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RADIOMETRY IMAGING SYSTEM WITH DIGITAL SIGNAL PROCESSING

Zenon Grytskiv and Sviatoslav Voloshynovskiy

Abstract. The problem of high resolution radiometry imaging is considered. An iterative method of radiometry image processing is presented in the paper. The problem of image reconstruction is considered as the inverse ill-posed problem. The method proposed makes use of the iterative technique and regularization procedure to improve image quality. Nonlinearity of the method is provided by a nonnegative constrain and a space limitation on the probable image extent that makes possible to accomplish band-limited extrapolation and enhance the resolution.

1. Introduction

The radiometry imaging is known to be used in the diverse fields such as radio astronomy, microwave computerized tomography, the earth remote sensing, etc. The radiometry imaging technique is based on the own object radiation measurements in dependence on the spatial directions. The radiometry temperature (radiometry image) of the direction is reproduced by a brightness (or color) on TV screen in the pixel corresponded to spatial antenna beam orientation. However, quality of the image obtained by means of the above technique is very low that is determined by a beam width. To improve quality of the radiometry image it is necessary to increase the spatial resolution. The classical approach to solve the problem is to exclude the antenna smoothing out influence by aid of the image processing considered as the solution of the inverse problem [1]. The inverse problem is known to be the ill-posed one characterized by the fact that arbitrarily small variations in the initial data lead to arbitrarily large changes of the solution. Therefore, it requires to implement the method which is able to solve the above problem in the least- squares sense.

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The authors are with State University "Lvivska Polytechnika", Lviv, Ukraine.

In this paper a possible approach is presented to obtain high quality radiometry image for the further TV reproduction.

2. Formulation of the problem

Assume the following structure of the radiometry imaging system as it is shown in Fig. 1.

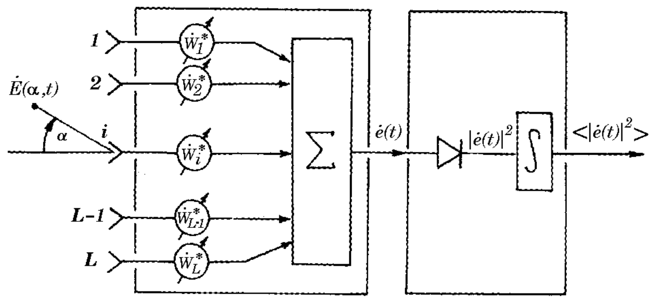

Fig. 1. Block diagram of radiometry imaging system consists of beamformer and receiver

In the general case the process of the radiometry imaging can be presented by the Fredholm integral equation of the first kind [2]

$$g(\theta_1', \theta_2') = \int_\Omega \int h(\theta_1 - \theta_1', \theta_2 - \theta_2) f(\theta_1, \theta_2) a\theta_1 a\theta_2 + n(\theta_1', \theta_2') \qquad (1)$$

where $g(\theta_1, \theta_2)$ is the received image smoothed out by the directional pattern, is the directional pattern, $h(\theta_1, \theta_2)$ is the initial image needs to be reconstructed for TV reproduction, $n(\theta_1, \theta_2)$ can be considered as the noise component or the errors of measurements. The antenna scans in θ_1, θ_2 spatial coordinates in the range of the Ω observation field. Equation (1) is also very often named convolution.

The problem of the image reconstruction means the solution of the above integral equation (deconvolution). The image $f(\theta_1, \theta_2)$ is to be estimated from (1), but due to the noise component the above problem is ill-posed that requires the special technique for the solution.

For the further presentation convenience equation (1) may be written in the operator form

$$g = Hf + n, \qquad (2)$$

where g is the received image, H is the operators denotes the directional pattern, f is the estimated image and n is the noise component.

3. Problem discussion

3.1. General solution

To obtain the high resolution TV image it is necessary to exclude the smoothing out directional pattern influence that decreases the level of high frequency components in the Fourier transform of the initial image f. The high frequency components determine quality and the details of the image. Therefore, their reconstruction can improve the TV image quality reproduction and increase the equal spatial resolution.

A lot of linear methods are known to solve equation (2) in the least-squares sense

$$\hat{f} = (H^*H)^{-1}H^*g, \tag{3}$$

but most of them need the matrix inversion. In the case of TV dimension image reconstruction it is not efficient, because the technical realization meets a lot of difficulties. The iterative methods were chosen, because they have a number of advantages in comparison with Wiener [3] and Kalman filtering [4], Tikhonov regularization [5] which are based on (3).

3.2. Iterative solution

The iterative methods make possible to organize the parallel computational process and don't need the matrix inversion that is very important for practical realization [6]. The use of the solution constrains allows to obtain nonlinear iterative method able to reconstruct the depressed high frequency components that is impossible to accomplish by means of the above linear methods.

The constrain iterative method with regularization can be written [7]

$$\hat{f}^{k+1} = P[\hat{f}^k + \beta(H^*g - (H^*H + \alpha C^*C)\hat{f}^k)], \tag{4}$$

$$0, \beta \leq \frac{2}{|| \; H^*H + \alpha C^*C \; ||},$$

where $\hat{f}^{k+1}$ is the estimation of $\hat{f}$ on $k+1$ iteration, $P[\cdot]$ is the constrain operator, C is stabilization operator, "$*$" denotes ermitian matrix transpose, α is regularization parameter and $|| \cdot ||$ denotes matrix norm.

The condition of the iterations convergence is

$$| \; I - \beta(\tilde{H}^*(m)\tilde{H}(m) + \alpha\tilde{C}^*(m)\tilde{C}(m) \; |, 1, \tag{5}$$

where $\tilde{H}(m)$, $\tilde{C}(m)$ are the Fourier transform of H and C, respectively.

The constrains are linked with a priori information on negativity of the image f (i.e. f is the power) and the spatial limitation on the probable image extent

$$P[\hat{f}_i] = \begin{cases} \hat{f}_i, & \text{if } \hat{f}_i \geq 0 \text{ and } i_b \leq i \leq i_c \\ 0, & \text{else} \end{cases}$$

where i_b and i_c are the beginning and the end of the spatial sector, respectively. The use of the constrains transforms the linear algorithm into nonlinear one that makes possible to perform the extrapolation in the field of high frequencies. All possible a priori information is desired without loss of generality. It can be the general expected power of the image, the covariance matrix or some information on the separated parts of image if it is available for some reasons, etc. The use of the constrains makes to converge the iterative process even in the case when condition (5) is not satisfied.

4. Computer simulation

In this section the results of computer simulation are presented. The test image was chosen to investigate the possible resolution enhancement of the imaging system. The test image consists of two separated square "spots" with intensity equals 1. The modeling was accomplished for 3 antennas with the uniform field distribution in antenna aperture and with dimensions D equal 60λ, 100λ and 200λ. The results of direct measurements by means of the above antennas are shown in Fig. 2(a,b,c). The signal to noise ratio is chosen high enough (SNR=45dB) to investigate the potential abilities of this system. For the smallest antenna ($D = 60\lambda$) peaks are not resolved. The "spot" form is not also distinguished for antenna with $D = 100\lambda$. Some conclusions about image structure could be only made for antenna with $D = 200\lambda$. The results of computer restoration by means of method (4) for the above antennas are shown in Fig. 2(d,e,f). The peaks are resolved and image structure are recognized even for the smallest aperture. The image in Fig. 2f is practically the same as the test one. Comparing the obtained results with the results of direct measurements and taking into consideration the correspondence of these images to the initial one we can conclude that the resolution enhancement is about 3.3.

Thus, the use of the proposed signal processing in radiometry imaging systems makes possible to increase its metrology characteristic, i.e. spatial resolution. Knowing the main features of the nonlinear methods, i.e. extrapolation ability, noise immunity, it is possible to optimize the radiometry

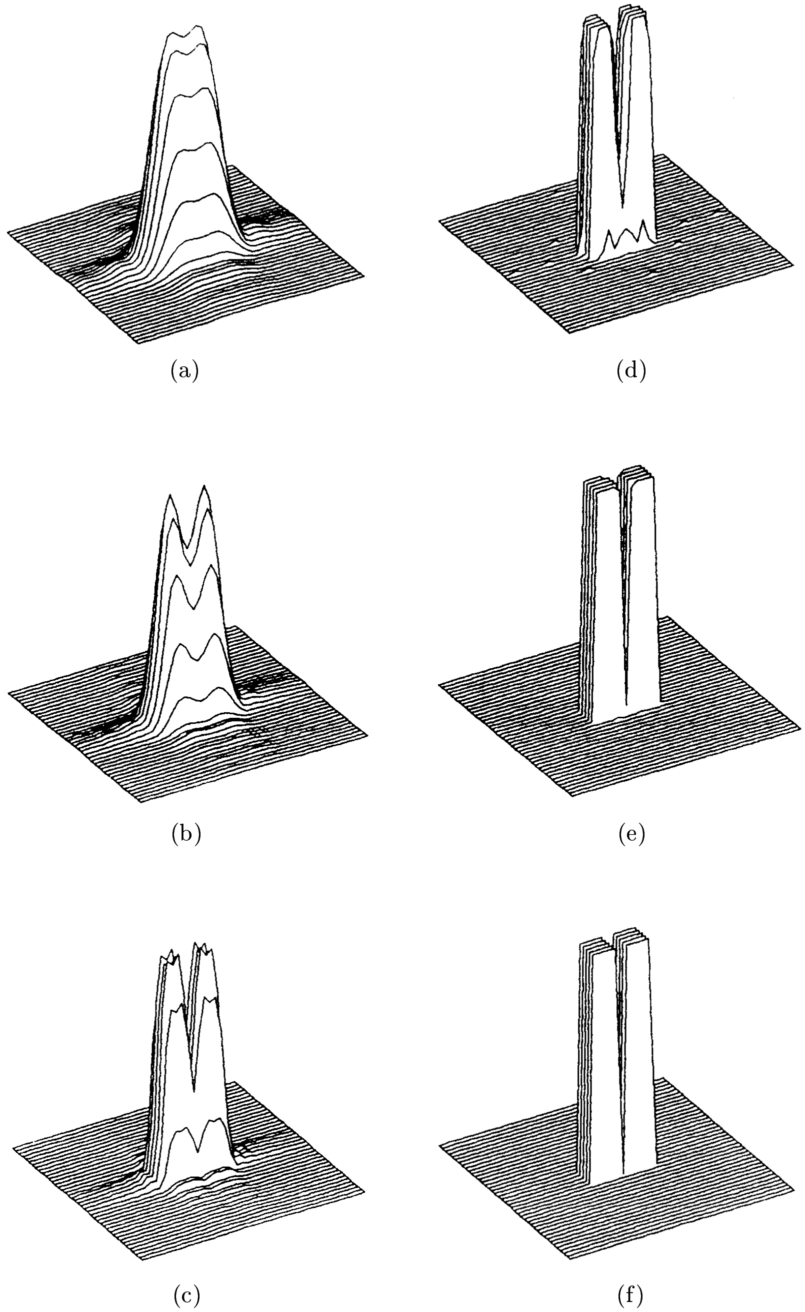

Fig. 2. The results of computer modeling show the possible resolution obtained by means of direct measurements (a, b, c) *and processing by nonlinear method* $(d.e, f)$

imaging system, and namely to match antenna characteristics with the methods of signal processing. The preliminary study indicates that the optimal field distribution in antenna aperture exists. Moreover, it is possible to decrease the general quantity of array elements for the given spatial resolution in comparison with the filled array. Therefore, the additional opportunity appears to design the optimal antenna geometry according to the features of the method.

The use of the above approach makes possible to obtain radiometry image with the resolution about 5 times better for the matched optimal antenna than the resolution determined by the physical beam width at half power points. For comparison the resolution enhancement obtained by means of the linear methods like (3) is about 2 times better than the physical beam width.

5. Conclusions

Thus, the use of the described iterative method allows to increase the spatial resolution of the radiometry imaging system and optimize its characteristics.

The proposed approach is computationally very efficient and the use of the parallel and vector solution of the linear system of equations makes possible to perform the real time image processing.

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