Denote subsequently $P^I$ as a set of all $L$ characteristic points generated from the registered radar image. Let $G^I$ be a directed graph in which vertexes are radar image characteristic points and every vertex is connected with other vertexes except oneself through two reverse directed edges described by bearing and distance. Matrixes, $\mathbf{M}^I = \left[m_{ij}^I\right]_{L\times L}$, $\mathbf{D}^I = \left[d_{ij}^I\right]_{L\times L}$ (a distances matrix) and $\mathbf{NR}^I = \left[NR_{ij}^I\right]_{L\times L}$ (a bearing matrix) complete definition of $G^I$. Let in turn $G^{I,i}$, a subgraph of $G^I$, be the graph describing a point $p_i^I$ arisen through removing all edges not running from the point $p_i^I$.

The task of the system is finding in the set of characteristic pattern points and in the set of characteristic points of the image two points which corresponding graphs will best suit. Graphs matching concerns their edges i.e. bearings and distances that describe every edge.

Let's take two any points $p_i^W \in P^W$ and $p_j^I \in P^I$. A graph corresponds to every point. A graph $G^{I,j}$ describes the point of the radar image registered for the certain range $R$ and a graph $G^{W,i}{}_R$ defines the pattern point.

Let's now present edges of every graph as a vertexes of graph $G_{ij}^{D}$, in which the set of vertexes could be divided into two disjoint sets – edges $g_k^{G^{I,j}}, k = 1..\left|P^I\right| - 1$ of the graph $G^{I,j}$ constitute the first set and edges $g_l^{G_R^{W,i}}, l = 1..\left|P_R^{W,i}\right| - 1$ of the graph $G^{W,i}{}_R$ belong to the second set. A matrix of mutual edges assignment $\mathbf{A}^{G_{ij}^D} = \left[a_{lk}^{G_{ij}^D}\right]_{N \times M}$, where

$$a_{lk}^{G_{ij}^D} = \begin{cases} 1 & \text{if connection exists from } g_l^{G_R^{W,i}} \text{ to } g_k^{G^{I,j}} \\ 0 & \text{if connection does not exist from } g_l^{G_R^{W,i}} \text{ to } g_k^{G^{I,j}} \end{cases} \tag{1}$$

complete definition of the graph $G_{ij}^{D}$.

Components of this matrix have additionally to fulfill a condition connected with possibility of an assignment to every vertex belonging to one set of the graph only one vertex from the other set. Similarity of individual edges we place in a matrix $\mathbf{B}_{ij} = \left[b_{lk}^{ij}\right]_{N \times M}$, where

$$b_{lk}^{ij} = \left| g_l^{G_R^{W,i}} \; g_k^{G^{I,j}} \right| \tag{2}$$

Among all possible assignments we eliminate these for which all components do not fulfill following condition: $b_{lk}^{ij} \leq b_{\min}$. The matrix $\mathbf{B}_{ij}$ together with a parameter $b_{\min}$ define a set $\Omega_{\mathbf{B}_{ij}}^{b_{\min}}$ of acceptable graphs $G_{ij}^{D}$ that we can create for a pair $\left(p_i^W, p_j^I\right)$.

## THE ALGORITHM OF CHARACTERISTIC POINTS IDENTIFICATION

The first activity of the algorithm is fixing, for every couple of points $\left(p_i^W, p_j^I\right)$, a graph that defines the edges assignment and for which we are not able to find better assignment. Denote wanted graph as $G_{ij}^{D^*}$.

Evaluation of any graph $G^D \in \Omega_{\mathbf{B}}^{b_{\min}}$ constitutes a vector:

$$\mathbf{E}^1\left(G^D\right) = \left(Z\left(\mathbf{A}^{G^D}\right), S_{\mathbf{B}}\left(\mathbf{A}^{G^D}\right)\right) \tag{3}$$

where

$$Z\left(\mathbf{A}^{G^D}\right) = \sum_{l}^{A_{Height}} \sum_{k}^{A_{width}} a_{lk}^{G^D} \tag{4}$$

$$S_{\mathbf{B}}\left(\mathbf{A}^{G^D}\right) = \sum_{l}^{A_{Height}} \sum_{k}^{A_{width}} b_{lk} a_{lk}^{G^D} \tag{5}$$

Graph $G^{D^*} \in \Omega_{\mathbf{B}}^{b_{\min}}$ is defined following:

$$\forall G^D \in \Omega_{\mathbf{B}}^{b_{\min}} \quad \mathbf{E}^1\left(G^{D^*}\right) \overset{2}{\succ} \mathbf{E}^1\left(G^D\right) \tag{6}$$

where $\overset{2}{\succ}$ is the following relation:

$$(x,y) \overset{2}{\succ} (z,r) \Leftrightarrow (x > z) \vee (x = z \wedge y < r) \vee (x = z \wedge y = r) \qquad x,z \in N,\ y,r \in R \tag{7}$$

The second task of the algorithm is fixing a couple of points $\left(p_i^W, p_j^I\right)^* \in P^W \times P^I$ that fulfill following condition:

$$\forall \left(p_k^W, p_l^I\right) \in P^W \times P^I,\ k = 1..K, l = 1..L \ \ \mathbf{E}^2\left(\left(p_i^W, p_j^I\right)^*\right) \overset{3}{\succ} \mathbf{E}^2\left(\left(p_k^W, p_l^I\right)\right) \ \ i = 1..K, j = 1..L \tag{8}$$

where $\overset{3}{\succ}$ is relation defined in $N \times R \times R$ such that:

$$(x,y,p) \overset{3}{\succ} (z,r,s) \Leftrightarrow (x > z) \vee (x = z \wedge y < r) \vee (x = p \wedge y = r \wedge p < s) \vee (x = z \wedge y = r \wedge p = s) \tag{9}$$

for $x,z \in N,\ y,p,r,s \in R$. $\mathbf{E}^2$ is defined following:

$$\mathbf{E}^2\left(\left(p_i^W, p_j^I\right)\right) = \left( Z\left(\mathbf{A}^{G_{ij}^{D^*}}\right), S_{\mathbf{B}_{ij}}\left(\mathbf{A}^{G_{ij}^{D^*}}\right), d_{jc} \right) \tag{10}$$

where $d_{jc} = \left| p_j^I p_c^I \right|$. $p_c^I$ is a central point of the radar image at coordinates $x_c = \dfrac{W_x - 1}{2}, y_c = \dfrac{W_y - 1}{2}$ (we assume that $W_x, W_y$ are odd).

The couple $\left(p_i^W, p_j^I\right)^*$ and the graph $G_{ij}^{D^*}$ let us determine position of the point $p_j^I$ as well as other points considered in the matrix $\mathbf{A}^{G_{ij}^{D^*}}$ and occurring in the graph $G^{I,j}$. Eventually, knowledge about the location of radar image points and the application of traditional methods of radar navigation yields us potential to fix ship's position.

## VERIFICATION OF THE ALGORITHM

Performance of the algorithm was examined during a simple test with the application of data obtained from radar and chart images covering the Gdansk Bay area. The task of the experiment was merely to check a reaction of the algorithm in a straightforward, evident situation, in which a navigator would not have any problems with taking proper decision concerning the identification of characteristic points present on the radar image. An in-depth analysis of the algorithm performance in more elaborate situations will be conducted subsequently. The radar image used during tests was registered for the radar observation range – 6 Nm and possessed resolution 224x200 pixels. The chart image corresponds to the scale 1:100000 and was reduced to the size 360x292 pixels. Characteristic points of the radar image as well as pattern points of the chart image were generated manually. Their location was so established, that every image contained both points that should be recognized (the algorithm should assign these points together) and points that constituted noise (they should be rejected during algorithm processing).

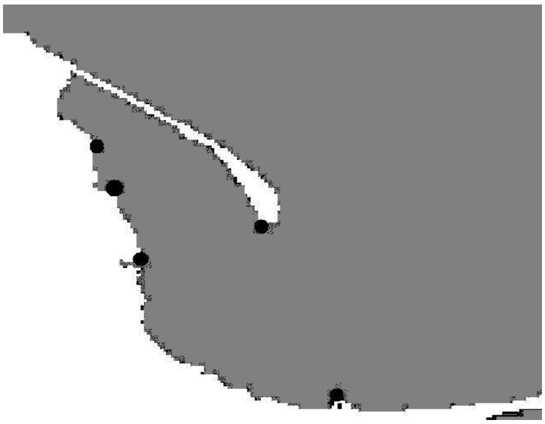

Fig. 1. The test chart image with marked pattern points

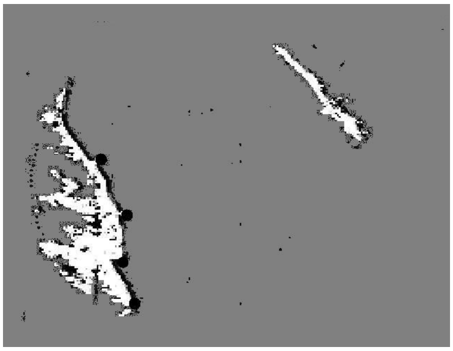

Fig. 2. The test radar image with marked characteristic points

During experiments two values of parameter $b_{\min}$ were established – 2 and 5. Conducted tests consisted in fixing by the algorithm the couple $\left(p_i^W, p_j^I\right)^*$. Possible results of the algorithm performance were: a proper points assignment, a wrong assignment or a situation in which the algorithm was not able to identify any characteristic point of the radar image. The latter contingency could happen in the case when value of $b_{\min}$ was too demanding and the algorithm did not find for any characteristic point of the radar image the sufficiently good equivalent among pattern points. The following figure depicts outcomes of driven tests.

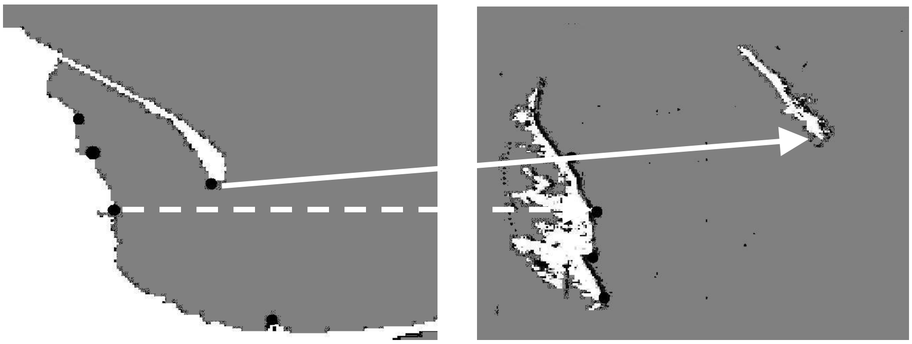

Fig. 3. The best assignment $\left(p_i^W, p_j^I\right)^*$ for both values of $b_{\min}$ – solid line

Regardless of $b_{\min}$ value the algorithm as the best assignment chose a couple of points marked on the fig. 3 by solid line. This assignment possessed as „good" assignment graph as assignment marked on the fig. 3 by dashed line. A final decision of the algorithm resulted from the distance of every characteristic point from the center of the image. It is assumed that the closer the given characteristic point is located from the center of the image (in the center our ship is situated) the more accurate bearing and distance to this point and consequently more accurate fixed position.

## CONCLUSIONS

The article describes the method of characteristic points, extracted from the radar image, identification. The proposed solution is based on comparison of relative bearings and distances fixed for pattern points (from a chart) and for points extracted from the radar image.

Preliminary tests of the algorithm application, conducted on the simple training data, demonstrated correct behavior of the algorithm, which properly identified characteristic points present on the radar image. However the accomplished experiment did not completely determine capabilities of the presented method. For in-depth analysis of usefulness of the algorithm it is necessary to carry out additional tests that would take into consideration such parameters as: a density of characteristic points deployment or an error of the radar image orientating according to the North-South direction.

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