Method of producing the multidimensional radar display

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Abstract: - This article presents methods for creating multidimensional radar presentation. Radar image distortion and problems related to the visualization of these images in the ECDIS have been described.
The cardinal question in producing three-dimensional radar image display is a method of acquisition of information about the third coordinate. Contemporary navigational radars are the equipment which is based on two coordinates. Amplification of the displayed echo in radar display is depended on the effective reflection area, which may manifest a size of the observed object only in part. The reflection area is not always directly proportional to the observed objects sizes. It may be increased if appropriate radar reflectors are used. Thus the third dimension, the third coordinate, may be obtained through finding out a level of radio location signal, reflected and coming back to the receiver.

Key-Words: - Radar, 3D Visualization, ENC

1 Introduction

The three-dimensional display of a radar image, produced in accordance with the above description, is presented below. For this purpose there was used a program for 3D visualization of the sea bottom map, worked out by the Authors.

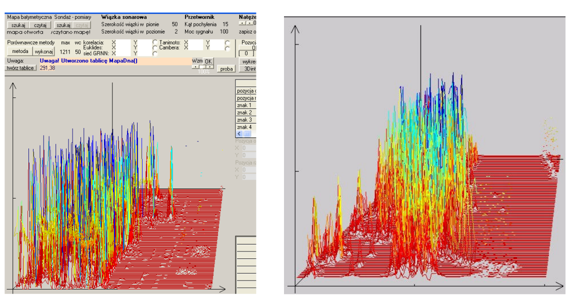

Fig. 1. Three-dimensional display of the radar image

In modelling of three-dimensional surface it is convenient to use ready-made technological solutions.
Having the radar image recorded as a three-coordinate vector, for producing three-dimensional visualization we may take advantage of the applicable graphic libraries. They enable to code three-dimensional graphic applications operated under control of the operating system. It may be performed, for example, owing to the libraries of DirectX Microsoft graphics.
Three-dimensional images are in DirectX constructed in accordance with vector graphics rules. Every object is composed of a certain number of polygons (in DirectX the triangles are polygons). The most essential problem is arrangement of the objects in order – starting from those, lying at the farthest, up to these, which are located nearest to the observer.
DirectX offers z-Buffer algorithm to perform this assignment. It uses a structure of the memory, where Z coordinates of every pixel are stored. For each animation frame, Z coordinates of all the pixels, which constitute the 3D objects display, are compared with Z coordinates saved in Z-Buffer (of the previous frame). In case a specific pixel is characterized with shorter Z coordinate, then it is drawn up on the previous one’s place.
The next step in visualization of 3D stage is texture mapping. It consists in covering an object, composed of 3D polygons, with a two-dimensional bitmap. Textures placing algorithm is based on at least two bitmaps, different in sizes. If the observer is close to the object, then the largest bitmap is placed on; with moving away, the bitmaps are replaced each time with smaller ones.
The successive stage of constructing the image is illumination of the object. Following are the light sources offered by DirectX:

- point light – the light which disperses uniformly to all directions; calculation of this light requires high computing powers;
- spotlight – reflector light, emitted in a cone shape form (for example a torch); only the objects which are embraced by the light cone are visible;
- directional light – the light which is characterized by a specific orientation within 3D stage; it is used, for example, for simulation of sunlight; it does not require high computing powers.

The following stage comprises shading of polygons. The whole such polygon is filled with a colour either of one of the angular points, or the colours' values are interpolated from all its angular points.

Using the library enables fast construction of radar images in three-dimensional representation. It is illustrated by the presented below projections of the application screen, worked out in VisualBasic, with a use of DirectX library. The radar 3D images were produced basing on the recorded values of the visual signal voltages and pictural information, assigned specially for placing textures on.

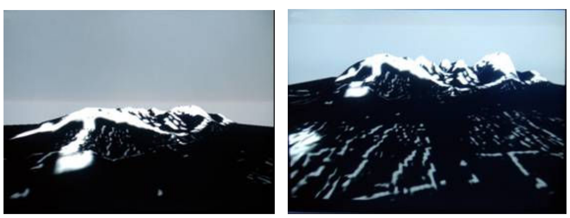

Fig. 2. Radar 3D image of the Gulf of Gdańsk (visualization of Radar3D program, worked out in VisualBasic6.0)

The application enables presentation of the display in a form of regular grid of triangles, to be covered with textures. It is presented in the Figure below.

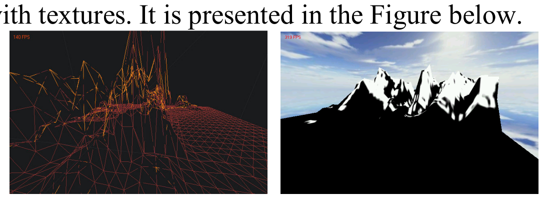

Fig. 3. Radar image presented as a regular grid of triangles and after placing textures on

For displaying the radar image in its three-dimensional form, also the commonly available applications for modelling multi-dimensional surfaces can be used. Below there is presented the radar image, displayed in Surfer program.

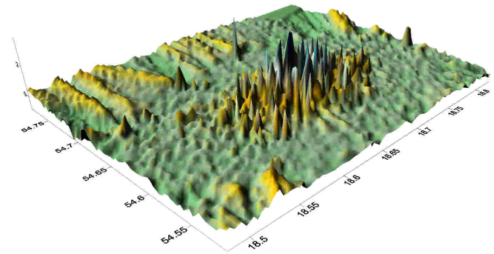

Fig. 4. Visualization of radar image applying the Surfer program (Visual signal, recorded on ORP Arctowski vessel in the Naval Harbour of Gdynia)

A feature of the above presentation (Fig. 4) is that it was produced using the primary (original) visual signal. Detecting weak echoes is eased. The operator can freely turn the image, bring it near and analyze every change in the surface.

2 Description of multi-dimensional (three-dimensional) model of radar presentation in ENC

A majority of contemporary radars presents digital visualization in the Cartesian coordinates system. On the contrary to analog visualization, presented in the old type radar scope lamps, the radar image is displayed on monitors in a form of a square matrix of an equal pixels number in rows and in columns. It is of raster structure and it is presented in Cartesian coordinates system, what has already been said. Such an image may be saved in the computer's memory as a bitmap. The BMP file is a grid of the bitmap, presenting one or three layers of colours (one – 256 shades of grayness; three – 256 shades of colours: red – R, green – G, blue – B). It is also feasible to save the image in four levels of colours CMYK (applied commonly in computer graphics). In a majority of navigational radars there are usually applied two or three main colours to distinguish particular elements of radar presentation: "echo" and "water", also, possibly, for auxiliary graphics displayed (vectors of motion, zone of acquisition, etc.).

A colorful radar image differs significantly from the one, presented in shades of grey. The first one is recorded applying 24 bites of accuracy, whereas the second one, the 8 bites accuracy. The colorful image is stored in three-dimensional matrix. Pixel is a three-element vector, of R, G, B constituents (of 0 – 255 range). Therefore each pixel takes 3 bites of storage (that is why the colour is called 24-bites one). Each constituent of pixel (this three-element vector) contains a number of bites equal to 8.

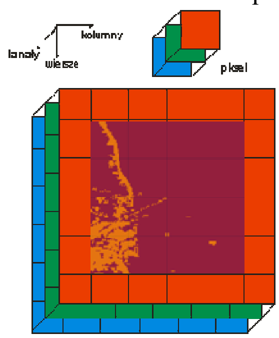

Fig. 5. Raster radar 24 bites image

Apart from presentation of colour images, there is a possibility to produce the images displayed using shades of grayness (colloquially called mono-chromatic). Such an image display is stored in two-dimensional matrix. The data are contained in "one channel". Pixels are singular elements of values ranging between 0 and 255 (8 bites of memory).

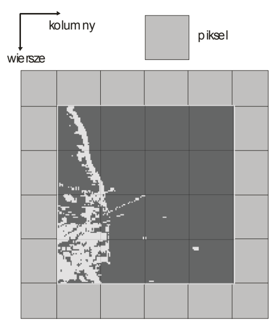

Fig. 6. Radar image presented with shades of grayness (8 bites)

A radar image, stored in computer memory as a raster, is a set of data, which are subject to changing and the changes are affected by circumstances in a place in the observed space: hydrometeorological conditions, configuration of coastline and occurrence of various objects etc. A set of continuous data may be a regular grid of points presenting the radar image, however recorded as a vector. Node points spread out evenly in the radar image can be given a spatial reference – by assigning thereto specific geographic coordinates. Each point of radar image, displayed as a discrete value, presents the next vector's coordinate, informing about radar echo occurrence. Especially in case of sea radar images, where the image pixels which present "water", assume at any place the same value and they are of no significance (simply a lack of echo), thus the information about them may be with no doubt disregarded. Therefore it is convenient to construct the vector radar images basing on irregular grid of points of discrete values, which next may form lines and areas. All these elements will refer to the coastline, land, also fixed and movable objects, located at the water area observed by the radar.

A digital radar image certainly may be presented using these forms. Coastline and singular points, describing characteristic elements of the water area are components of so-called in-variant display of radar image. A method of in-variant originating, also of the other forms and representations of radar image, was described many a time in earlier works of the authors [12][13][14][15].

The principal problem in producing three-dimensional radar presentation is the method of acquisition of information on the third coordinate. The contemporary navigational radars are two-dimensional facilities. With using such facilities there is no possibility to acquire information about the observed objects' altitude/height coordinates. Anyhow, it would be necessary to consider a purposiveness of knowing data on such objects' heights. Are those data really indispensable for navigation, in radar presentation? Amplification of the displayed echo in the radar presentation depends on effective reflection area. The area is not always directly proportional to values (sizes) of the observed objects. Thus the third dimension, the third coordinate, may be a level of the reflected radiolocation signal, returning to the receiver. The above value is visualized as a level of visual signal amplification W or U (see: relations (1) and (2)). Such an approach offers more extensive possibilities in visualization and presentation of selected elements of radar presentation. The most important assignment to perform before producing 3D display is recording the radar image in digital form to enable reading three coordinates for each pixel of the image. The representations presented above refer to the radar image recorded as vector defined on the real numbers set:

$$\mathbf{O}^k \to R \qquad (1)$$

where:

$$\mathbf{O}^k = \left\{ \begin{matrix} (\varphi, \lambda, W) : \varphi \in < 0, \pm 90^0 >, \lambda \in < 0, \pm 180^0 >, \\ W \in < 0, K > \wedge \varphi, \lambda, W \in R \wedge K \in N \end{matrix} \right\}$$

φ, λ – geographic coordinates of the specific image pixels;

W – level of amplification of pixel of the image identified as radar echo and for visual signals recorded in the polar coordinates system:

$$\mathbf{O}^b \to R \qquad (2)$$

where:

$$\mathbf{O}^b = \left\{ \begin{matrix} (\alpha, d, U) : \alpha \in < 0, 360^0 >, d \in < 0, Z >, \\ U \in < 0, u > \wedge \alpha, d, U \in R \wedge Z, u \in R \end{matrix} \right\}$$

α – polar coordinate identified as a bearing (NR);
d – polar coordinate identified as a distance (d_r);
U – visual signal voltage.

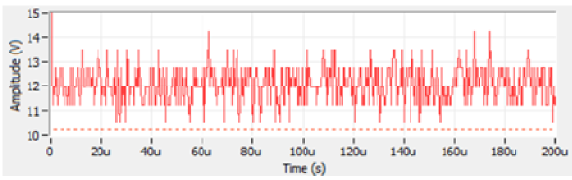

Fig. 7. Values of BM252 navigational radar visual signal's amplification

The recorded values of amplification of visual signal U with a use of the oscilloscope for recording and visual signal analysis are presented above. Such amplification is represented as a value of voltage of analog visual signal expressed in volts (V).

3 Mapping distortions in radar images

For every navigator a similarity of any coast radar image display and its equivalent in the respective map is noticeable. The radar image display is a form of the most truly made representation of vessel surrounding space, with any objects situated on its surface. It is a two-dimensional picture representation of the environment, in which the vessel is found. The objects which reflect the radar tracking beam are represented on the radar screen in a form of echoes and displayed applying the vessel's polar coordinates system. The vessel's coordinates system is in this case understood as a local system, which displaces together with a watercraft being in motion at sea. Accuracy of such representation depends on technical parameters of radar and meteorological conditions occurring in the area. A representation close to the one, presented in radar representations is the azimuth representation, often used in cartography. Thus, in our further deliberations the azimuth representation will be a characterized radar image. An occurrence of many distortions, characteristic for specificity of carrying out radar observance has to be pointed out as well. A radiolocation survey (measurement of distances to objects within bearings) is performed with a use of radar antenna, turning round with a constant speed. Meanwhile the vessel keeps moving toward a direction conforming to its true course. Such a phenomenon is presented in the Figure below.

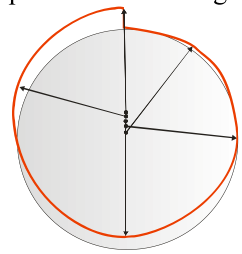
Fig. 8. Distortions in radar display caused by the proper vessel motion

When the vessels move at low speeds the occurring distortions are ignorable minor. If the vessel speed is high, what takes place i.e. in case of quickly manoeuvering naval vessels, the distortions are of great importance. If rotation of the antenna around its axis takes about 3 sec., then occurring distortions, resulting from the fact of vessel's dislocation, may reach even above 30 m.
Much more meaningful distortions appear in case of surveying a bearing directed toward the objects of the same size but at different distances from the vessel. Displacement of the proper vessel affects to a lesser degree a value of angular deformations in displays of the objects at long distance. It is concluded therefore that in a time of carrying out observations the navigator should decide on its range to have the observed objects nearby its maximal values. It means that while approaching port heads, at a distance of about 2.5 nautical miles, a navigator should reduce a range of observations from 6 to 3 nautical miles. Within the port water area it has to be the same, the observations should never be carried out at ranges above 1.5 nautical miles etc.

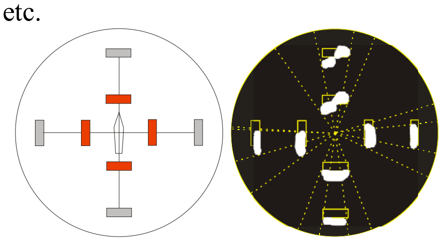
Fig. 9. Geometric layout of immobile objects in relation to the vessel in motion (map picture and radar image display)

In the Figure above (Fig. 9.) there is presented a situation, picturing a radar image display obtained at a vessel in motion. The image was acquired within a time of one rotation of the radar antenna. Distortions of a distance and major distortions of angles, especially in images of close objects, are noticeable.

A subsequent group of distortions which differentiates radar image and map picture includes distortions resulting from specificity of radiolocation radiation. Sizes and a character of radar image display of a point target depend on sounding impulse duration, directional characteristics width and a distance between the image under consideration and the radar screen centre point. Deformation of the coastline echo configuration and displacement of it in the radar image display, resulting from the reasons discussed before, is presented in the radar image drawing, recorded in Gdynia Naval Harbour.

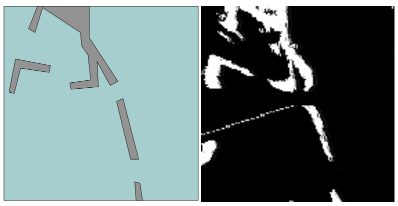

Fig. 10. Gdynia Port; map picture and true radar image display

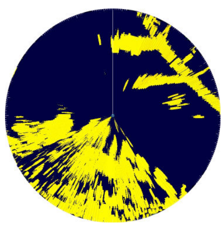

Fig. 11. Deformations of radar echo in case of small radar observation ranges (0.25 nautical miles)

Another type of radar image distortions is caused by non-linearity of time base impulses and the deflector coil structure. Two cases may occur here. The first one, occurring when the accretion line of sawtooth time base pulse is concave, causes that distances between constant circles are unequal and grow while approaching the screen's edge. "Drawing" of echoes toward the screen central point takes place at that time. The second case occurs when the accretion line of sawtooth time base pulse is convex, what causes reducing distances between circles while moving away from the screen central point. Then "widening" of echoes away of the screen centre takes place [5].
Radar operators know very well distortions and disturbances/interferences in radar image displays caused by deformations of brightening pulse, echoes coming from sea waves and from precipitations. An operator is able to identify also the multiple echoes, indirect echoes, those on side lobes directions as well as the second–time-round echoes and interference disturbances. All these disturbances and distortions usually cause no problem in proper interpretation of radar image display.
The other type of deformations results from radar resolving power. It is analyzed in two following aspects: as a capability of range discrimination and resolution in angle.
Range discrimination ability stands for minimal distance between two point targets set in the same bearing, resulting in acquisition of two separate echoes while radar is operated at the smallest observation range. A relation of the minimal interval between subsequent pulses $\Delta l_{\min}$ and a duration time allowing for a singular measurement of the range is given in [16]:

$$\Delta l_{\min} = t_i \cdot v_p + \phi \tag{3}$$

where:

t_i – sounding pulse duration time;
v_p – speed of spot;
ϕ – diameter of spot.

Taking the above into account, the minimal range differentiated at two point objects is [16]:

$$\Delta d_{\min} = \frac{c \cdot t_i}{2} + \frac{c \cdot \phi}{2 \cdot v_p} \tag{4}$$

where:

c – radio waves propagation velocity in the atmosphere (abt. $3 \cdot 10^8$ m/s).

The same is with angular discrimination; there is determined the most acute angle of view of two point objects situated at an equal distance from radar, in which the objects' echoes appear in the screen individually, describing it with a dependence [16]:

$$\Delta \alpha_{rozr} = \Theta + \frac{\phi}{l_e} = \Theta + \frac{\phi}{M_S \cdot d_1} \tag{5}$$

where:

Θ – directional characteristics width;
l_e – distance from echo to the screen centre.

Concluding the above we can state that all the mentioned distortions as well as those resulting from diversity of waves propagation conditions and hydrometeorological conditions, also other (described in papers [5][6][11][16]), affect quality of the radar image and cause that the image differs from the true picture. All the more, it differs from a nautical chart picture, which is presented in various representations, not always convergent with the radar image representation.

With contemporary techniques and capabilities in contemporary systems of electronic maps, transformation from one type of projection into the other is not a problem. Therefore comparing radar images and nautical charts we can perform transformation of a map picture, its projection, into a representation much more similar to the radar image.

One of the concepts suggested in [9] is application of the dynamic perspective azimuth display with the positive point of projection. The above display should be generated dynamically together with the proper vessel in motion. Carrying out navigation (route range) in such representation is hard, as in such display parallels in latitude and meridians are not mutually perpendicular and loxodromic line is not a straight line crossing meridians at the same angle. However, this display, as a demonstrative one, should provide the navigator with a chance to compare it to the radar image, to identify objects and targets appearing around the proper vessel and to control correctness of indications shown by position fixing systems. It may be performed through precise matching the radar image and the map and possible correction of the observed mistaken position.

For this display the range correction is calculated applying the following dependence:

$$\Delta = d - \frac{k \cdot R \cdot \sin(\frac{d}{R})}{K - R \cdot \cos(\frac{d}{R})} \tag{6}$$

where:

R – radius of the Earth,

K – elevation of the projection point counted from the Earth's centre,

k – distance between the plane of projection and the point of projection,

d – radar operation range (distance to the central point on the reference plane).

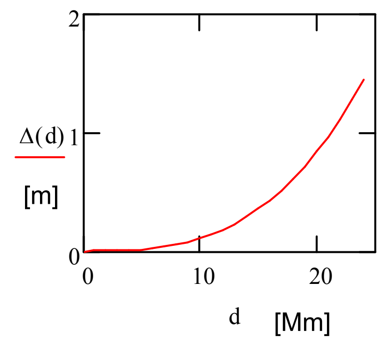

Fig. 12. Range correction for perspective azimuth display with positive point of projection

An influence of range distortions is ignorable small for distance ranges below 24 nautical miles, as it is barely ~ 1,5 m. Thus, for nautical charts of 1:50000 scale, the minimal "spot diameter" is 0.24 mm allowing the coordinates reading accuracy equal to 12 m. One can see that the distortion – both for the map and radar image display are minor.

4 Generation of three-dimensional representation in ECDIS prototype

It is suggested for the Numerical Terrain Model representation to apply the dynamic perspective display. The model thereof was presented in the Project Manager's doctor thesis [7]. The model is lacking in description of principles of transformation of the ellipsoidal "map" points coordinates and radar echoes to Cartesian ones and the requirements referring to WECDIS in respect of visualization of radar image three-dimensional display.

It is assumed that the laboratory WECDIS prototype will be based on a computer application provided with the worked out in this Paper, implemented model of three-dimensional display of radar images. Within a time of the image generation process, the functions contained in the graphic library OpenGL will be used in the application [3][4].

The image generation process will be consisted of the following succeeding sub-processes:

- modelling of geometric "voltage" radar image display,
- modelling of material properties,
- modelling of illumination,
- displaying in monitor's screen the modelled, three-dimensional surface of multi-dimensional radar representation in the dynamic perspective representation.

Geometric modelling of ”voltage” radar image display will be performed basing on geo-spatial data, coded in the Electronic Navigational Chart/Map, in selected objects of geo and meta features. It will consist in determination of the ellipsoidal squares grid describing the radar image, generating an image of “flat” nautical navigation map in Mercator’s representation and covering with this image an earlier determined grid model. It is assumed that the same way of modelling will be obligatory for geo-spatial data defining the multi-dimensional radar image.

Modelling of properties of the material covering the ellipsoidal squares grid will consist in determination of ambient light reflection for it and incident light diffusion factors, gloss degree and intensity of emitted light and reflections.

Modelling of illumination will consist in determining properties of ambient light, diffused light and reflections.

In monitor screen the displays of modelled three-dimensional surface of radar image in the dynamic perspective representation will be performed for specific projection parameters, which, in case of the graphic library OpenGL are called parameters of camera. The following are these parameters: camera position defined with the ortho-Cartesian coordinates in relation to the geocentric reference system, spatial orientation angles (tilt, inclination and deflection) as well as the course and camera displacement speed [1][10][8][4][2].

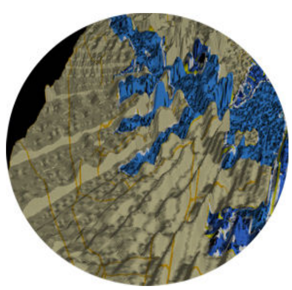

Fig. 13 Exemplary representation of multi-dimensional radar display

An example of radar 3D display visualization is presented above. To be able to prepare it there was applied the worked out application provided with OpenGL library. Due to the fact that measurement data were recorded in the polar coordinates system, the application carried out necessary interpolation of measurement points to acquire the regular network of coordinates. In the Figure there are shown characteristic stripes of subsequent azimuths, on which the visual radar signal measurement was taken.

The description and operation of the application for creation of multi-dimensional radar display are presented in next author’s article: “Electronic Navigational Chart in aid of generation of multi-dimensional radar display”.

6 Conclusion

Application of radars on sea-going ships and vessels is essential for safety of navigation, especially in poor visibility and bad weather conditions. Radars are used in navigation for fixing positions and for detection and identification of vessels, objects and other targets. A process of carrying out navigation basing on automated anti-collision systems ARPA is till now characterized with comparatively low accuracy. The reasons thereof are not only, difficult to eliminate, radio waves interferences and technical constraints in presentation of radar echo on the screen, but also misidentification of radar echo, as well as random and deterministic disturbances of radar observations.

The main aim of the research presented in the article was to develop a new multidimensional presentation for navigation radar. The presentation, which in the aspects of technology, meets the standards, referring to three-dimensional visualization of space data; it also improves safety of navigation through providing navigators with more accurate radar information in a form much easier for interpreting. Initially it was assumed that the new presentation would increase a possibility of detecting echoes of small signal amplitude. Radar echoes may come from vessels and targets, characterized with lowered qualities of microwaves reflection, as, for example, objects constructed applying stealth technology. The research proved that the three-dimensional representation of the original visual signal improves detection of small signal amplitude echoes. Application of the digital signal’s filtration methods may provide navigators with information about the objects which remain invisible on the contemporary radars’ indicators. It does happen, as their echo is at a level (or below) of noise and interferences occurring within the radar presentation. When the original visual signal is examined in navigational radar’s receiving block and the advanced technology used to produce multi-dimensional visualization, the radar image can be presented applying representation, increasing probability of detecting those objects. Apart form the fact, that in IMO Regulations the requirements referring to radar indicators and detecting capabilities of deck radiolocation equipment are explicitly defined; it is purposeful to search for new solutions in this subject, having in mind increasing safety of sailing.

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