Tomasz Praczyk
Naval University of Gdynia

IDENTIFICATION OF CHARACTERISTIC POINTS OF THE RADAR IMAGE ON THE BASIS OF "CONTOUR" INVARIANTS COMPARISON

ABSTRACT The article presents the one element of the autonomous maritime positioning system which task is the identification of characteristic points generated from the radar image. The system to fix position in automatic way requires extraction of characteristic points, their identification and subsequently in the last calculation step an application of classical methods of the radar navigation. The present article illustrates the characteristic point's identification algorithm based on the invariant representation of the radar image.

INTRODUCTION

The article undertakes an issue of the autonomous coastal positioning system, which could constitute an alternative for satellite systems (e.g. GPS) in case we could not take advantage of the last mentioned system. The proposed system would work on the basis of the same rules and methods, which a navigator uses in the process of fixing position and applying to this purpose an image obtained from radar. The first activity of the system is a registration of the radar image. Subsequently, after an initial image processing phase consisting in an elimination whole echoes coming from moving objects, an extraction of characteristic points from the radar image follows. In the next stage points that match the most pattern points generated from the chart and memorized in a database of the system are selected. Exact positions of pattern points are next assigned to selected characteristic points. An attempt is then made to correct a location of image's points in order to match the best their mutual deployment and mutual deployment of pattern points. Vectors of distances and bearings between pattern points could be used to this purpose. In the last stage of calculations the system equipped in positions of selected image's points and applying classical methods of the radar navigation fixes the ship position.

There are a lot of methods that serve to fix the position on the sea and use to this purpose information incorporated within the radar image. The first idea was straightforward comparison of the registered radar image to pattern images memorized in the database. The pattern image the most similar to the image from radar fixes ship position. Another solutions use to these purpose artificial intelligence methods, particularly artificial neural networks that are sensible for approximation of any nonlinear function. The fixing position problem on the basis of the radar image we could reduce to the approximation function task. Other approaches attempt to substitute the radar image or its representation obtained with the aid of any feature extraction methods for the set of points situated on the image and uses these points in the fixing position process. One of the potential solutions in this area is the application of the vector of bearings and distances between extracted characteristic points as an input data to the neural network, which learned with the help of the set of such points is capable to fix the vessel position. Another example of a solution that works on the basis of characteristic points of the image is the method that is the content of the present article.

In principle, the article is divided into two parts. In the first of them the proposed method of characteristic point's identification is presented. The second part reports the verification of the method on the strength of two sets of data: pattern and test set. Pattern data constitute characteristic points fixed from the electronic chart whereas test data are points extracted from sample radar images.

INVARIANT REPRESENTATION OF AN IMAGE POINT

The invariant representation of the radar image for its central point was yet defined in [Praczyk, 2004] and is following:

$$g_{inw}(NR) = \min_{P^c \in D(NR)} \left| P^o P^c \right| \quad (1.)$$

where: P^0 is the image central point;
NR - the bearing fixed from the point P^0;
$D(NR)$ - the set of "bright" points lying on the bearing NR.

In order to define the invariant representation for any point that does not lie in the image center, it is necessary to specify the equation (1.) in the following manner:

$$g_{inw}^{P}(NR) = \min_{P^c \in D^P(NR)} \left| P P^c \right| \quad (2.)$$

where: P is any point of the radar image (e.g. characteristic point);
NR - the bearing fixed from this point;
$D^P(NR)$ - the set of "bright" points lying on the bearing NR.

In order to enable comparison of radar image invariants fixed for characteristic points of that image to invariants determined for pattern characteristic points generated from the navigational chart it is first of all necessary to reduce all invariants to the "common denominator". Note, that the chart and the radar image could be in different scales. In order to ensure compatibility of invariants it is necessary to fix them using every time real distances e.g. in nautical miles but not distances between image pixels. Another crucial issue is taking a restricted field of vision in the radar image case into consideration. Area size we can observe with the radar is limited by radar range. Therefore, g_{inw}^{P} values for any radar image point *P* and for any bearing *NR* are always less then 2**R*. In case that we deal with the radar image in which center all the radar situation is located (Fig 1a), maximum value $g_{inw,MAX}^{P}$ for the bearing *NR* is as follows:

$$g_{inw,MAX}^{P(x,y)}(NR)=\begin{cases} 0 \text{ dla } \left(\left(NR=0^\circ \vee NR=180^\circ\right)\wedge\left(x=0\vee x=W\right)\right)\vee\left(\left(NR=90^\circ \vee NR=270^\circ\right)\wedge\left(y=0\vee y=W\right)\right) \\ f^R(w_1),\ w_1=y-y_1 \text{ dla } NR=0^\circ \wedge x\neq 0\wedge x\neq W \\ f^R(w_2),\ w_2=y_2-y \text{ dla } NR=180^\circ \wedge x\neq 0\wedge x\neq W \\ f^R(w_3),\ w_3=x-x_1 \text{ dla } NR=270^\circ \wedge y\neq 0\wedge y\neq W \\ f^R(w_4),\ w_4=x_2-x \text{ dla } NR=90^\circ \wedge y\neq 0\wedge y\neq W \\ f^R(w_5),\ w_5=\sqrt{(x-x_3)^2+(y-y_3)^2} \text{ dla } \left(270^\circ < NR < 360^\circ\right)\vee\left(180^\circ < NR < 270^\circ\right) \\ f^R(w_6),\ w_6=\sqrt{(x-x_4)^2+(y-y_4)^2} \text{ dla } \left(90^\circ < NR < 180^\circ\right)\vee\left(0^\circ < NR < 90^\circ\right) \end{cases} \quad (3)$$

$$x_1=x^o-\sqrt{2y^o y+\left(W/2\right)^2-y^2-\left(y^o\right)^2} \quad (4)$$

$$x_2=x^o+\sqrt{2y^o y+\left(W/2\right)^2-y^2-\left(y^o\right)^2} \quad (5)$$

$$x_3=\frac{x^o-z(NR)(y-z(NR)x)+z(NR)y^o-\sqrt{\begin{array}{l}2x^o y^o z(NR)-2x^o z(NR)(y-z(NR)x)-(y-z(NR)x)^2\\+2y^o(y-z(NR)x)-\left(y^o\right)^2-\left(x^o z(NR)\right)^2+\left(W/2\right)^2\end{array}}}{1+z(NR)^2} \quad (6)$$

$$x_4=\frac{x^o-z(NR)(y-z(NR)x)+z(NR)y^o+\sqrt{\begin{array}{l}2x^o y^o z(NR)-2x^o z(NR)(y-z(NR)x)-(y-z(NR)x)^2\\+2y^o(y-z(NR)x)-\left(y^o\right)^2-\left(x^o z(NR)\right)^2+\left(W/2\right)^2\end{array}}}{1+z(NR)^2} \quad (7)$$

$$y_1=y^o-\sqrt{2x^o x+\left(W/2\right)^2-x^2-\left(x^o\right)^2} \quad (8)$$

$$y_2=y^o+\sqrt{2x^o x+\left(W/2\right)^2-x^2-\left(x^o\right)^2} \quad (9)$$

$$y_3 = z(NR)x_1 + y - z(NR)x \tag{10}$$

$$y_4 = z(NR)x_2 + y - z(NR)x \tag{11}$$

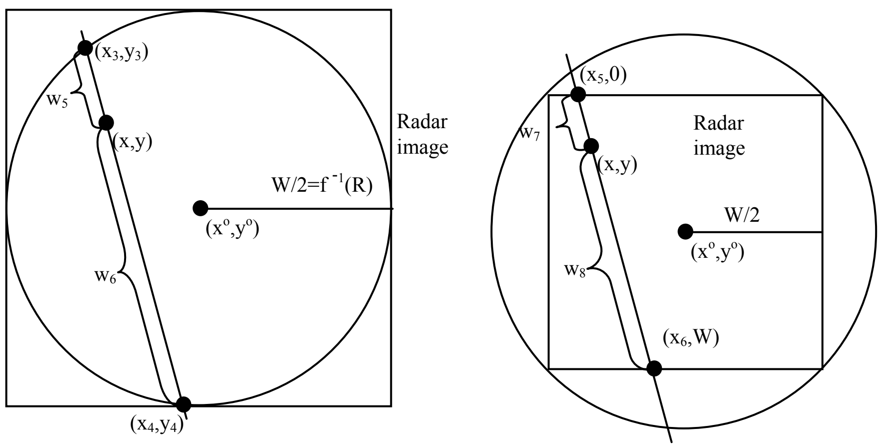
where: x, y are coordinates of the given characteristic point – we assume that x, y holds following inequality $(x - x^o)^2 + (y - y^o) \le (W/2)^2$;

W - size of the radar image (it is assumed that the image height is the same as the image width);

x^o, y^o - coordinates of the radar image central point, $x^o = y^o$ (coordinates of left upper pixel of the image are equal (1,1));

$f^R(\bullet)$ - function that converts the distance between image points into the real distance, it is dependant on *R*;

$z(NR)$ - function that define a line that goes through point x, y and is consistent with the bearing *NR*;



a) **b)**

Fig. 1. Illustration of the range observation from the radar image point (x,y).

In the situation depicted on Fig 1b i.e. when the radar image covers only a portion of an available radar situation, maximum value $g^P_{inw,MAX}$ is as following:

$$g^{P(x,y)}_{inw,MAX}(NR) = \begin{cases} 0 \text{ dla } ((NR = 0^\circ \vee NR = 180^\circ) \wedge (x = 0 \vee x = W)) \vee ((NR = 90^\circ \vee NR = 270^\circ) \wedge (y = 0 \vee y = W)) \\ f^R\left(W/2 - |y^o - y|\right) \text{ dla } (NR = 0^\circ \vee NR = 180^\circ) \wedge (x \ne 0 \wedge x \ne W) \\ f^R\left(W/2 - |x^o - x|\right) \text{ dla } (NR = 90^\circ \vee NR = 270^\circ) \wedge (y \ne 0 \wedge y \ne W) \\ f^R(w_7),\ w_7 = \sqrt{(x - x_5)^2 + y^2} \text{ dla } (315^\circ \le NR < 360^\circ) \vee (0^\circ < NR \le 45^\circ) \\ f^R(w_8),\ w_8 = \sqrt{(x - x_6)^2 + (y - W)^2} \text{ dla } (135^\circ \le NR < 180^\circ) \vee (180^\circ < NR \le 225^\circ) \\ f^R(w_9),\ w_9 = \sqrt{x^2 + (y - y_5)^2} \text{ dla } (225^\circ < NR < 270^\circ) \vee (270^\circ < NR < 315^\circ) \\ f^R(w_{10}),\ w_{10} = \sqrt{(x - W)^2 + (y - y_6)^2} \text{ dla } (45^\circ < NR < 90^\circ) \vee (90^\circ < NR < 135^\circ) \end{cases} \tag{12}$$

where:

$$x_5 = \frac{z(NR)x - y}{z(NR)} \tag{13}$$

$$x_6 = \frac{z(NR)x - y + W}{z(NR)} \tag{14}$$

$$y_5 = y - z(NR)x \tag{15}$$

$$y_6 = z(NR)W + y - z(NR)x \tag{16}$$

In case of pattern points, occurring on the chart image, values g_{inw}^{P} are limited merely by the image size that is usually larger then the range of radar observation. Thus, it is necessary to carry out the procedure that consists in cutting values g_{inw}^{P} if they exceed maximum acceptable value. This value depends on the bearing NR and on this what characteristic point of the radar image is compared to the given pattern point. In order to compare invariants for two points – the characteristic point of the radar image and the pattern point of the chart image – it is necessary to reduce them to the "common denominator". Maximum values of invariants that we could obtain for the given bearing and for both points should be equal. Formally, we could define it as follows:

$$g_{inw,MAX}^{P_i^{OR}}(NR) = g_{inw,MAX}^{P_j^{OM}}(NR)$$

where: P_i^{OR}, P_j^{OM} denote respectively i^{th} characteristic point of the radar image and j^{th} pattern point of the chart image.

THE ALGORITHM OF RADAR IMAGE CHARACTERISTIC POINTS IDENTIFICATION

The task of the algorithm is not assigning an identity (a counterpart on the chart) to every characteristic point. The function of the algorithm is determination a set of pairs – (the radar image characteristic point, the chart image pattern point) – which components the most suit each other. Note that this set does not have to contain pairs that identify every characteristic point. The algorithm relays on comparison of every characteristic point of the radar image to every pattern point (we compare invariants for every point). The degree of similarity between individual points is determined by a matrix $\mathbf{A} = [a_{ij}]_{N \times M}$, where N and M describe respectively a number of characteristic points and a number of pattern points. We assume that every row and every column of the original matrix $\mathbf{A}$ possess a unique number determining an index of the point associated with a given row or column. The elements of $\mathbf{A}$ are following:

$$a_{kl} = \frac{\sum_{i=0}^{b-1}\left(g_{inv}^{P_k^{OR}}(i\Delta NR) - g_{inv}^{P_l^{OM}}(i\Delta NR)\right)^2}{b} \quad (17)$$

$$g_{inv}^{P_l^{OM}} = \begin{cases} g_{inv,MAX}^{P_l^{OM}} \text{ dla } g_{inv}^{P_l^{OM}} > g_{inv,MAX}^{P_l^{OM}} \\ \text{lub} \\ g_{inv}^{P_l^{OM}} \end{cases} \quad (18)$$

In the equation (17) k, l denote indexes assigned to individual characteristic and pattern points, b determines the amount of bearings for which invariants are fixed (accuracy of the invariant representation) and ΔNR denotes bearing increase, necessary to fix consecutive invariant values.

For every row of **A** (the characteristic point of radar image) a maximum component is fixed that indicates which of pattern points matches the best the characteristic point corresponding to the given row of the matrix **A**. All rows for which values of maximal components do not exceed assumed threshold δ are removed from **A**. We assume that we can not find suitably resemble equivalents among pattern points for characteristic points assigned to canceled rows. Furthermore, among all rows, which maximum components are located in the same column we remain only one with the largest value of maximum entry. It is performed in order to remove every ambiguity in pattern point's assignment to individual characteristic points.

Next to last activity of the algorithm is elimination from the matrix **A** every column that does not incorporate maximum component for any row. Pattern points corresponding to removed columns do not have appropriately good equivalent among characteristic points of the radar image. Ultimately, an ordering of every assignment, determined by maximum component, according to increasing values of these components is performed. Assignments from the beginning of the ordering indicate characteristic points identified with the greatest confidence. Degree of confidence is determined by the value of the maximum entry that corresponds to given assignment. More formally the described algorithm is as follows.

1. Fix invariants for every characteristic point of radar image,
2. Fix invariants for every pattern point,
3. Determine elements of matrix A according to equation (),
4. Remove k^{th} rows from matrix **A** for which $\forall_{l \in I^{OM}} a_{kl} < \delta, k \in I^{OR}$

   where I^{OM}, I^{OR} are indexes sets for respectively individual pattern points and characteristic points of radar image, indexes set corresponding to eliminated rows we denote $I^{OR,\delta}$,

5. Determine for every k^{th} row of modified matrix **A** maximal elements $a_{kl}^* = a_k^*$ such, that $\underset{r \in I^{OM}}{\forall} a_{kl}^* \geq a_{kr}, k \in I^{OR} - I^{OR,\delta}, l \in I^{OM}$. In the case, when there exists more then one such element it is necessary to choose arbitrarily one of them,
6. Eliminate r^{th} rows from **A** for which $a_{rt}^* < a_{kl}^* \wedge l = t,\ k, r \in I^{OR} - I^{OR,\delta}, l, t \in I^{OM}$, indexes set of removed rows we denote $I^{OR,\gamma}$,
7. In the case when rows remain in the matrix A for which $a_{rt}^* = a_{kl}^* \wedge l = t$ it is necessary to remain only one of them, $I^{OR,\beta}$ denotes indexes set of eliminated rows,
8. Remove l^{th} columns from modified **A** for which $\underset{k \in I^{OR,\text{mod}}}{\forall} a_{kl} \neq a_k^*, l \in I^{OM}$ where $I^{OR,\text{mod}} = I^{OR} - I^{OR,\delta} - I^{OR,\gamma} - I^{OR,\beta}$, $I^{OM,\text{mod}}$ denotes set of indexes of pattern points that remain in matrix **A**,
9. Order elements that belong to $\Phi = \{(k,l) \in I^{OR,\text{mod}} \times I^{OM,\text{mod}} : a_k^* = a_{kl}^*\}$ (characteristic points of the radar image to pattern points assignments set) in the way so that $\underset{(k,l),(r,t) \in \Phi}{\forall} \pi(k,l) < \pi(r,t) \Leftrightarrow a_{kl}^* > a_{rt}^*$ where $I\pi$ is an index assigned to a given assignment in the ordered set of assignments.

VERIFICATION OF THE ALGORITHM

Performance of the algorithm was examined during a simple test with the application of data obtained from the radar and chart images covering the Gdańsk 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 problem 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).

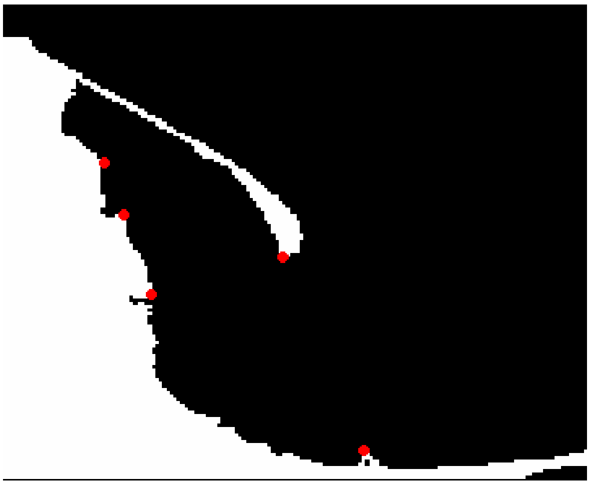


Fig. 2. The test chart image with marked red pattern points

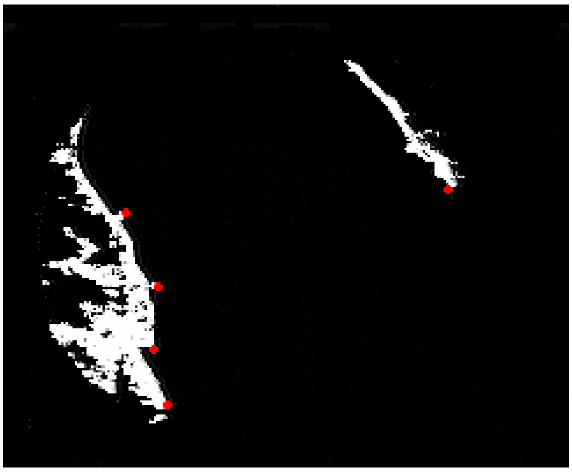


Fig. 3. The test radar image with marked red characteristic points

Invariants for every point were fixed in the range form 0º to 259º every 1º. Tests were conducted for two values of δ parameter - δ=0,2 and δ=0,1. Performance of the algorithm is illustrated on Fig 4.

Fig. 4. Identified characteristic points, solid arrows indicates identification for δ =0,2, dashed arrow determines identification for δ =0,1

The picture presents proper behavior of the algorithm, which filter pattern points and radar image points set from points for which it could not find suitably „good" equivalents, preserving only points that invariants were sufficiently similar.

CONCLUSIONS

The article describes the method of characteristic points, extracted from the radar image, identification. The comparison of invariants fixed for radar image points to invariants determined for pattern points, situated on the navigational chart, constitutes the basis of the identification.

Preliminary algorithm behavior assessment in the simple test situation was conducted. The experiment demonstrated the proper reaction of the algorithm, which was able to assign appropriate radar image points to pattern points (with known accurate position).

During subsequent researches a detailed analysis of algorithm capabilities in more elaborate situations will be carried out. The algorithm behavior in a situation of characteristic points dense deployment i.e. in case of larger similarities between invariants should be checked. Moreover in the future experiments error of magnetic compass that serves to orientating the radar image according to the North-South direction should be taken into consideration. The rotation of the image affecting the form of the invariant could consequently influence results of the algorithm.

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Received September 2005
Reviewed November 2005