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SIMULATION METHOD OF RANGE DETECTION OF MARINE NAVIGATION RADARS

ABSTRACT

The paper describes theoretical fundamental of the connection between particular technical parameters of navigation radar and its effectiveness in variable hydrometeorological conditions — changes in detection ranges. The further part of the paper presents propositions for simulation assignment of radar detection.

Keywords:
navigation radar, range of detection.

INTRODUCTION

The wide-spread opinion is that sea navigation radar is assigned for detection of objects on water surface, determination of the objects' coordinates and, on a large or limited scale, realization of anti-collision functions. An important matter becomes also a possibility of using radar in carrying out salvage activities connected with searching castaways at sea and training on target the salvage crews. Determination of castaways' location coordinates in such circumstances may be performed basing on the methods as follows:

— the active one — with active response — radar is operating as a receiver and interpreter of electromagnetic pulses which are sent by a transmitter of castaways' salvage kit (radar transponder) released with radar sounding pulses;
— the active one — with passive response — radar is sending and receiving its own pulses reflected from ship hulls (their remains) of watercrafts which experienced disaster, radar reflectors which rescue boats and life rafts should be equipped with.

A character of effects producing physical properties of a majority of the sea environment factors, as well as of their permutations, is fluctuating, not determined and random. In consequences it causes a change of radio waves' propagation (attenuation of signals) and passive type disturbances. The disturbing signal, together with an effective/useful signal reflected from the detected object affects the radar receiver's input. A result of such an action is similar to raising a level of input noise of the receiver's circuits and, at the same time, its own noise coefficient.

Deliberations included in the paper are aimed at presenting the assumptions of the simulatory method of determination of an influence of the factors, connected with technical navigation radar parameters and conditions of carrying out radio-locative observations, on its maximum detecting distance, in relation to detection probability for the case of the active method with passive response.

FORMULATION OF THE RESEARCH PROBLEM

The essential appears to obtain complete characteristics connected with detective capabilities of navigation radar in various conditions of radio-locative observations (hydrometeorological conditions). The characteristics should include a dependence between the detection range and probability P_W of detecting an object on water surface (after a some specified number of antenna's rotations) exceeds a settled given value (i.e. $P_{zad} = 0{,}6$) assuming, that for *m* times of the object illuminations, a number of *k* detections occurs. It becomes necessary to determine probability of detection within a time of one illuminating the detected object P_{poj} ; the event based on such situation, that a power of the received signal is exceeding a threshold of comparison in the radar receiver, separately for each radiation.

SOLUTION OF THE PROBLEM

To asses probability P_{poj} let's assume that the radar receiver is equipped with a square detector (optimal solution for receiving weak signals) and to its input there are coming non coherent packages of echo-signals (reflected from the detected object). Having assumed the above, probability P_{poj} for a time period of one illumination of the on-surface object can be determined applying dependence [Hrynkiewicz 1980]:

$$P_{poj} = \left(\frac{l \cdot q + l}{l \cdot q} \right)^{l-1} \cdot \exp\left(-\frac{y_o}{l \cdot q + l} \right), \tag{1}$$

where:

l — number of impulses received in one package within a time of one illumination of the object;

q — discriminative ability coefficient;

y_o — normalized threshold of power comparison — for the specified probability level of false alarm and specified number of impulses in the package (determined from J. Pachares's Table).

For objectification of the result data, the area of phenomena related to physical properties of the propagation trajectory (path?), so essential for the microwave range, also an influence thereof on radar detection ranges. Condition of the environment is described with WPO vector, of the coordinates $WPO = (sa, sm)$, where sa is parameter, describing a current state of the ambient environment's weather conditions. Its magnitude depends on precipitation occurrence (or non occurrence), its type and intensity. Instead *sm* means parameter, describing a present state of sea within the observation area.

It has been presumed that the coordinate *sa* may assume the values presented below:

sa:
- 0 — no precipitation (oxygen + water mist / vapour)
- 1 — rainfall of low intensity of 4 mm/hour or fog with sight distance up to 200 m
- 2 — rainfall of medium intensity of 8 mm/ hour or fog with sight distance up to 100 m
- 3 — rainfall of high intensity of 16 mm/ hour or fog with sight distance up to 30 m

Specific conditions of the ambient environment's weather are characterized with adequate attenuation coefficients and the unitary effective hydro-precipitation reflection area. State of sea is characterized with the unitary effective area of sea wave reflection in relation to a waving type.

A form of the expression which determines the radar detection range *R*, taking into consideration technical parameters of the equipment and the properties of the ambient environment is as follows [Marszałkowski 2004]:

$$R = \sqrt[4]{\frac{P_i \cdot G_{\max}^2 \cdot \lambda^2 \cdot \sigma_c}{(4 \cdot \pi)^3 \cdot q \cdot P_o \cdot L}} \cdot K_{osl} \cdot f(\rho, R) \cdot f(sz) \cdot F_e(\Theta), \qquad (2)$$

where:

P_i — transmitter's impulse power;

P_o — radar receiver's threshold power (sensitivity);

q — discriminative ability coefficient understood as a contrast of the received signal, usable on the noise and disturbances background at the radar receiver's output;

G_{max} — maximum value of the antenna directive gain;

λ — working wave's length;

σ_c — effective reflection area of the object which is detected;

K_{osl} — weakness coefficient — function which determines a spherical surface effect of the sea and refraction of electromagnetic waves in troposphere;

$f(\rho,R)$ — function, describing attenuation of (power weakening) usable signal in pure atmosphere, in hydro-precipitations;

$f(sz)$ — function considering summary disturbances introduced through microwaves reflection from the sea surface, hydro-precipitations;

$F_e(\Theta)$ — normalized voltage directional characteristic of antenna and radar;

L — energy losses coefficient in the industrial radar lines.

With the assumption, that a condition necessary to allow detecting a signal reflected from the detected object by the radar receiver's detectors, is to have the signal power at least equal to a summary power of noise and disturbances at the receiver output ($q = 1$), we determine a distance between the radar and the object on water surface, conforming to this event, designated with R_{unor} (normalized reference distance):

$$R_{unor} = \sqrt[4]{\frac{Pi \cdot G_{\max}^2 \cdot \lambda^2 \cdot \sigma_c}{(4 \cdot \pi)^3 \cdot q \cdot P_o \cdot L}} \cdot K_{osl} \cdot f(\rho, R) \cdot f(sz) \cdot F_e(\Theta). \qquad (3)$$

It can be concluded from the above dependence, that every location of an object on water surface (R) in relation to the radar corresponds with normalized reference distance R_{unor}. With designation R_{unor} from dependence (3) substituted in dependence (2), there are obtained as common factors:

$$R = Runor \cdot (q)^{-1/4} \quad \text{from where} \quad q = \left(\frac{Runor}{R}\right)^4. \qquad (4)$$

For determination of R_{unor}, q, P_{poj} it is necessary to calculate the values presented below:

— the radar capacity range according to the dependence $R_{ener} = \sqrt[4]{\frac{P_i \cdot G_{\max}^2 \cdot \lambda^2 \cdot \sigma_c}{(4 \cdot \pi)^3 \cdot q \cdot P_o}}$;

— a number of impulses in the package $l = \frac{\Theta_\alpha \cdot F_p}{\Omega}$,

where :

Θ_α — width of antenna characteristic in horizontal plane,
F_p — frequency of sounding impulses repetition,
Ω — antenna's rate of turning;

— height scales $H_x = 0.5 \cdot \sqrt[3]{\frac{R_e \cdot \lambda^2}{\pi^2}}$;

— distances scales $L_x = \sqrt{2 \cdot R_e \cdot H_x}$;

— normalized height of the radar antenna fixing point $Y = \frac{h_a}{H_x}$;

— normalized distance from radiolocation horizon $x_o = \sqrt{Y}$;

— distance from radiolocation horizon: $R_o = x_o \cdot L_x$.

Moreover, taking advantage of the complying relations included in [Hrynkiewicz 1980, Marszałkowski 2004] the following is to be determined:

— normalized voltage characteristic of the radar $F_e(\Theta)$;
— distance from the upper limit of the intervention zone R_{in};
— weakening coefficient K_{osl} — in the light zone, shadow zone and half-light zone;
— weakening of electromagnetic waves in troposphere $f(\rho, R)$ for the ambient environment condition defined with coordinates of vector WPO;
— power of interfering signals, appeared as an effect of:
  - reflection from sea waves,
  - reflection from hydro-precipitations.

Figure 1 presents algorithm, which is a basis for the simulation model functioning; it is a basis for implementing the program application as well.

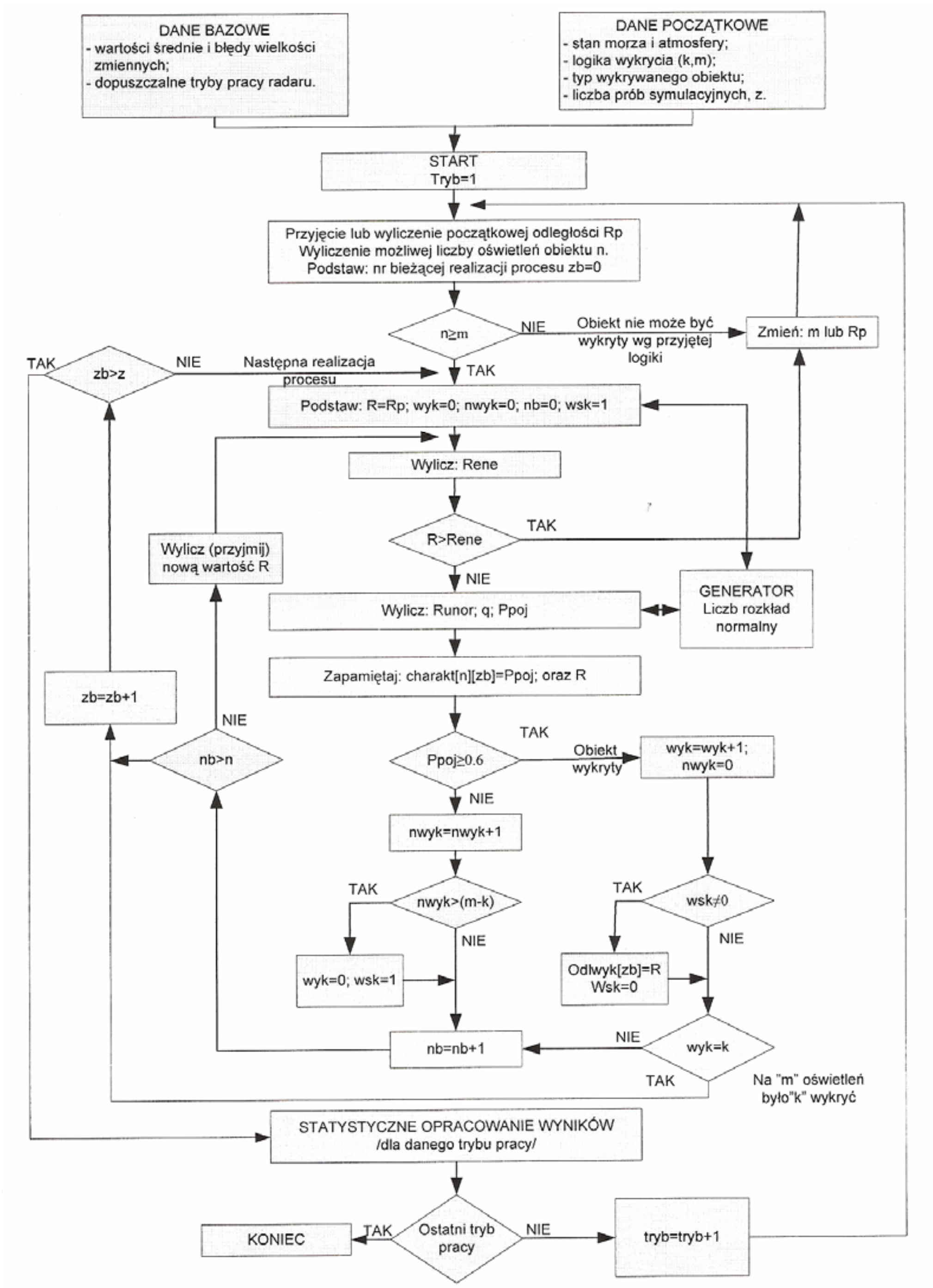

Fig. 1. Functional algorithm of simulation model

It is suggested to ascertain a fact of appearing (or not appearing) of an echo on the radar indicator display for every rotation of the antenna, basing on a value of probability P_{poj}. There is created a sequence of numbers 0 and 1, where 1 refers to an event when an echo from the detected object appears on the indicator display (when $P_{poj} \geq P_{zad}$ for a specific light), whereas 0 — an event when the detected object does not appear on the indicator display (when $P_{poj} < P_{zad}$ for a specific light).

For every case of echo appearance on the indicator display, there will be recorded (and saved) a corresponding distance *R* between the object and the radar.

The results (detection range *R*) obtained in simulation research will be treated as of *z* independent observations (*z* — simulation experiments) having an identical distribution of random variables. The ordered distribution series will be worked out as regards statistics; within the framework of such working out, the basic distribution elements can be computed: the mean value of detection range *R* (value anticipated), variation *D*, also standard deviation σ.

THE RESULTS AND CONCLUSIONS

To determine an effect of the sea environment on a range of detecting objects on water surface there has been used the author's program, exercising the procedures included in the simulation model algorithm, and implementation of the simulation process has proceeded according to the following scheme:

1. There has been settled as follows:
   - technical parameters of navigation radar;
   - detection logic, which specifies a number of singular detections with a known number of the consecutive (occurring successively one by one) illuminations of the detected object.
2. According to the set distributions there have been changed as follows:
   - values characterizing state of sea and ambient environment weather conditions;
   - values describing propagation of microwaves;
   - change of the detected object's effective dissipation area.
3. There has been defined a character of changes of the object detection probability in relation to a distance between the radar and the object.

Last elements of the input data were the parameters, defining detection logic. In the researches there has been accepted, that an object is considered detected, if for $m = 3$ of its successive illuminations there occurred $k = 2$ — two events of obtaining a set value in target detection probability.

The issue of knowledge and appropriate interpretation of sea navigation radar capacity can be considered in two aspects:

1. Referring to a need of working out by a potential user of radar equipment the tactical and technical requirements for manufacturers of the future equipment, designed in conformity with new technologies development.
2. Secondly, in an aspect of optimal use of the navigational radar, operated in different, often variable hydrometeorological conditions.

The presented in this paper method of simulatory examination of the navigational radar in the wider aspect can be used as an element of the model for analyzing areas of radiolocation cover in the naval technical observation system or civil system of vessels traffic monitoring.

The exemplary results of simulation process for the navigational radar of Bridge Master II type in a form of tables are presented below.

Table 1. Maximum radar reflector's detection ranges

Detected object type RADAR REFLECTOR SPO = 10 [m^2]							
AMBIENT ENVIRONMENT CONDITIONS							
State of sea — 0 Weather conditions — 0		State of sea — 3 Weather conditions — 0		State of sea — 6 Weather conditions — 1		State of sea — 9 Weather conditions — 2	
R [m]	Pw	R [m]	Pw	R [m]	Pw	R [m]	Pw
11852.1	0.154	10613.8	0.243	8551.7	0.199	6124.3	0.176
11552.1	0.189	10313.8	0.295	8251.7	0.128	5824.3	0.255
11252.1	0.195	10013.8	0.374	7951.7	0.143	5524.3	0.294
10952.1	0.265	9713.8	0.491	7651.7	0.336	5224.3	0.378
10652.1	0.436	9413.8	0.561	7351.7	0.411	4924.3	0.415
10352.1	0.498	9113.8	0.686	7051.7	0.482	4624.3	0.499
10052.1	0.562	8813.8	0.790	6751.7	0.567	4324.3	0.554
9752.1	0.744	8513.8	0.853	6451.7	0.675	4024.3	0.635
9452.1	0.867	8213.8	0.920	6151.7	0.687	3724.3	0.744
9152.1	0.898	7913.8	0.954	5851.7	0.772	3424.3	0.827
8852.1	0.970	7613.8	0.968	5551.7	0.796	3124.3	0.845
8552.1	0.974	7313.8	0.972	5251.7	0.865	2824.3	0.895
8252.1	0.985	7113.8	0.984	4951.7	0.955	2524.3	0.945
7952.1	0.991	6813.8	0.988	4651.7	0.967	2224.3	0.976
7652.1	0.992	6513.8	0.990	4351.7	0.987	1924.3	0.987
7352.1	0.996	6213.8	0.991	4351.7	0.991		
7052.1	0.998	5913.8	0.992				
MAXIMUM REFLECTOR'S DETECTION RANGE							
10052 m		9413 m		6751 m		4324 m	

Table 2. Maximal ranges for detecting a life raft

Detected object type LIFE RAFT SPO = 2 [m^2]							
AMBIENT ENVIRONMENT WEATHER CONDITIONS							
State of sea — 0 Weather conditions — 0		State of sea — 3 Weather conditions — 0		State of sea — 6 Weather conditions — 1		State of sea — 9 Weather conditions — 2	
R [m]	Pw	R [m]	Pw	R [m]	Pw	R [m]	Pw
7122.3	0.163	6612.4	0.173	4365.7	0.132	3574.1	0.145
6822.3	0.189	6312.4	0.185	4065.7	0.193	3274.1	0.231
6522.3	0.262	6012.4	0.224	3765.7	0.243	2974.1	0.355
6222.3	0.305	5712.4	0.261	3465.7	0.256	2674.1	0.391
5922.3	0.336	5412.4	0.311	3165.7	0.372	2374.1	0.425
5622.3	0.381	5112.4	0.346	2865.7	0.445	2074.1	0.489
5322.3	0.462	4812.4	0.420	2565.7	0.489	1774.1	0.534
5122.3	0.534	4512.4	0.483	2265.7	0.526	1474.1	0.599
4822.3	0.593	4212.4	0.531	1965.7	0.648	1174.1	0.679
4522.3	0.648	3912.4	0.614	1665.7	0.752	874.1	0.865
4222.3	0.760	3612.4	0.688	1365.7	0.846		
3922.3	0.824	3312.4	0.793	1065.7	0.899		
3622.3	0.885	3012.4	0.878				
3322.3	0.945	2712.4	0.921				
3022.3	0.965	2412.4	0.934				
2722.3	0.972	2112.4	0.945				
2422.3	0.989	1812.4	0.951				
MAXIMUM RANGE FOR LIFE RAFT DETECTION							
5122 m		4212 m		2265 m		1774 m	

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