Simulation of marine radar performance and false echoes

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Abstract

Computer simulation of abnormal atmospheric propagation condition and false echoes of marine radar have always been the difficulties in this field. The author of this paper has already done some constructive work.

Key words Radar/ARPA Radar simulation Computer program

Marine radar/ARPA simulator can provide the environment that operators are able to handle ships and operate radar/ARPA at a simulated sea environment in laboratory. This training will do great help to master vessel position fix, navigation and collision avoidance by the proper operation of radar/ARPA. Marine radar/ARPA simulator has always played an important role in maritime education and marine investigation since it was first came out in 1960s. As an international convention the 1995'STCW Convention puts standard functions for simulator and emphasizes the role of simulator in seafarers marine certification training and assessment for the first time.

1.Special performance and observation phenomena in marine radar simulator

Most of efforts done in radar simulator in the world have lone time focused on radar ordinary transmitting, receiving and display performance as well as most common radar observation phenomena such as the reappearance of radar land scope, coastlines, sea clutters, rain/snow clutters and movable target etc. at sea. The strength of simulated targets and noises changes with the gain control. The displayed target strength changes with tuning. The strength of sea or rain/snow clutters decreases when use anti-clutter controls. Position fix and sailing navigation can be operated on simulator by range marker and bearing line. The functions and observation phenomena mentioned above are those happed daily for real radar/ARPA. Thus all the simulators without exception have those functions. We call them common performance and observation phenomena in marine radar simulator.

Besides common performance and phenomena in radar observation practice, deck officers may use functions or observe many phenomena that are not as common as above, for example, the change of radar performance and echo strength due to different working frequency and pulse width, super- or sub-refraction due to atmospheric/sea or radio propagation condition, target distortion owing to shadow sector, gain reduced arc behind obstruction target, as well as radar false echoes etc. In convenience these are called special performance and observation phenomena in marine radar simulator during our development. It is stated in part A and B of annex of attachment 2 to 1995'STCW Convention that radar simulation equipment shall be capable of simulating the operational capabilities of navigational radar equipment and enable candidates participated training and assessment understand relevant knowledge of radar operation and observation.

The paper presented here are some explicit designs of simulation of radar transmitting band, pulse width, minimum detection range, abnormal atmospheric propagation and false echoes when we developed the simulator.

2.Simulation of radar specification

As a common marine radar works on S and X band which centre wavelength are 10cm and 3cm respectively. According to SOLAS Convention two radar sets should be installed on board ship of more than 10,000 tonnage and at least one of them should work on X band. Most of ships have one X band and another S band radar.

2.1 Simulation of radar working band

Generally speaking, compare with S band radar, X band radar has better bearing discrimination, fine echo returns and higher detection ability for weak targets. But it is influenced by sea and atmospheric condition more seriously, also sea and rain/snow clutters will be displayed stronger. Because the refraction rate will get higher with the falling of frequency, the horizon of S band radar should be slightly longer than that of X band.

We setup S and X band selector on simulator operation panel, the simulated sea and rain snow random pixel decrease but their density increases when X band is selected, the target generated by default value.

2.2 Simulation of radar pulse width

The transmitting pulse width of marine radar which usually has two or three of its values can be selected manually or automatically. When long pulse is selected, radar will have full output power, stronger echo returns, lower range discrimination, wider blind area (minimum detection ability), and be able to detect longer distant target. While on the contrary, radar will have better ability to detect target nearby when short pulse is selected.

We setup pulse length selector on simulator operation panel, the program would run at default value when short pulse is select. While long pulse is select, the followings is defined,

(1) target expands 4 pixels along its sweep line;

(2) minimum target detection range is defined at 30m;

(3) pixels of random generated sea and rain/snow clutters increase.

2.3 Simulation of radar minimum detection range

The minimum radar detection range is influenced by radar specifications also. A radar receiver cannot receiver any returns during transmitter working period and TR switch recovery time. Targets less than about 25m range cannot be found as usual. This is one of the factors that affect radar minimum detection range.

When radar is installed on board as shown in Fig.1, the minimum detection range is also influenced by vertical beam width β_0, antenna height and target height. Usually installation factor is the key to minimum detection range.

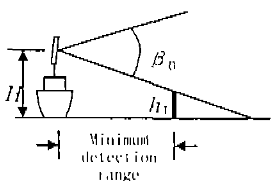


Fig 1 Radar minimum detection range

According to IMO recommended radar performance standards, we define the angle of radar zero transmission line and sea surface as 25 degree, antenna height is 15m above sea surface, thus the minimum detection range is 33m at sea, and the minimum detection range is 22m of 5m high buoy. Moreover the minimum detection range of other taller targets is 25m. The targets whose ranges are less than this are not able to display.

3.Simulation of abnormal propagation condition

The density, humidity and temperature are changing with height on the earth surface. Strictly to say, the atmosphere medium of electromagnetic wave traveled is not even. Thus refraction phenomenal can occur when electromagnetic wave travels on the earth surface. The condition of atmosphere is not a constant, so the electromagnetic wave refraction rate in air is not a constant, too. Radar detection range is influenced by the changing of atmosphere accordingly.

Radar radio wave slightly bends to the earth surface while travelling under the normal radiation condition. When temperature decrease rate gets steep and /or relative humidity increases with the gain of height, the sub-refraction will occur. This will bring on the curvature of radar wave decreasing and even the radar wave bending to sky. As a result, the targets that lie within radar range originally cannot be detected. On the contrary, radar wave will bend to the earth when super-refraction occurred. Radar can detect the targets faraway below radar horizon. See Fig.2.

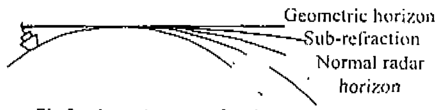


Fig.2 sub- and super refraction

Atmosphere is always changing, so sub- and super-refraction is anywhere and anytime. The difference is the distinctness of extent. Sometimes radar observer may not notice that.

Moreover, the influenced detection range for certain targets, whether sub- or super-refraction, are mainly those whose distances are longer than radar horizon. Because radar vertical beam width is about 20~30 degree, unless so sever sub-refraction makes radar wave bend to sky as to lost targets nearby, the targets within radar horizon will not be influenced.

Suppose radar antenna height is $h_1=15$m above sea level, radius of the earth is 6371.0km, then the radar horizon is,

$$R_G = 2.23\sqrt{h_1} \approx 8.6 \quad \text{(n miles)}$$

in order to simulate target detection range and atmospheric refraction effect, we strictly define our radar data base according to target property and height parameter, circumscribe and range the vertex number of fixed targets (such as coast lines), then design target maximum detection data base for different targets according the theory of electromagnetic wave.

3.1 Simulation of radar sub-refraction

Under sub-refraction situation, the radar horizon for those target detection distance longer than 9nm is defined as,

$$R_{max} = 1.3\,(\sqrt{h_1} + \sqrt{h_2})$$

where, h_1 is antenna height above sea level, h_2 is the height of target above sea level.

Target radar detection range then can be recalculated under sub-refraction situation, the result of course as target maximum detection distance data base overwrites the original one.

3.2 Simulation of radar super-refraction

Under super-refraction situation, the radar horizon for those target detection distance longer than 9nm is defined as,

$$R_{max} = 3.2\,(\sqrt{h_1} + \sqrt{h_2})$$

Target radar detection range then can be recalculated under super-refraction situation, considering the attenuation of electromagnetic wave as well, the result of course as target maximum detection distance data base overwrites the original one.

3.3 Simulation control

The sub- and super-refraction is controlled on instructor station according to the need of practice.

4.Simulation of radar false echoes

Radar false echoes include indirect echo, sidelobe echo, multiple echo and second trace echo. Here we present the way that we program the indirect echo and multiple echo

4.1 Simulation of indirect echoes due to own ship's funnel

Own ship's funnel can reflect radar wave to other direction and hit some targets, then the target returns will come back to radar antenna through the same way. In this way, one target may appear on radar screen two returns. One is the true echo and the other is indirect echo due to the funnel reflection.

This kind of false echo has following characteristics.

(1) The targets that can produce indirect echo should be those in short distance (whose distance not more than 2nm) and with perfect reflection ability.

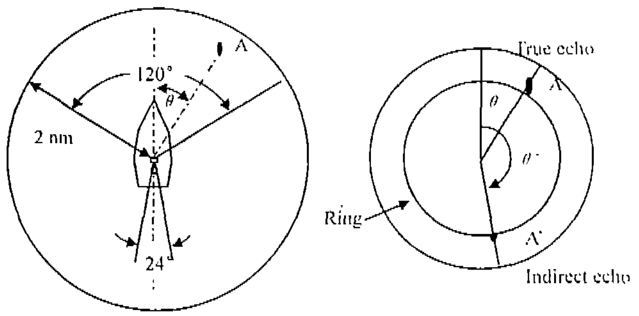
(2) The indirect echo has the same radar measure distance with its true echo, but the bearing is in the funnel direction.

(3) Indirect echoes always appeal in radar funnel blind sector.

(4) Compare with true echo, the movement of false echo is abnormal. When true target moves on screen, the bearing of false one always remains on the funnel blind sector unchanged while the distant changes The false echo may sudden disappears when the target moves to certain position.

(5) The false echo is weak and distorted compare with its true echo.

Considering the size and shape of ship's funnel, we define relative bearing of $\frac{14}{15}\pi \sim \frac{16}{15}\pi$ as radar reflection angle, ie. the indirect echo can be displayed within 24 degree stern scope while its true target lies within $\frac{5}{3}\pi \sim \frac{1}{3}\pi$ relative bearing and distant not more than 2 nm as shown in Fig.3.



The angle of simulated indirect echo Simulated indirect echo

Fig 3 The simulation of indirect echo

In order to get better simulation effect, the bearing of false echo may change slightly with its true, ie. as long as the true is close to bow, then the false is close to stern. We develop the algorithm below.

Assume target A meets following conditions,

(i) distance to own ship is $R_A \leqslant 2$ nm, and (ii) relative bearing to own ship is $\frac{5}{3}\pi \leqslant \theta \leqslant \frac{1}{3}\pi$.

If own course is C ($0 \leqslant C < 2\pi$), target polar coordinates is A (R_A, θ), then when $|\theta - C| < \pi$, the bearing of indirect echo A' is at $\left(R_A,\ C+\pi-\frac{\theta-C}{5}\right)$; and when $|\theta-C|>\pi$, the bearing of indirect echo A' is at $\left(R_A,\ C+\pi-\frac{\theta-C-\mathrm{sign}(\theta-C)\cdot 2\pi}{5}\right)$. The brightness of false is less than 30 degree of its true

4.2 Simulation of multiple echoes

Multiple echoes are caused by the reflection of the signal between own hull and strong nearby reflection target before its energy is finally collected by the scanner. Multiple echoes have following characteristics.

(1) There are one or more echoes besides the original echo.

(2) They are equidistantly spaced and having ranges of multiples of the true range.

(3) They are weakening in intensity outwards.

(4) They are on the same line of bearing.

See Fig.4, the echo A which is stronger and nearby sweep origin is true echo, outward B and C are false.

Multiple echoes generally happen at short ranges up to about one mile, often when another vessel is passing closely, beam-on or nearly bean-on to own ship.

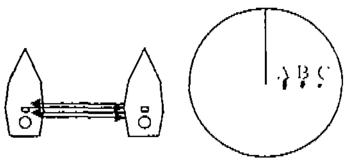


Fig.4 Multiple echoes

Assume target A meets following situations.

(i) distance to own ship is $R_A \leqslant 1$ nm.

(ii) relative bearing to own ship is $\frac{1}{3}\pi \leqslant \theta \leqslant \frac{2}{3}\pi$ 或 $\frac{4}{3}\pi \leqslant \theta \leqslant \frac{5}{3}\pi$.

Thus multiple false echoes B due to A should be in the same bearing line of A, range should be $2R_A$. The brightness of false is less than 30 degree of its true.

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