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FILTERING METHOD FOR ANALYSIS OF THE IMAGE RECEIVED BY MICROWAVE PROBING

The article offered a complex of program procedures which can be used to process the point arrays of the space complex amplitudes obtained after reconstructing the images received by microwave probing. The procedures allow creating space «depth maps» of the probed object by filtering and fitting algorithms. The detail level is enough to make a comparative analysis with «depth maps» of video systems based on pairs of stereo video cameras.

INTELLIGENT IMAGE FILTERING SYSTEMS; MICROWAVE TECHNOLOGY; IMAGES OF RADIOWAVE PROBING.

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МЕТОДИКА ФИЛЬТРАЦИИ АНАЛИЗА ИЗОБРАЖЕНИЙ МИКРОВОЛНОВОГО ЗОНДИРОВАНИЯ

Предложен комплекс программных процедур обработки массивов точек пространства комплексных амплитуд, полученных в ходе процесса восстановления изображений микроволнового зондирования, способных создавать на основе алгоритмов фильтрации и сглаживания пространственные карты глубины зондируемого объекта, с уровнем детализации, достаточным для осуществления сравнительного анализа с картами глубин видеосистем, на основе конструкции стереопары.

ИНТЕЛЛЕКТУАЛЬНАЯ СИСТЕМА ФИЛЬТРАЦИИ ИЗОБРАЖЕНИЙ; МИКРОВОЛНОВАЯ ТЕХНИКА; ИЗОБРАЖЕНИЯ РАДИОВОЛНОВОГО ЗОНДИРОВАНИЯ.

The term «microwave image of the object» is usually understood as a distribution of complex scattered field amplitudes within the object space. This term, however, only slightly matches the classical definition of the image received «in visible light». However, unlike visible light, it fully informs of the characteristics of the electromagnetic field in the inspected area.

Considering all the above-mentioned, we face a question whether it is possible to obtain similar images of the objects in a visible and microwave range, taking into account differences in optical transmission and deflection properties of mediums, where the radiation propagates. This article considers the method of analyzing and reconstructing images of the conducting objects. It is known, that in the microwave frequency range of the electromagnetic radiation the conducting objects have a higher reflection index [3], which depends on the conductive properties of the object.

During the field reconstruction by the method described in the article [1], among all the range of the reconstruction points, the scattering centers will be the only points which have the biggest amplitude. It is worth noting that in the case of a electromagnetic wave and conductor the scattering centers are actually the points on the outer surface of the object. Since scattering the wave of the given frequency range takes place on the skin layer of the conductor, which is usually not more than several microns.

Thus we can say that points of the probed space, where, during the field reconstruction, the amplitudes of the reconstructed signal are maximal, are the points on the surface of the conducting object, i. e. those points, which could be seen by the video system.

Amplitude distribution of the reconstruction points is not a high gradient function. It is likely to be a function with a smoothly falling amplitude value depending on the distance to the scattering center [2]. This can also mean that if there is a noise component in the signal, the maximal amplitude could shift during the reconstruction in vicinity of the scatterer, and that may cause some uncertainty when trying to identify the scatterer's real location.

Filtering Based on Amplitude Distribution. According to the above-mentioned information, the procedure of locating scattering centers should start from identifying areas of probable localization for these centers, e. g. by using amplitude histogram. In order to distinguish which points of the grid belong to the reflecting surface of the object, we can speculate that a field amplitude value when the signal is reflected from the conducting surface is much bigger than at some distance from the surface. For this purpose a histogram of amplitude distribution (more precisely – of common logarithms of the amplitudes) is built for all points of the array as it is shown in the Fig. 1.

Supposing that the distribution of the amplitude logarithm is Gaussian, i. e. normal, the average value of the logarithm $< \lg(\mathrm{Amp}) >$ and standard deviation — are calculated using standard formulas.

$$< \lg(\mathrm{Amp}) >= \sum_{i=1}^{N} \frac{\lg(\mathrm{Amp})_i}{N} \qquad (1)$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (\lg(\mathrm{Amp})_i - < \lg(\mathrm{Amp}) >)^2}{N}} \qquad (2)$$

where N is a number of elements in an array (number of coordinate grid nodes).

Parameter R will be the one showing the contrast of the final microwave image; if this parameter takes high values, borders of the object surface will blur, whereas if the values are low, some surface areas will disappear. The choice of the parameter value depends on the object, its location relatively to emitting antennas and many other conditions. The optimal value for this parameter is determined manually and is based on the imaging results. This filtration is used to turn down further analyzing those points of the coordinate grid, in which the field amplitude is lower than the set value. In order to do this, we use values $< \lg(\mathrm{Amp}) >$, — from the amplitude diagram and R value from the set program parameters.

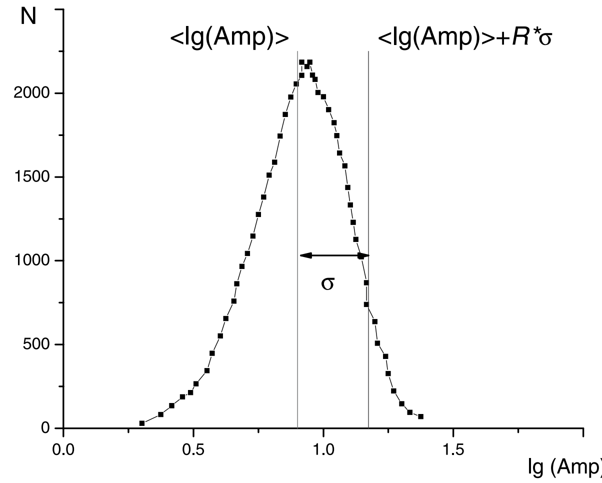

Fig. 1. Histogram of amplitude distribution

The operation algorithm for this filter is the following:

During the cycle all values of the $(\mathrm{Amp})_i$ array are compared with the value $(< \lg(\mathrm{Amp}) > +R\sigma)$.

If $(\mathrm{Amp})_i \geq 10(< \lg(\mathrm{Amp}) > +R\sigma)$, then $(\mathrm{Amp})_i$ saves it value.

If $(\mathrm{Amp})_i < 10(< \lg(\mathrm{Amp}) > +R\sigma)$, then $(\mathrm{Amp})_i = 0$.

Usually R value is 2-2.1 and after this filter is applied, the amplitude array has less than 5 % of the non-zero elements. After the described filtration is applied, those areas around the points are marked, which corresponds to the object surface, but the precise location of the surface borders is yet undetermined. In order to identify precise borders of the object, it is necessary to determine the point which has the maximal amplitude value. The main difficulty is to choose the direction (axis) of the search for this maximal value, because if the direction is wrong, it will result into duality of the scattering center coordinates.

Modelling the scattering processes for the microwave field implies the direction of the search for the maximal values of the reconstructed field intensity. This strongly depends on the shape and size of the effective aperture of the probing emitting array and on the location of the receiving antennas. We used the emitting array consisting of 256 transmitting elements with the square aperture [5]. Each of the elements of the antenna array generated a monochromatic microwave wave with the frequency between 10.5 and 16 GHz. In general, 16 generating frequencies were used. A receiver was placed at the distance of 1 m from the antenna array.

Each side of the square-shaped antenna array is 30 cm. The center of the antenna array (Fig. 2–4) is located in the coordinates (300; 0) along the *X* and *Z* axes accordingly. *Y* axis in this case is not taken into consideration, since Fig. 2–4 show only a two-dimensional (*XZ*) cut of the three-dimensional (*XYZ*) space. For the chosen configuration the scattering center is located on the normal-(beginning in the center of the array)-to-the-antenna array. Fig. 2 shows the reconstructed microwave field for the modeled point scatterer with the coordinates (300; 150).

As it is clear from Fig. 2, the maximal amplitude value and distribution of the secondary maximums of the reconstructed field is done only along the normal line to the receiving antennas array. The direction of the normal line coincides with *Z* axis of the coordinate system.

When the scattering center shifts relatively to the antenna array, the direction of the distribution of the secondary maximums of the scattered field also changes. The direction of the search for the maximal value should change respectively. Hereby the direction of the search will be presented by the line connecting

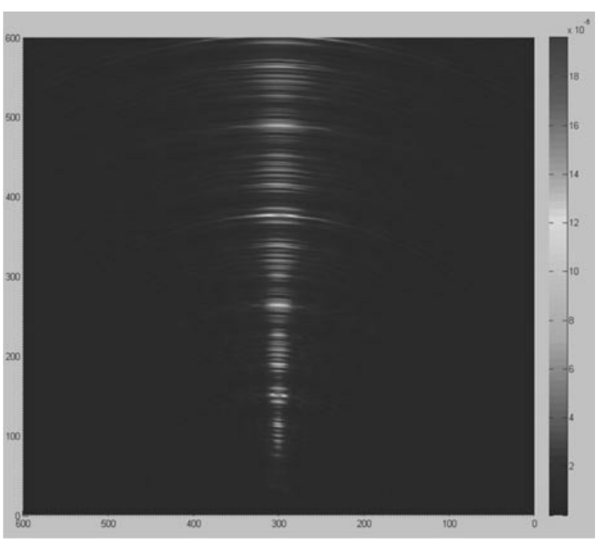

Fig. 2. Distribution of the reconstructed field with the point scatterer located in (300; 150)

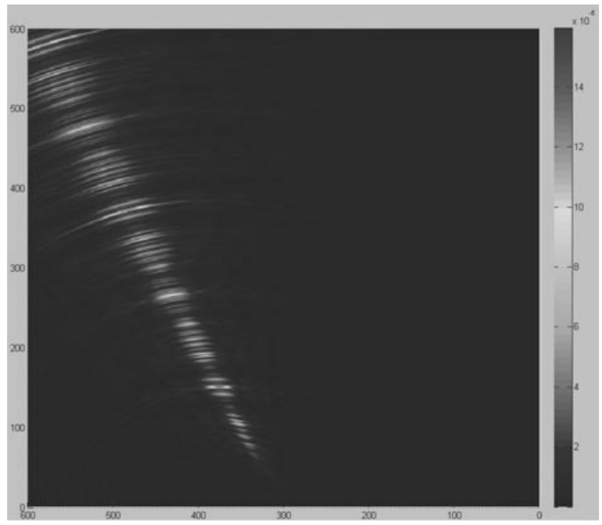

Fig. 3. Distribution of the reconstructed field with the point scatterer located in (380; 150)

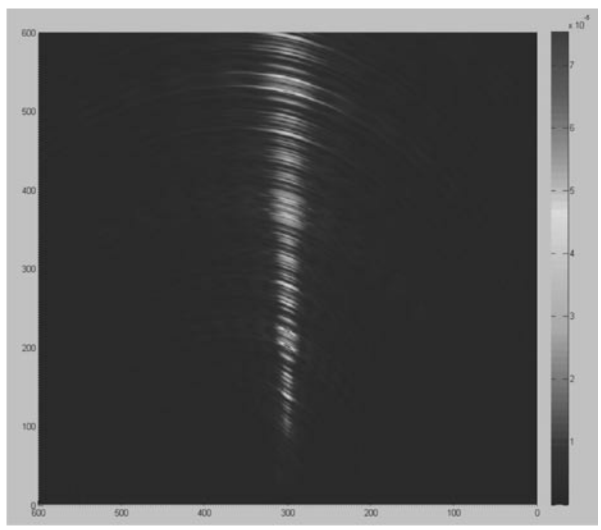

Fig. 4. Distribution of the reconstructed field with two point scatterers in the free space located at the 10 cm distance from each other along *Z* axis

the center of the mass of the antenna array and the scattering center.

When reconstructing one point object, it is necessary to choose correctly the axis, along which the search for the maximum will be done. This is not an obvious task. Below we consider the example in which the incorrectly chosen direction of the search for the maximum value could cause serious errors. Fig. 4 shows the distribution of the intensities of the reconstructed microwave field for two point scatterers with coordinates (300; 200) and (300; 210) respectively.

If the direction of the search for the maximum value lies along Z axis, we will receive a reconstructed image for only one scatterer instead of two. This may cause serious quality issues (up to the omission of certain elements) on the images of the real objects.

The direction of the search for the maximal values in this case should be determined by the location of the antenna array aperture centers and scattering centers.

When it comes to the practical use of the described method for the reconstruction of the images of the real objects, it is worth noting that the process of the microwave field reconstruction requires a lot of resources and depends directly on the number of the reconstructed points, i. e. on the size of the reconstructed space and required resolution of the object. It was concluded that the direction of the search for the maximal field value should be chosen so that each of the reconstructed points should form a certain direction of the search for the maximal value. This also requires a geometrical fit of a discrete set of the reconstructed points with the location of the receiving-transmitting elements.

After the unambiguous correlation between coordinates of the points with maximal amplitude values is found, filtering of the image does not include only analyzing the field amplitudes, but analyzing a point cloud corresponding to the object surface.

Filtering Based on the Video Image. During further filtering the microwave image is processed together with the video image of the object. The main idea is to eliminate the points of the microwave field, which are not presented on the video image, from the microwave image [4]. The similar data array, which describes the video image, comes from the video image processing module. These data are presented as a 2D-array of the coordinate values of stereo video image points. If some points of the video image with a pair of coordinates x_i and y_i are not available, the corresponding points from the microwave image are also deleted, otherwise the points save their previous values.

Filtering Based on the Method of the Connected Domains. The initial 3D model, which is formed during the image reconstruction, has a certain amount of noises caused by outer electromagnetic noises, imperfect light conditions and shape and texture of the

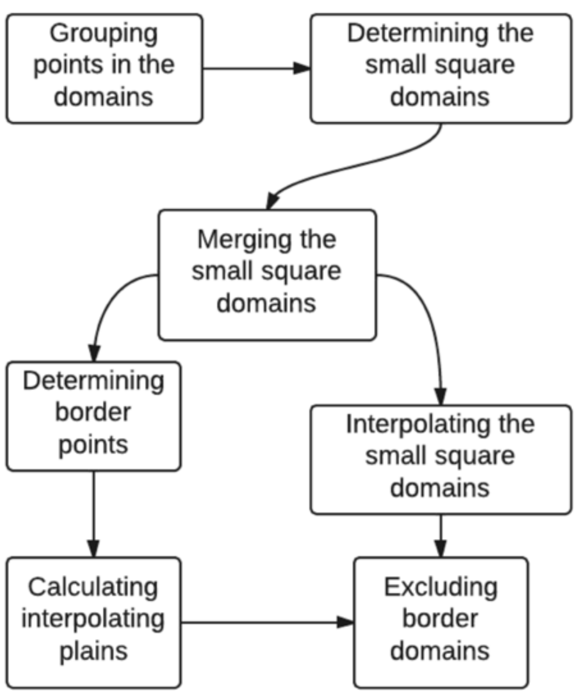

Fig. 5. Diagram of the filtering and interpolation algorithm applied to the reconstructed microwave image

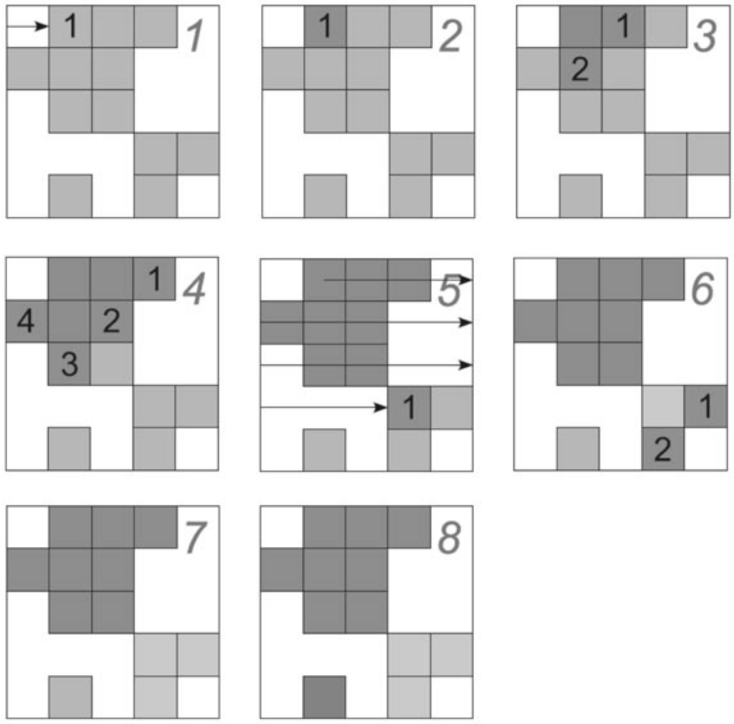

Fig. 6. Method of connected domains

objects. Filtering and interpolation are applied to the 3D model to lessen the influence of the above-said parameters during the following processing steps. The output data are shown as Z matrix with $n_x \times n_y$ dimensions. Values for each Zij element are equal to the distance to the point of the object with coordinates (x_i, y_j). During the first step of filtering the connected domains are determined. In other words, if any (i, j) point belongs to K domain, each neighboring points $(i + \delta i, j + \delta j)$, $\delta i, \delta j \in \{-1, 0, 1\}$. $\left|Z_{i+\delta i, j+\delta j} - Z_{i,j}\right| < \Delta z$, describes conditions of belonging to K domain, where Δz – a threshold value.

For each element, which still belongs to no group, all neighboring elements are determined, which belong to the same group, and the same operation is applied to those elements. This continues while any new neighboring elements, which meet the connecting condition, are available. Then the group is closed and processing goes to the next yet «uncoloured» point. Schematically the process is shown in Fig. 6.

A number of points belonging to each domain is identified. Domains, whose square is less than the certain threshold value, should be interpolated. Two of such domains are merged if they have at least two adjacent bordering points. After merging the domains are interpolated. The interpolation is done with areas of plains located on the edges of the interpolated domain. For each interpolated domain $K0$ all domains Kj are chosen for those bordering on it. The points belonging to these domains and bordering on $K0$ are used to calculate the regression coefficient for the plain. The interpolated domain is filled with distance values corresponding to the found plain. Full scheme of processes of «connected domains» filter is shown in Fig. 5.

In this article the author described the filtering method for the microwave images received by probing conducting objects. The method is based on the number of the discrediting methods of the microwave image components which do not belong to the surface of the inspected object. The present method could be considered as a set of main filtering steps, without any description of methods that are used to smooth or increase the image quality. Nevertheless, the method could be used as a basic approach to receive images of this type.

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