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Complex Objects Separation Approach Based On Radar Data

Abstract. *The radar image formation model, which takes into account the system, object and underlying surfaces parameters, is presented in the paper. Objects detection and separation approach based on grouping of spots on the radar image are given. Considered approach based on grouping some "spots" acquired from a separate object with the assumption of spatial relations of these spots.*

Summary. *Artykuł przedstawia sposób formatowania złożonych obrazów radarowych. Detekcja i separacja obiektów bazuje na odpowiednim grupowaniu różnych miejsc obrazu radarowego. Poszczególne części obrazu są grupowane w oparciu o przestrzenne zależności między tymi miejscami. (**Separacja złożonych obiektów na obrazach radarowych**)*

Keywords: radar imaging, radar signal, objects separation.
Słowa kluczowe: obrazowanie radarowe, sygnał radarowy, separacja obiektów.

Introduction

Nowadays radar applications become a casual thing for many human activities like automotive applications, in military and civil aviation, monitoring and so on [1]. The distance to the observed scene and objects is reduced. That's why some of the objects on radar images have quite large angular dimensions. Due to the specific of coherent radar imaging result images don't contain optical-like images of object but contain set of "light" spots [2-4] distributed around the object's spatial region. This fact makes radar images processing quite a complicated technical and scientific problem. One of the important and actual problems of radar image processing is detection and separation objects on the observed scene.

Radar image forming

In general, the radar image is formed by two-dimensional scene scanning with radiation pattern of the radar system. Radar images is a set of discrete values of the received signal due to scanning space with radiation pattern of the receiving antenna recorded in the discrete coordinate system. Received signal in a given direction (pixel in the image) is presented in a complex form and contains information about the parameters of the object and the scene.

In this paper, a model of the object is represented by a set of a large number of elementary spots like reflectors with similar properties. The radar signal is represented by two components - a specular and diffuse [5, 6]. Non-coherent waves scattered indicating diffuse radiation. Useful information about object within the element separation in this process is absent. Specular radiation is a result of coherent radio waves. At the paper we accepted that the energy absorption on the surface of objects is insignificant.

Specular component $\dot{E}_{spec}(\Omega)$ of the radar signal for each direction of the scene:

$$\dot{E}_{spec}(\Omega) = \frac{1}{2R(\Omega)} \cdot \dot{k}_{refl}(\Omega, \Omega_{sc}) \cdot \dot{F}_{refl}(\Omega, \Omega_{sc}) \cdot e^{-j \cdot 2\beta \cdot R(\Omega)} \quad (1)$$

where - Ω coordinates of spatial angle scenes; Ω_{sc} - spatial angle of the scan coordinates; $R(\Omega)$ - the distance from the observation point to each point on the scene; $\dot{k}_{refl}(\Omega, \Omega_{sc})$ - complex reflection factor for each point of the scan, which depends on the direction of scanning parameters, surface of the object and scene, lengths waves and polarization; $\dot{F}_{відб}(\Omega, \Omega_{sc})$ - function of the reflecting from the surface of objects, which depends on the field distribution on the object's surface in the direction of scanning; $\beta = \frac{2 \cdot \pi}{\lambda}$ - phase ratio; λ - wavelength.

Diffuse component $\dot{E}_{diff}(\Omega)$ of the radar signal in each direction scene is defined as follows:

$$\dot{E}_{diff}(\Omega) = \frac{1}{2R(\Omega)} \cdot (1 - \dot{k}_{refl}(\Omega, \Omega_{sc})) \cdot \dot{F}_{diff}(\Omega) \cdot e^{-j \cdot 2\beta \cdot R(\Omega) + \Delta_{diff}(\Omega)} \quad (2)$$

where $\dot{F}_{diff}(\Omega)$ - diagram of diffuse scattering objects on the scene; $\Delta_{diff}(\Omega)$ - the random phase change signal caused by the heterogeneity of the object scattering.

Signal intensity of the radar image (pixel) $\dot{I}_{Radar}(\Omega_{sc})$ is determined by the result of the summation of signals from all points on scene:

$$\dot{I}_{Radar}(\Omega_{sc}) = \int\limits_{\Omega_{scene}} \dot{F}(\Omega - \Omega_{sc}) \cdot \frac{1}{2R(\Omega)} \cdot [\dot{k}_{refl}(\Omega, \Omega_{sc}) \cdot \dot{F}_{refl}(\Omega, \Omega_{sc}) \cdot e^{-j \cdot \beta \cdot 2R(\Omega)} + (1 - \dot{k}_{refl}(\Omega, \Omega_{sc})) \cdot \dot{F}_{diff}(\Omega) \cdot e^{-j \cdot 2\beta \cdot R(\Omega) + \Delta_{diff}(\Omega)}] d\Omega + n(\Omega_{sc}) \quad (3)$$

where $\dot{F}(\Omega - \Omega_{scan})$ - a complex pattern of receiving antenna; Ω_{scene} - the scan spatial angle; $n(\Omega_{sc})$ - additive noise value.

An analog signal (3) is discretised and quantized to obtain digital images. The discrete signal $\dot{I}_{Radar}(k_{sc}, l_{sc})$ of radar channel, which corresponds to one pixel with angular coordinates in the elevation and azimuth planes, is described by the following expression:

$$\dot{I}_{Radar}(k_{sc}, l_{sc}) = \frac{1}{N \cdot M} \sum_{k,l} \dot{F}(k - k_{sc}, l - l_{sc}) \cdot \frac{1}{2R(k,l)} \cdot [\dot{k}_{refl}(k, l, k_{sc}, l_{sc}) \cdot \dot{F}_{refl}(k, l, k_{sc}, l_{sc}) \cdot e^{-j \cdot \beta \cdot 2R(k,l)} + (1 - \dot{k}_{refl}(k, l, k_{sc}, l_{sc})) \cdot \dot{F}_{diff}(k, l) \cdot e^{-j \cdot 2\beta \cdot R(k,l) + \Delta_{diff}(k,l)}] + n(k_{sc}, l_{sc}), \quad k = 1..M;\ l = 1..N; \quad (4)$$

where k_{sc}, l_{sc} - coordinates of the scan, i.e. number of rows and columns in the matrix that generated an image; M, N - the number of rows and columns of the matrix corresponds to the full azimuthal and elevation angles of the input scene.

Radar imaging numerical simulation

Test model [6] is chosen to simulate the formation of the radar images (Fig. 1), which is a set of matrices Z_i *[N × M]*, each representing a set of values of i-parameters and characteristics from (4). The total number of elements in each matrix S = N × M.

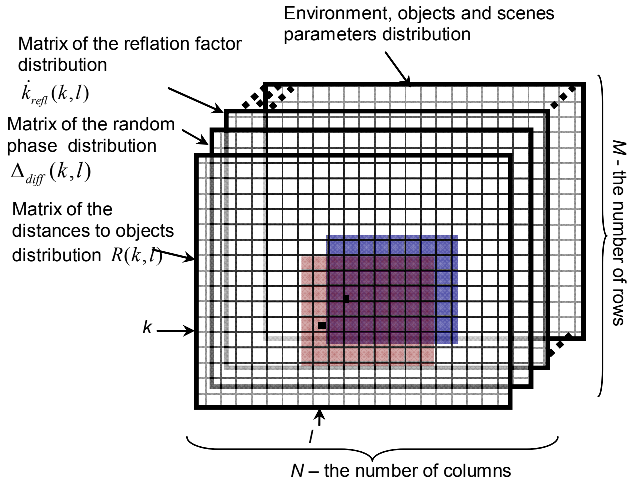

Fig.1. The model of the input parameters forming

In the presented model there are introduced matrices with the following parameters:

• Matrix of the distance distribution $R(k,l)$ from the observation point to the object (scene) one;

• Matrix of angles distribution $\alpha(k,l)$ for each point relatively to the center scene of rectangular matrix. These data is used for reflecting factor calculation;

• Matrix of complex reflection factor for each point on the object's surface and for a given wavelength;

• Matrix of distribution parameters of the environment objects and scene;

• Matrix of diffuses random phase component of the signal distribution $\Delta_{diff}(k,l)$, that depend on the surface roughness.

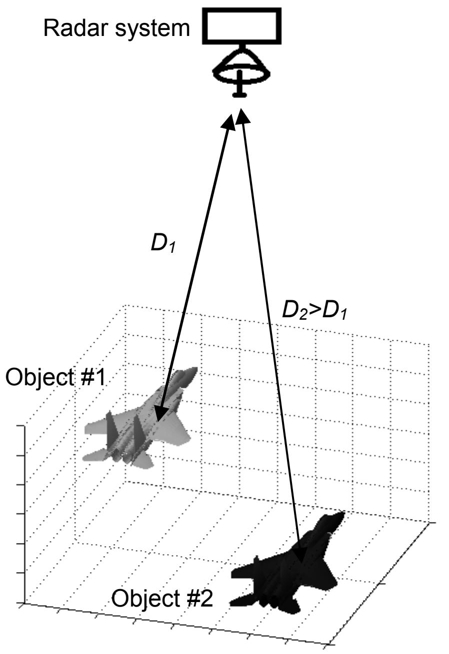

Fig. 2. Radar image of scene with two aircrafts

An example scene was created (fig.2) to demonstrate the proposed algorithm. The scene included two aircrafts. For simplification of the underlying surface it is defined as a homogeneous surface. Based on a certain scene and point of view there are extracted several matrices with data for further simulation. As an input there can be used a scene built with VRML language. Using these 3D data, which contains a lot of elementary triangles of certain material with their own electromagnetic properties mirror and diffusion reflection coefficients are calculated as well as angles to the normal line and a few additional parameters, necessary to calculate the reflected field near receiving antenna.

This approach to build radar image is flexible due to possibility to combine different materials with different properties in one model with different surfaces. For detail simulation a huge number of calculations are necessary and therefore it takes a while. The fast algorithms of convolution calculation were used with the aim to speed-up the results obtaining. As a result the calculation performance was obtained a few hundred times faster.

The distribution of the reflection angles from the surface of the object $\alpha(k,l)$ that is taking into account the location of the object on the scene in relation to the point of scanning is presented on Fig.3.

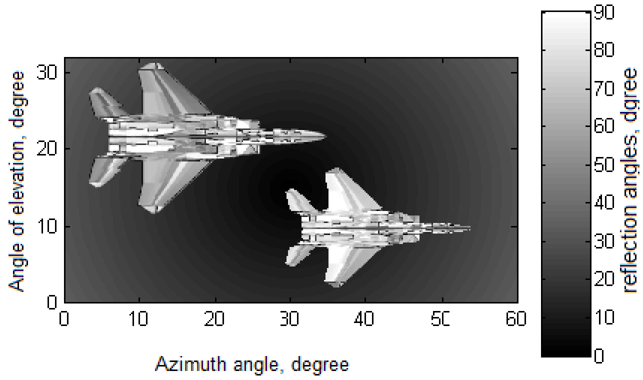

Fig. 3. Distribution of the reflection angles from the object and scene

As a result of coherent summation according to (4) there is formed a radar image is presented in Fig. 4. The radar image has been built as a scanning of the scene from a single point with the azimuth angle + / - 30º and elevation angle + / -16º ranges.

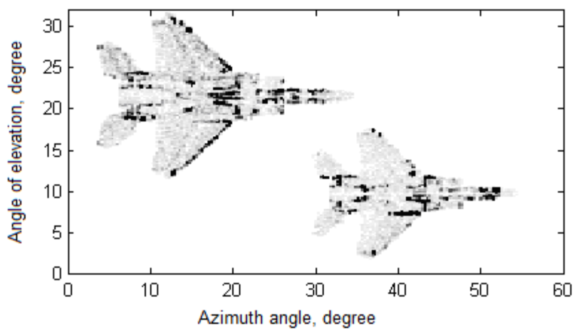

Fig. 4. Radar image of scene with two aircrafts

The principle of the objects separation

The radar system forms the image, which contains a large number of distributed points on the object (Fig. 4) in opposite to the optical or passive radio monitoring systems. Therefore it is impossible to use simple techniques to detect objects as they give a lot of false alarms, since they identify a number of objects instead of one. It should be noted that the spatial arrangement of an object and the observatory has a large impact on the number of points of radar images, their location and their intensity [4, 7].

Separate spots on the radar image should be combined within one separate object. The minimum spatial distance between radar points can be used for the unification of the radar image pixels into a single object. Then there is the opportunity to bring the point of radar images with a given spatial region in a single object. This approach makes it possible to connect and relate the individual points within a single object. Thus, the selection and separation of objects become more reliable. Unlike optical systems, radar systems have information about the distance to the object on the scene, and this is another opportunity to improve the separation of the objects.

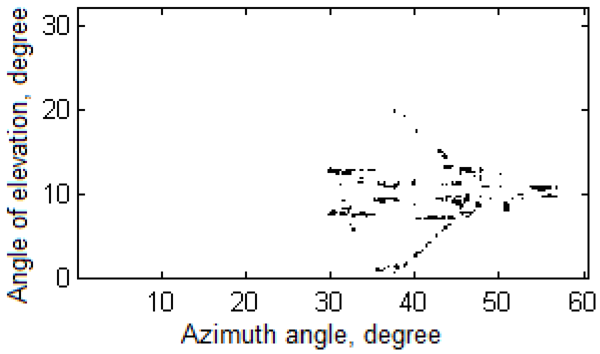

Fig.5. Binary radar image of detected object #2

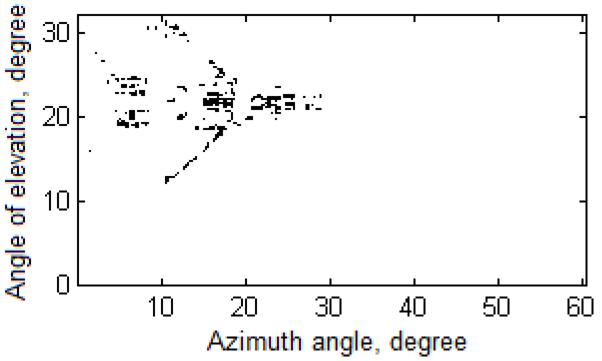

Fig.6. Binary radar image of detected object #1

For separation all the points on the object radar images at spatial coordinates are incorporated into a single array of data. This array also includes the intensity of each spot. The separation process starts from the point with the biggest radar signal intensively. The distance to the next spot is proportional to the radar intensity. That's why a sphere is formed with a specified radius that is proportional to the signal intensity and the center of start point in the array. Next search for all points within the sphere is formed to find out all related spots. Similarly there are considered the points built in the spatial volume and the search is kept on for further related points. Thus, there are extracted all the related points in one array, which corresponds to a single object. The above procedure is repeated, and all points are allocated in subsequent objects. If the number of points that belong to the object is very small, their intensity (signal) is small, then it is assumed that this is not the object but the noise or interference. The result of the division of objects is stored in separate data sets that can be represented as a single image as in Fig. 5 and Fig. 6.

Conclusion

The proposed model radar images formation provides a possibility to take into account the system parameters, objects and environments characteristics, and assess their impact on the quality of the generated image and the process of identifying objects.

Given approach improves detection and object separation abilities of radars for area-extensive objects and reduces probability of false detection of objects. Furthermore it is possible to improve characteristics of radar systems involving information from other channels or systems which observe the same scene.

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