Tomasz Praczyk
Naval University of Gdynia

THE METHOD OF EXTRACTION OF CHARACTERISTIC POINTS FROM THE RADAR IMAGE OF THE SEA SHORE FOR THE NEEDS OF POSITIONING SYSTEM

ABSTRACT The problem of continuous position availability is one of the most important issues connected with human activity on the sea. Because the availability of the electronic navigational systems can be limited in some cases (for example military operations) we should considered additional methods of gathering information about ship's position. In this paper one of these methods is presented, which is based on extraction specific features from radar images – characteristic points of the coast line.

INTRODUCTION

The primary positioning system can be unplugged, destroyed or malfunctioning. Therefore this is a reason why the alternative methods of position estimating should be taken into account. This is especially important for the naval ships. The military, auxiliary positioning system should be as autonomous as it is possible. It should give the possibility to estimate the ship's position without information from electronic navigational systems like GPS or others.

Solution of using traditional radar navigational algorithms (based on using the information about the bearing and distance to the characteristic points) together with extracting characteristic points from radar images algorithm has such a feature.

In this paper method of extracting characteristic points from the radar image is presented.

FUNCTIONING OF THE SYSTEM

Hypothetical structure of the whole system is presented on the Fig. 1.

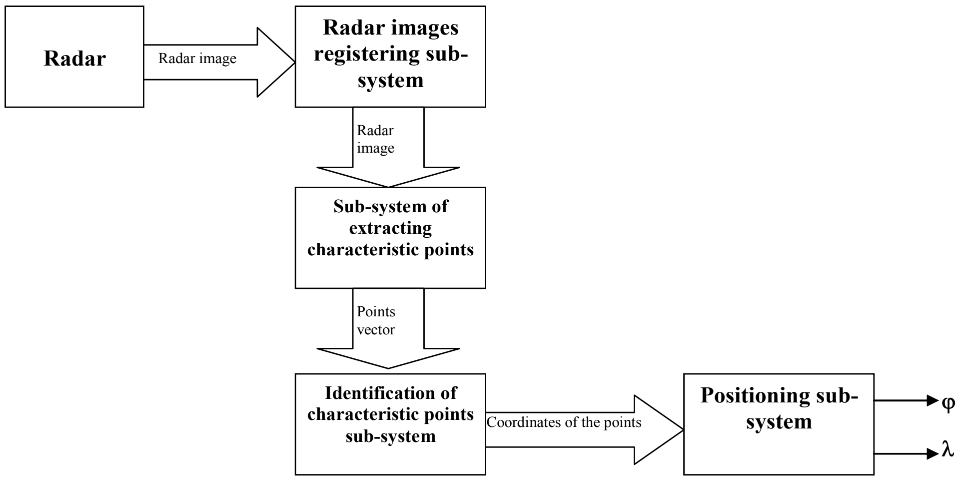


Fig. 1. Structure of the system

The main task of the radar images registering subsystem is transferring radar signal to the digital form. The additional task is eliminating of the echoes coming from the moving ships. In this case the subsystem should be able to track the images coming from radar in order to distinguish the constant objects from the moving one.

The main task for the subsystem of extracting characteristic points is preparing a vector of characteristic points from the coast area visible on the registered radar image.

In the next phase a vector of bearings and distances between characteristic points will be a base for the identification subsystem. The main task for this subsystem is identification the sufficient number of points to calculate ship's position.

In the final step the system estimates the ship's position using identifying points and traditional navigational methods.

METHOD OF EXTRACTION OF CHARACTERISTIC POINTS FROM RADAR IMAGE

When talking about extracting the characteristic points from radar image we should start from the presenting considering images in the form of contour invariant.

First we should define the image. Let the analog monochromatic image will be presented by the function $L^a(x,y)$ [11]:

$$L^a : O^a \to R \tag{1}$$

where O^a is a set of points $P^a(x,y)$ that:

$$O^a = \{(x,y) \in R^2 : x \in <0, N>, y \in <0, M>\} \tag{2}$$

$N, M \in \mathrm{N}$ - determine the size of the image.

The digital image in our case we may determine as a function $L^c(n,m)$:

$$L^c : O^c \to \mathrm{N} \tag{3}$$

where $O^c \subset O^a$ is a set of points $P_i^c(n,m)$ that i =0,1..,N*M-1 and

$$O^c = \{(n,m) \in \mathrm{N}^2 : n \in <0, N>, m \in <0, M>\} \tag{4}$$

Let assume that the N and M which determine the size of the image are odd, so for the each one image we can determine the central point $P^o(n_o,m_o)$ that:

$$n_o = \frac{N-1}{2}, m_o = \frac{M-1}{2} \tag{5}$$

The analog image as well as digital one can be presented in polar coordinate system. For that presentation each one point of image P(x,y) is determined by bearing NR on that point from central one and distance $d=|P^oP|$ [12].

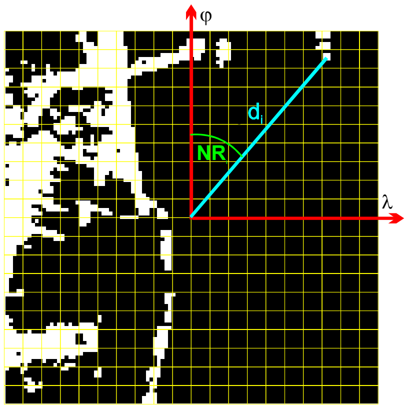


Fig. 2. Example of radar image presented in polar coordinate system

There is a possibility to change the representation from the polar coordinate system to the Cartesian coordinate system. A mapping function from the Cartesian to the polar coordination system and in the other way can be as follows (for the analog image):

$$NR = f_{NR}(x, y), d = f_d(x, y) \tag{6}$$

$$x = f_x^a(NR, d), y = f_y^a(NR, d), x, y \in O^a \tag{7}$$

For the digital image we should start from the determining the mapping of each point of analog image to the appropriate point of digital image.

$$f_{Pc} : O^a \to O^c \tag{8}$$

$$f_{Pc}(P^a) = \arg\min_{P^c \in O^c} \left| P^c P^a \right| \tag{9}$$

Finally we will get the mapping function between the polar and Cartesian coordinate system for the digital image:

$$(n, m) = f_{Pc}\left(f_x^a(NR, d), f_y^a(NR, d)\right) \tag{10}$$

The next step is the determining for each image the set of points lying on the bearing NR, that $D_{NR}^a \subset O^a$ and $D_{NR}^c \subset O^c$.

$$D_{NR}^a = \{(x, y) \in O^a : f_{NR}(x, y) = NR\} \tag{11}$$

$$D_{NR}^{c} = \{(n,m) \in O^{c} : (n,m) = f_{Pc}(P^{a}), P^{a} \in D_{NR}^{a}\} \tag{12}$$

Next we will define the set $D_{NR,W}^{c} \subseteq D_{NR}^{c}$ of visible points of digital image on the bearing NR.

$$D_{NR,W}^{c} = \{P^{c} \in D_{NR}^{c} : L^{c}(P^{c}) > 0\} \tag{13}$$

Finally we can define the function on contour invariant $d = g_{inw}(NR)$ that:

$$g_{inw}(NR) = \min_{P^{c} \in D_{NR,W}^{c}} \left|P^{o} P^{c}\right| \tag{14}$$

For the simplifying the algorithm of the presented method, function (14) have been replaced by function:

$$g_{inw}^{k}(k) = \min_{P^{c} \in D_{NR_k,W}^{c}} \left|P^{o} P^{c}\right| \quad k = 0,1,..,2(N+M)-1 \tag{15}$$

where $NR_{k} = f_{NR}(P_{b,k}^{c})$ it is the bearing at k coastal point of the image $P_{b,k}^{c} \in D_{b}^{c} = \{(n,m) : n = N \vee m = M\}$ and k is an index of the coastal point in the ordered series of coastal points. The ordering function can be presented as follows:

$$P_{b,k+1}^{c} = f_{b}(P_{b,k}^{c}) = \begin{cases} (n_k, m_k + 1) \text{dla} k = 0,1,..,M-1 \\ (n_k + 1, m_k) \text{dla} k = M,..,M+N-1 \\ (n_k, m_k - 1) \text{dla} k = M+N,..,2M+N-1 \\ (n_k - 1, m_k) \text{dla} k = 2M+N,..,2(M+N)-1 \end{cases} \quad n_0 = 0, m_0 = 0 \tag{16}$$

For the function determining contour invariant for the digital image we can define function $g_{inw}^{I}(x)$ determined on the set $I = \{x \in R : x \in < 0,2(N+M)-1 >\}$, than $g_{inw}^{I}(x) = g_{inw}^{k}(k) \text{dla } x = k$. This function defines contour invariant for the analog image. Proposed method of extracting the characteristic points from radar image is based on the analysis of the second derivative of the function $g_{inw}^{I}(x)$.

As an estimator of this function we may use the following:

$$\widehat{g}_{inw}^{I}(x,\sigma)=\frac{\sum_{k=0}^{2(N+M)-1} g_{inw}^{k}(k)\varphi_k(x,\sigma)}{\sum_{k=0}^{2(N+M)-1}\varphi_k(x,\sigma)} \tag{17}$$

$$\varphi_k(x,\sigma)=e^{-\frac{(x-k)^2}{2\sigma^2}} \tag{18}$$

The second derivative of that function is as follows:

$$r(x,\sigma)=\sum_{k=0}^{2(N+M)-1} g_{inw}^{k}(k)\varphi_k(x,\sigma) \tag{19}$$

$$e(x,\sigma)=\sum_{k=0}^{2(N+M)-1}\varphi_k(x,\sigma) \tag{20}$$

$$p(x,\sigma)=\frac{dr(x,\sigma)}{dx}=\sum_{k=0}^{2(N+M)-1}\left[g_{inw}^{k}(k)\varphi_k(x,\sigma)\left(\frac{k-x}{\sigma^2}\right)\right] \tag{21}$$

$$h(x,\sigma)=\frac{de(x,\sigma)}{dx}=\sum_{k=0}^{2(N+M)-1}\left[\varphi_k(x,\sigma)\left(\frac{k-x}{\sigma^2}\right)\right] \tag{22}$$

$$m(x,\sigma)=\frac{d^2r(x,\sigma)}{dx^2}=\sum_{k=0}^{2(N+M)-1}\left[g_{inw}^{k}(k)\varphi_k(x,\sigma)\left(\left(\frac{k-x}{\sigma^2}\right)^2-\frac{1}{\sigma^2}\right)\right] \tag{23}$$

$$n(x,\sigma)=\frac{d^2e(x,\sigma)}{dx^2}=\sum_{k=0}^{2(N+M)-1}\left[\varphi_k(x,\sigma)\left(\left(\frac{k-x}{\sigma^2}\right)^2-\frac{1}{\sigma^2}\right)\right] \tag{24}$$

$$z(x,\sigma)=\frac{d^2\widehat{g}_{inw}^{I}}{dx^2}=\frac{(me-rn)e^2-2(pe-rh)eh}{e^4} \tag{25}$$

The algorithm should be able to estimate $z(k)$ for the σ in points $k=0,1,..,2(N+M)-1$ and then finding k, that

$$z(k)>\lambda\wedge z(k)>z(k-1)\wedge z(k)\geq z(k+1)\wedge f_{Pc}\left(f_x^a\left(NR_k,g_{inw}^{k}(k)\right),f_y^a\left(NR_k,g_{inw}^{k}(k)\right)\right)\notin D_b^c \tag{26}$$

where λ allows segregation of the set of potential characteristic points on the groups: visible - $z(k) > \lambda$ and hardly visible - $z(k) \le \lambda$. Another parameter of the algorithm is σ . We can say that λ eliminates hardly visible points from the list of characteristic points and σ prevents generating them.

Finally points:

$$(n,m) = f_{Pc}\left(f_x^a\left(NR_k, g_{inw}^k(k)\right), f_y^a\left(NR_k, g_{inw}^k(k)\right)\right) \tag{27}$$

are considered as characteristic points of the given radar image.
Below results of processing the radar image of Gdańska Bay are presented.

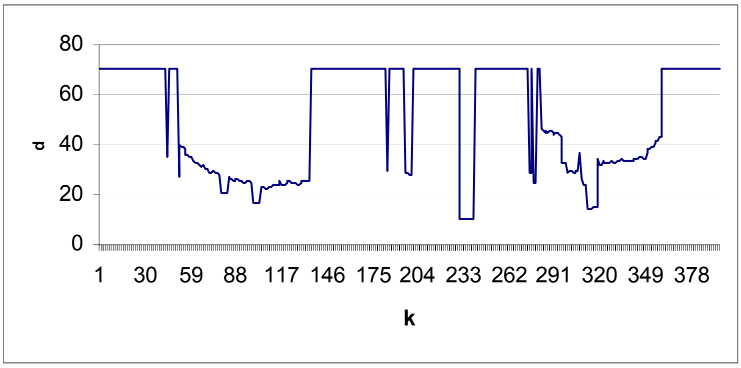


Fig. 3. Contour invariant of the radar image

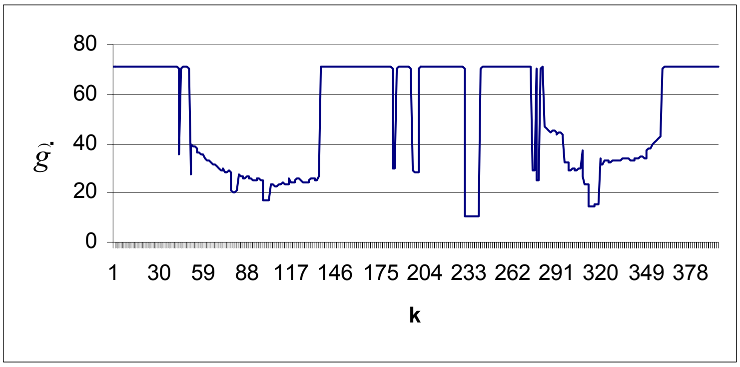


Fig. 4. Function $\hat{g}_{inw}^I(x,\sigma)$ in $k = 0,1,..,2(N+M)-1$ for σ =0.1

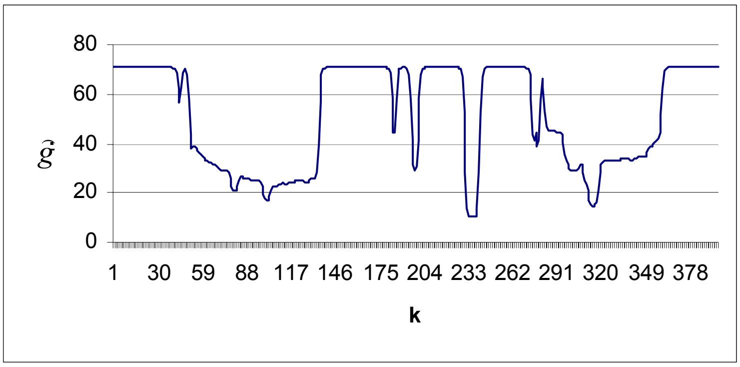


Fig. 5. Function $\hat{g}^{I}_{inw}(x,\sigma)$ in $k = 0,1,..,2(N+M)-1$ for σ =1

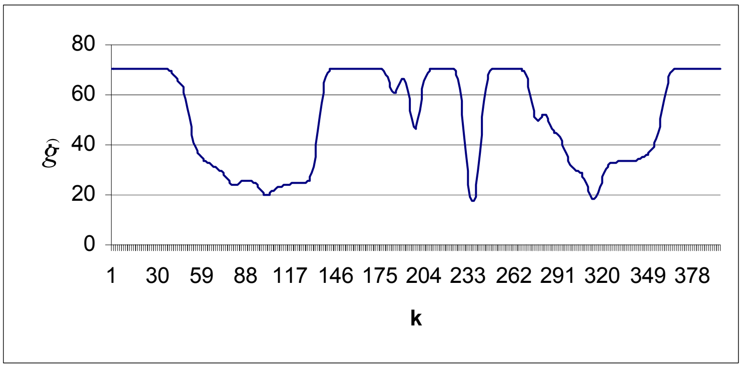


Fig. 6. Function $\hat{g}^{I}_{inw}(x,\sigma)$ in $k = 0,1,..,2(N+M)-1$ for σ =10

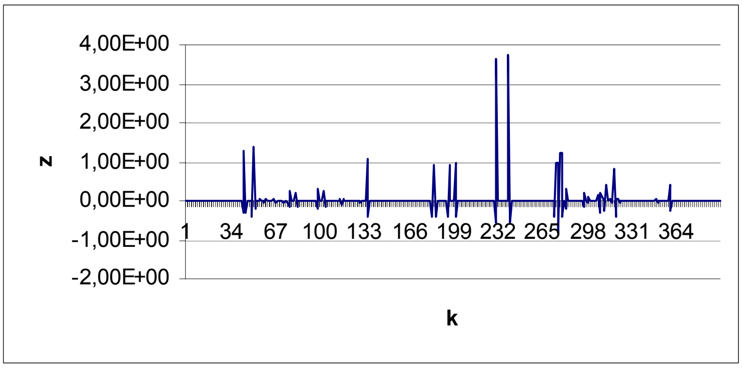


Fig. 7. Plot of $z(k)$ in $k = 0,1,..,2(N+M)-1$ for σ =0.1

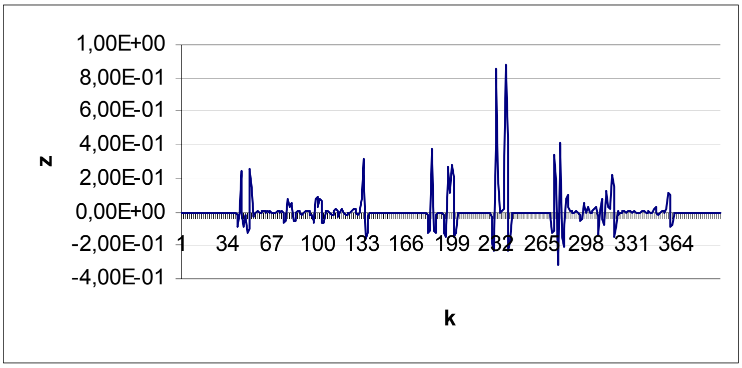


Fig. 8. Plot of $z(k)$ in $k = 0,1,..,2(N + M) - 1$ for σ =1

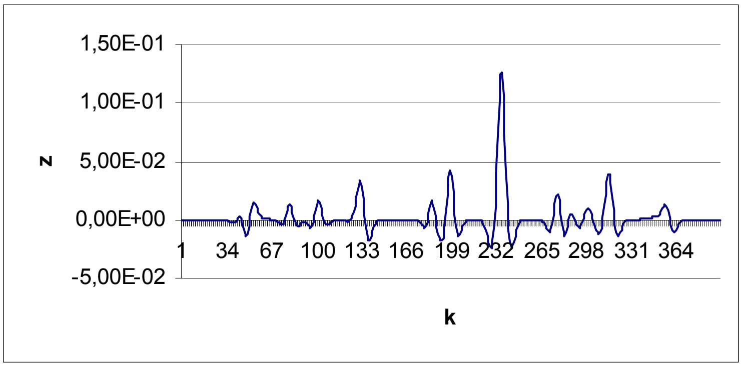


Fig. 9. Plot of $z(k)$ in $k = 0,1,..,2(N + M) - 1$ for σ =10

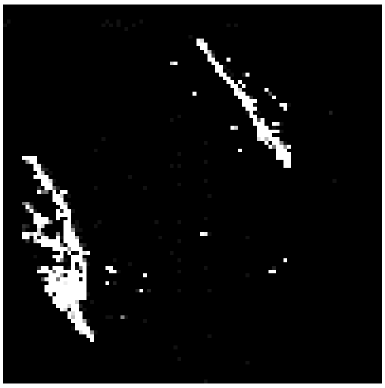
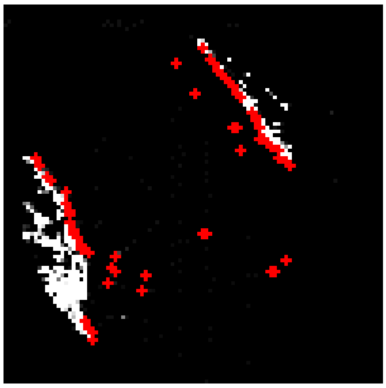
a)  b) 

Fig. 10. Original image (a), points calculated for σ =0.1, λ =0.01 (b)

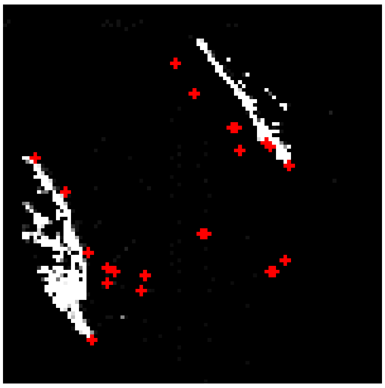
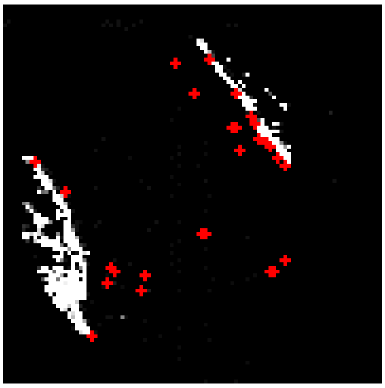
a)  b) 

Fig. 11. Characteristic points calculated for σ =0.1, λ =0.5 (a) and σ =1, λ =0.1 (b)

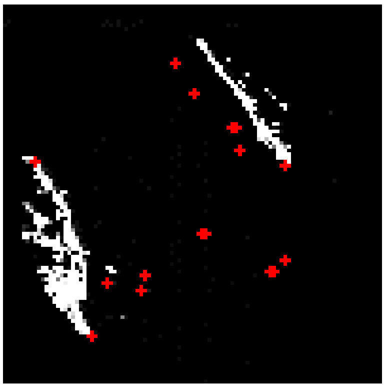
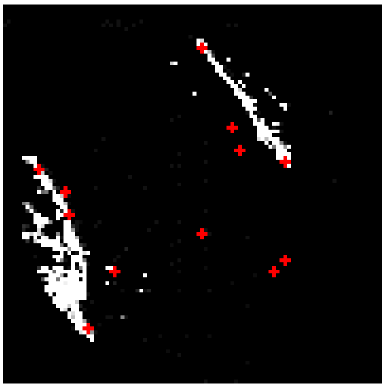
a)  b) 

Fig. 12. Characteristic points calculated for σ =1, λ =0.5 and σ =10, λ =0.01

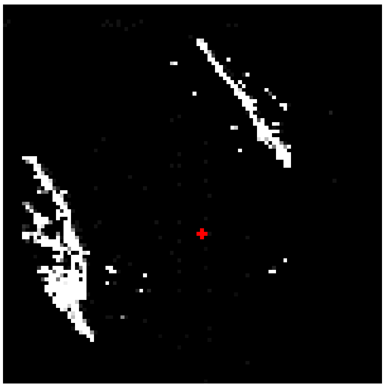


Fig. 13. Characteristic points calculated for σ =10, λ =0.5

CONCLUSIONS

We may draw the following conclusion, it is possible to apply presented algorithm to the task of extracting of characteristic points from the given radar image.

Conducted tests revealed that the key parameters are σ and λ. If σ>1, then algorithm consolidates very close characteristic points in one point or moves coast line points to wrong places. Thus we decided that value of that parameter should be approximately 0.1.

Presented algorithm may estimate characteristic points or be only considered as an auxiliary system for the operator, who finally estimate the location of characteristic points let's say by hand. This concerns situation when the object has a very large echo, and the algorithm can estimate it as a large object with the bigger number of characteristic points.

Another element of the system which can eliminate additional, impropriate points generated by extracting points subsystem, except the user, is identification subsystem. It should be able to choose only those points, as base points, which have their patterns in the base of knowledge and then what is very important correct their positions on the radar image.

REFERENCES

1. Cyganek B., Komputerowe przetwarzanie obrazów trójwymiarowych, AOW EXIT 2002.
2. Doros M., Przetwarzanie obrazów – materiały pomocnicze, WSISiZ, Warszawa 2000.
3. Kuchariew G., Przetwarzanie i analiza obrazów cyfrowych, Politechnika Szczecińska, Szczecin 1999
4. Pavlidis T., Grafika i przetwarzanie obrazów. Algorytmy, WNT, Warszawa 1987.
5. Praczyk T., Sieć Kohonena w kompresji obrazów radarowych, Zeszyty Naukowe AMW 2003 nr 1.
6. Praczyk T., Sieć GRNN w kompresji obrazów radarowych, Zeszyty Naukowe AMW 2003 nr 3.
7. Praczyk T., Cichocki A., Kompresja obrazu radarowego samoorganizującą siecią Kohonena. Prace naukowe Politechniki Radomskiej, 2003.
8. Skarbek W., Metody reprezentacji obrazów cyfrowych, Akademicka Oficyna Wydawnicza PLJ, Warszawa 1993.

9. Stateczny A., Praczyk T., Artificial Neural Networks In Radar Image Compression, Iternational Radar Symposium IRS 2003 Drezno.
10. Stateczny A., Praczyk T., Sztuczne sieci neuronowe w rozpoznawaniu obiektów morskich, Gdańskie Towarzystwo Naukowe, 2002.
11. Tadeusiewicz R., Flesiński M., Rozpoznanie obrazów, PWN, Warszawa 1991.
12. Wąż M., Metoda wyznaczania pozycji okrętu za pomocą porównania obrazu radarowego z mapą morską, Rozprawa doktorska AMW, Gdynia 2000.

Received October 2004
Reviewed December 2004