Software Complex for Representation and Processing of Images with Complex Structure

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Abstract. In the contemporary practice of digital image processing, special attention is paid to the solution of particular tasks, among which are delineation of boundaries, detection of anomalies, and pattern recognition. Usually, this approach is associated with the development of effective algorithms oriented to specific tasks. Now we have a sufficient number of applications that implements a variety of image processing algorithms. However, it is difficult to find software that implements a global approach to image processing based on the application of mathematical models. This article is devoted to the development of a software complex, the main functional of which is performed by using mathematical models of images. In addition to the task of representing images, the program implements algorithms for filtering, segmentation, and detection of anomalies in images. At the same time, the program is based on doubly stochastic autoregressive image models, which are best suited for describing spatially heterogeneous images. In addition, the algorithms implemented in the developed program can be applied to processing the real images. We also describe in details methods for simulating images containing a given number of structures and investigate segmentation algorithms for the proposed model of images.

Keywords: doubly stochastic models, image processing, segmentation, filtering, anomalies detection, image processing software, Matlab

1 Introduction

Methods of the multispectral (up to 10 spectral ranges) and hyperspectral (up to 300 ranges) registration of Earth surface areas have become widely used in recent years. Obtaining and processing significant amounts of information is a very difficult task, and it requires considerable computational costs.

Digital image processing is currently of interest to many researchers. For example, P. Markelj, D. Tomazevic, A. Mohamed Akil, V.R. Krasheninnikov, etc. devote their papers to medicine image processing [1–3]. B. Krishna Mohan, R. Harris, V.A. Soifer, V.V. Sergeev, V.V. Myasnikov, K.K. Vasiliev, etc. get the good results in processing the satellite images [4–6]. In addition, the adaptation of various image processing algorithms to signals of a different kind and for solving other problems is also actual.

There is an approach, in which image processing is based on any local or particular algorithms, and an approach, in which the mathematical model is used as the basis for a number of developed algorithms. It should be noted that a number of specialized application programs are devoted to the solution of particular problems, while there is practically no software for careful study of the model based approach.

Despite the diversity, the well-known mathematical models of multidimensional images have a number of shortcomings. The main disadvantage is considerable difficulties in describing a spatially inhomogeneous and time-dependent real material. A.S. Shalygin and Yu. I. Palagin suggested to use the mixed models [7] to describe such images. Then J. Woods and co-authors proposed a two-dimensional doubly stochastic Gaussian (DSG) model [8], which was introduced to provide a complete model for the spatial filters that adapt to the local structure in the image signal. In such a way, it was proposed to use combinations of different methods for the formation of random fields (RF) for image modeling.

A detailed investigation of the special case of doubly stochastic models based only on autoregressive (AR) processes was carried out in recent papers [9–12]. The methods of applying models and developing specialized software for the taxi order service are presented in paper [13]. Below, we consider a general software for the synthesis and analysis of doubly stochastic AR RF models.

2 Doubly stochastic model and representation of images

Most of the proposed mathematical models can not adequately describe real images due to their heterogeneity in space. Indeed, forming an image model with constant parameters, we obtain a uniform image. However, if we assume that the parameters of the simulated image change when each new element is formed, then the resulting image will be non-uniform. We will consider such models as ones with varying parameters.

Suppose we need to estimate the changing parameters of the doubly stochastic model of the RF such that it allows us to describe the characteristics of the real image $\{X_{i,j}\}$ with brightness RF $\{z_{i,j}\}$, $i = 1, 2, ..., M_1$, $j = 1, 2, ..., M_2$. We will describe it by using a model with multiple roots of characteristics equations with multiplicity (2.2) [12]

$$\begin{aligned} &\tilde{z}_{i,j} = 2\rho_{xij}\tilde{z}_{i-1,j} + 2\rho_{yij}\tilde{z}_{i,j-1} - 4\rho_{xij}\rho_{yij}\tilde{z}_{i-1,j-1} - \rho^2_{xij}\tilde{z}_{i-2,j} - \\ &-\rho^2_{yij}\tilde{z}_{i,j-2} + 2\rho^2_{xij}\rho_{yij}\tilde{z}_{i-2,j-1} + 2\rho_{xij}\rho^2_{yij}\tilde{z}_{i-1,j-2} - \rho^2_{xij}\rho^2_{yij}\tilde{z}_{i-2,j-2} + \\ &+b_{i,j}\xi_{i,j}, z_{i,j} = \tilde{z}_{i,j} + m_{zij}, i = 1, 2, ..., M_1, j = 1, 2, ..., M_2, \end{aligned} \tag{1}$$

where ρ_{xij} and ρ_{yij} are the correlation parameters, m_{zij} is the average value of the brightness.

Let us determine the values of the statistical parameters of the image $\{z_{i,j}\}$ in each pixel. To perform it, we will use the sliding window of $N * N$-size. Thus, we estimate the average statistical correlation coefficient for each pixel in a row ρ_{xij} and in a column ρ_{yij}, and, also, the average statistical expectations m_{zij} and the variances σ^2_{zij}:

$$\begin{aligned}
m_{z(i+\frac{N-1}{2})(j+\frac{N-1}{2})} &= \frac{1}{N^2} * \sum_{l=i}^{i+N-1} \sum_{k=j}^{j+N-1} X_{lk}, \\
\sigma^2_{z(i+\frac{N-1}{2})(j+\frac{N-1}{2})} &= \frac{1}{N^2-1} * \sum_{l=i}^{i+N-1} \sum_{k=j}^{j+N-1} (X_{lk} - m_{zlk})^2, \\
\rho_{xz(i+\frac{N-1}{2})(j+\frac{N-1}{2})} &= \frac{1-\sqrt{1-\left(\frac{\sum_{l=i}^{i+N-2}\sum_{k=j}^{j+N-1}(X_{lk}-m_{zlk})*(X_{(l+1)k}-m_{z(l+1)k})}{(N-1)*(N)*\sigma^2_{z(i+\frac{N-1}{2})(j+\frac{N-1}{2})}}\right)^2}}{\frac{\sum_{l=i}^{i+N-2}\sum_{k=j}^{j+N-1}(X_{lk}-m_{zlk})*(X_{(l+1)k}-m_{z(l+1)k})}{(N-1)*(N)*\sigma^2_{z(i+\frac{N-1}{2})(j+\frac{N-1}{2})}}}, \\
\rho_{yz(i+\frac{N-1}{2})(j+\frac{N-1}{2})} &= \frac{1-\sqrt{1-\left(\frac{\sum_{l=i}^{i+N-1}\sum_{k=j}^{j+N-2}(X_{lk}-m_{zlk})*(X_{l(k+1)}-m_{zl(k+1)})}{(N-1)*(N)*\sigma^2_{z(i+\frac{N-1}{2})(j+\frac{N-1}{2})}}\right)^2}}{\frac{\sum_{l=i}^{i+N-1}\sum_{k=j}^{j+N-2}(X_{lk}-m_{zlk})*(X_{l(k+1)}-m_{zl(k+1)})}{(N-1)*(N)*\sigma^2_{z(i+\frac{N-1}{2})(j+\frac{N-1}{2})}}}.
\end{aligned} \tag{2}$$

where z-index is introduced to describe the observed data.

Thus, we form the RFs of the correlation parameters $\{\rho_{xij}\}$ and $\{\rho_{yij}\}$, RF of mathematical expectations values $\{m_{zij}\}$, and RF of variances values $\{\sigma^2_{zij}\}$. The parameters allow us to simulate images with varying correlation parameters.

Fig. 1 shows an example of using the proposed method for simulating a real image. Fig. 1a corresponds to a real image with a size of 440 X 440 pixels. Fig. 1b corresponds to the image generated by doubly stochastic model of the multiplicity (2.2). Fig. 1c corresponds to the image generated by a doubly stochastic model of the first order. Statistical estimation of the parameters of the available image was carried out in a sliding window with the size of 15 X 15 pixels.

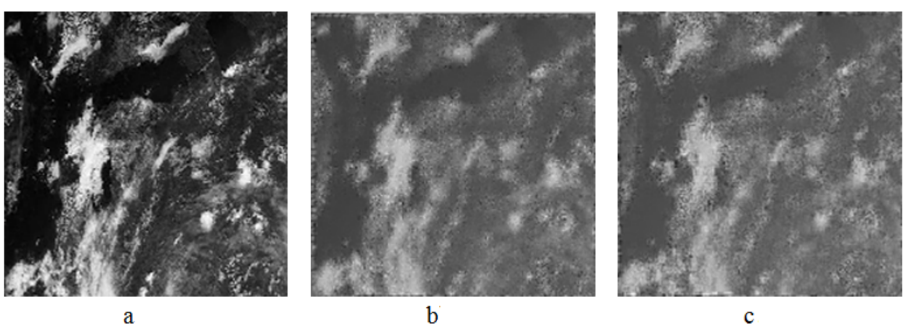

Fig. 1. Formation of an image with varying correlation properties

A direct comparison of the proposed method of simulating the satellite images with known algorithms using AR and wave models shows that the variance of the error between the real and simulated images is about 20 — 60%. It depends on the degree of heterogeneity of the image. It is less than the corresponding variances when using the known models.

Thus, the proposed technique for formation of the doubly stochastic images with varying parameters can be used to simulate real satellite imagery and is used as the basis for the developed software complex.

3 GUI software package

We chose the software complex MATLAB (Matrix Laboratory) as the main tool for implementing synthesized algorithms and models. This system is one of the most popular and carefully developed systems for the automation of mathematical calculations. It is based on an expanded representation and application of matrix operations. Matrix Laboratory provides the user with a powerful programming language that is oriented towards technical and mathematical calculations. It can surpass the capabilities of traditional programming languages that have been used for many years to implement numerical methods in terms of the simplicity of developing programs. Important advantages of the system are its openness and extensibility. So, the use of MATLAB seems to be an effective way of implementing algorithms for digital image processing in general and for the images generated by doubly stochastic models, particularly.

Furthermore, MATLAB includes the Image Processing Toolbox. It has powerful tools for processing and analyzing digital images. This application is a very convenient environment for developing and modeling various methods.

Belew, we consider the developed software packages.

The software package called Modeling was developed to simulate RF. The user is given the opportunity to simulate various ARs with a wide variation of parameters. Fig. 2 and 3 show the block diagram of the package and its workspace window, respectively.

The program module allows one to investigate the properties of doubly stochastic and AR RF models.

The software package called Formation implies that the image that will be generated on the basis of the doubly stochastic RF model is initially downloaded by the user to the working folder of the MATLAB system. The recommended file extension with the image is ".jpeg". The module generates an image with varying parameters based on the actual image. For comparison, the real image, its simulation by the model, as well as the variances field of the obtained image and the field of its correlation coefficients are given. Fig. 4 shows the workspace window of the Formation module.

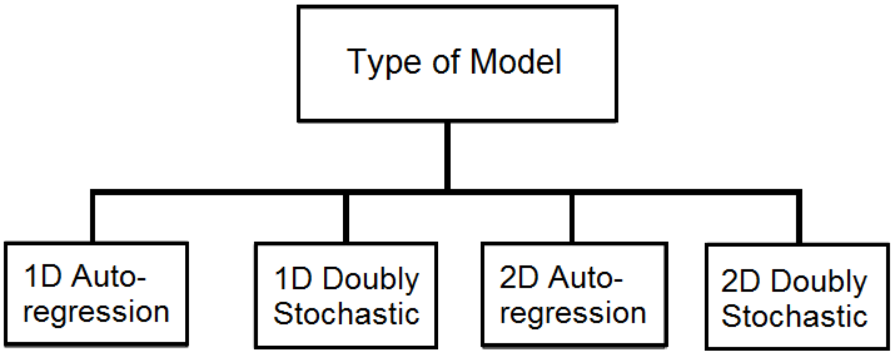

Fig. 2. Block diagram of the Modeling package

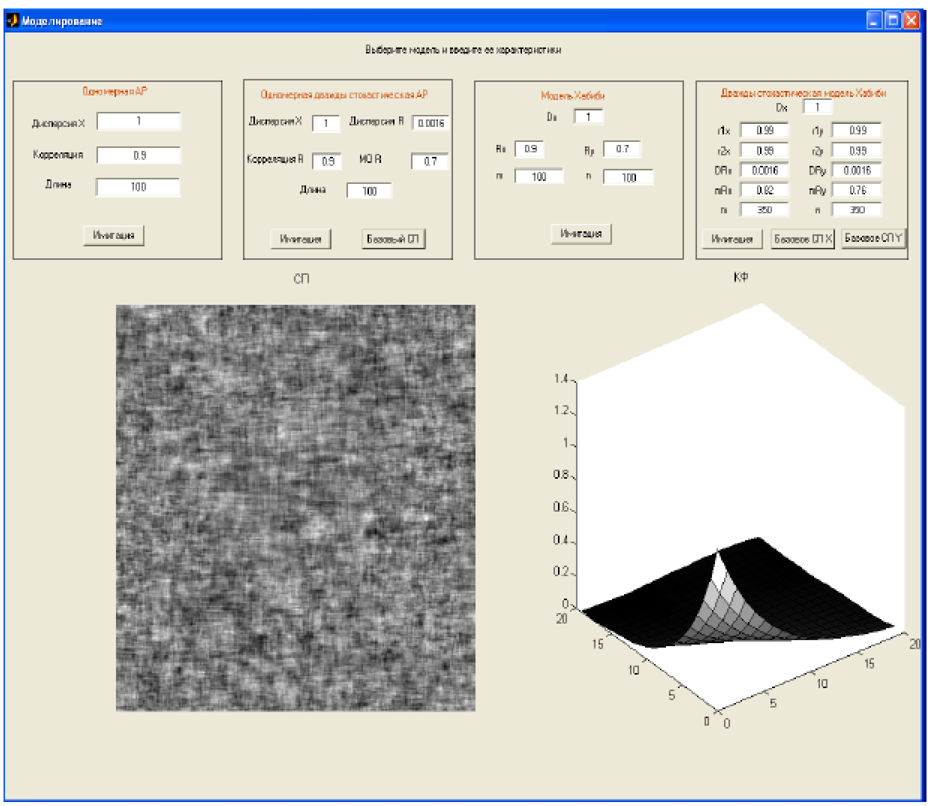

Fig. 3. Workspace window for the Modeling package

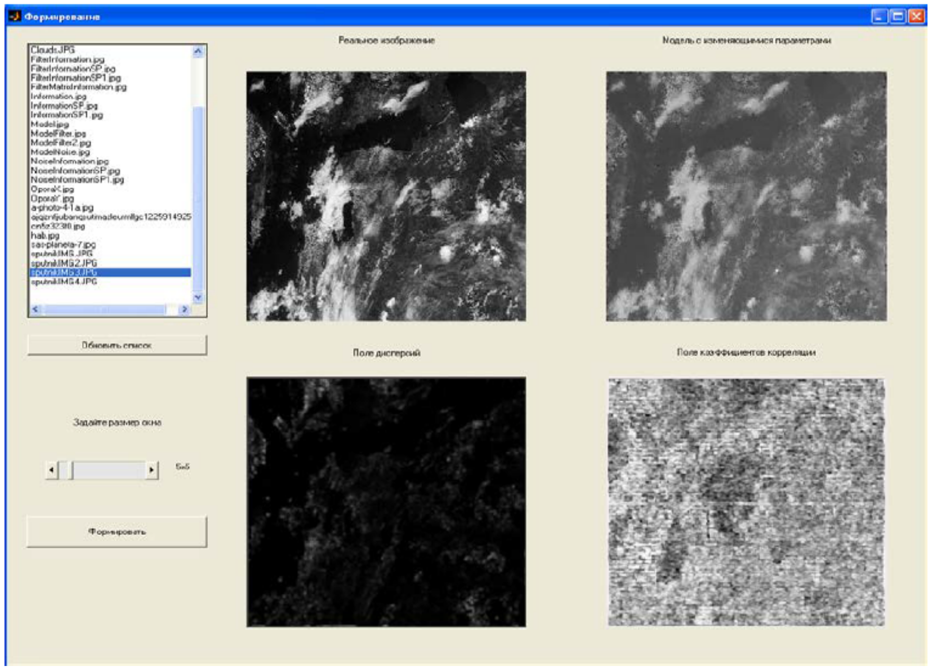

Fig. 4. Workspace window for the Formation package

This makes it possible to relatively easily adjust the model parameters for real images. In this case, one can increase the proximity of the simulated image to the real one due to the selection of the dimensions of the sliding window.

It should be noted that an important task is in identification of the model parameters. Indeed, the statistical characteristics of a doubly stochastic RF are related to its parameters; therefore, to generate signals or images having a given correlation function (CF), it is necessary to know the basic statistical parameters. In this regard, the Identification software package is developed to determine the parameters of a doubly stochastic signal model.

The user should enter the model parameters, on the basis of which identification will be performed. Thus, the comparison of the entered and identified parameters will allow one to determine the adequacy of the used identification algorithm and to evaluate its effectiveness. In addition, one can compare the type of the original RF and the RF with the identified parameters.

No less important task is the filtering of images, for which *a priori* knowledge of the model parameters is a rather important condition. Thus, if identification is effective, then in some cases it is possible to use the parameters obtained in its result to solve the filtering task. However, in the Filtering software package, it is assumed that the model parameters are known in advance and the main task is the noise suppression.

The Filtering software package was developed to filter doubly stochastic images and RFs. The user obtains the opportunity to simulate various doubly stochastic RFs with a wide variation of parameters. The module provides the use of Kalman (based on a nonlinear vector filter) and Wiener filters. Fig. 5 and 6 show the block diagram of the Filtering package and the workspace window of the program, respectively.

Thus, when working with the Filtering module, one should specify all the statistical parameters of the doubly stochastic model. After filtering, four images are displayed on the screen. They are the following:

— the original generated image;

— the image with white noise;

— the result of the processing by the Kalman filter;

— the result of processing by the Wiener filter.

Also, the filtering error variances are presented for each of the algorithms.

To implement the image segmentation algorithm, a technique is used to form a doubly stochastic model based on the binary base RFs. So, the formation of the main image at different pixels occurs with different statistical parameters, but according to one of the two specified AR RFs. In this case, the user has the opportunity to study the efficiency of the algorithm under different conditions.

The software implementation of the proposed algorithm is carried out using the Segmentation package. Fig. 7 shows the block diagram of the Segmentation module.

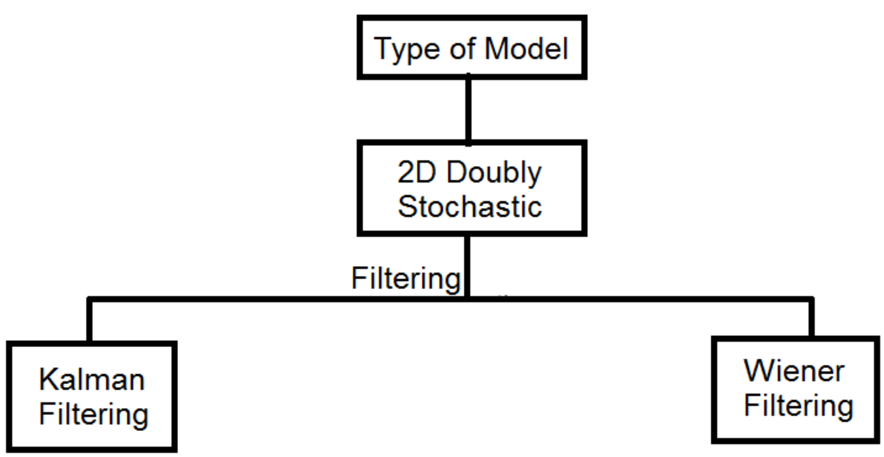

Fig. 5. Block diagram of the Filtering package

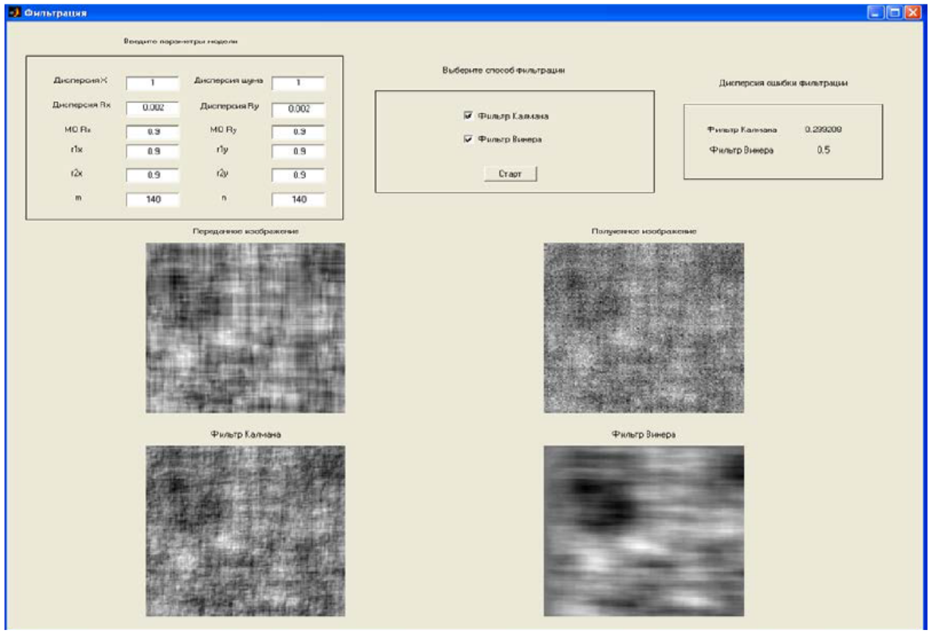

Fig. 6. Workspace window for the Filtering package

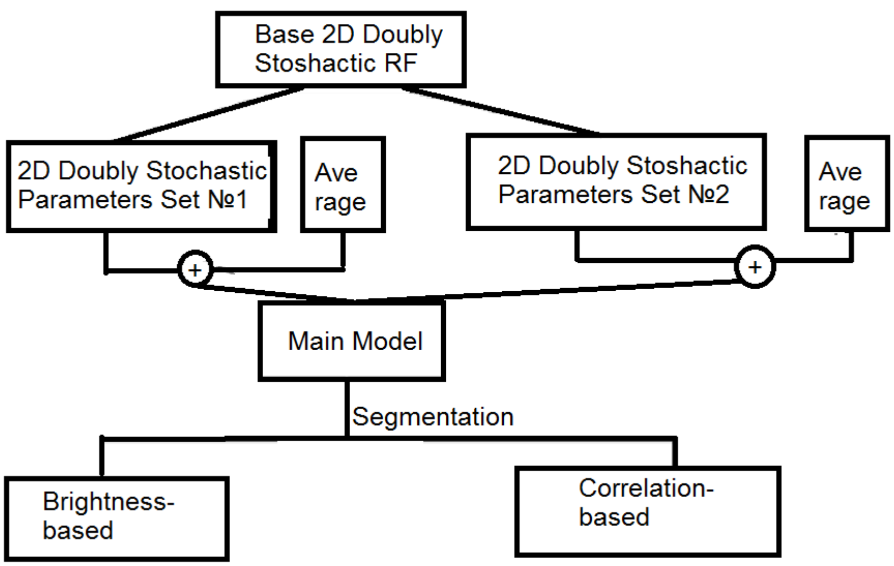

Fig. 7. Block diagram of the Segmentation package

Fig. 8 shows the workspace window of the Segmentation package.

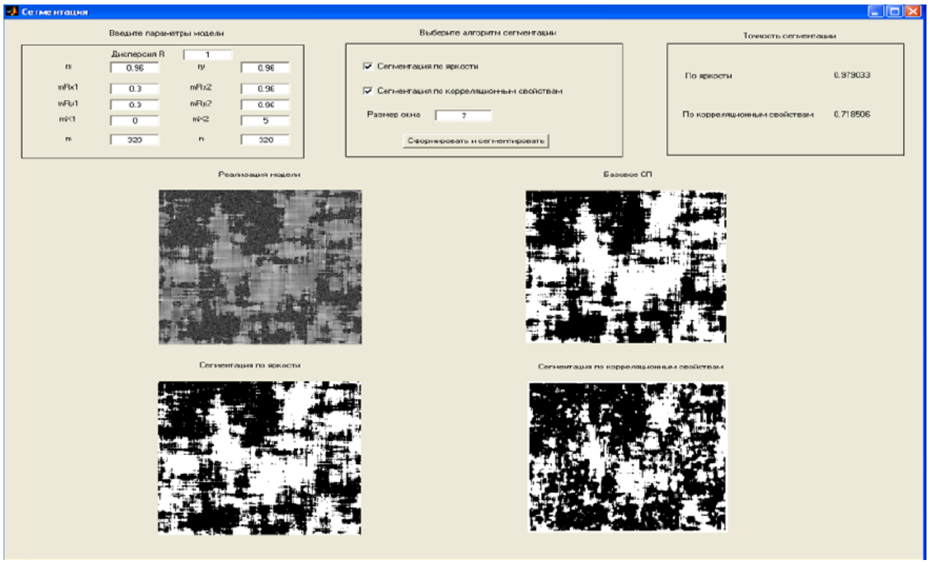

Fig. 8. Workspace window for the Segmentation package

4 Script-based software package for processing doubly stochastic images and real images

It should be noted that in the MATLAB environment, in addition to implementing programs with a user-friendly graphical interface, it is possible to develop programs oriented to mathematical modeling, numerical methods, and calculations. Despite the fact that MATLAB itself is required to run such applications, their main advantage is open source code, which can be updated and corrected at any time. The similar programs are the usual scripts executed by Matrix Laboratory, which can be used both for studying algorithms for processing doubly stochastic images within the framework of laboratory work at the university and for processing real material.

The base aim of developing such scripts is to have an introductory part. This section of the code allows one to set model parameters, select the uploaded image, and set the number of processing cycles. Thus, all scripts are tools for conducting statistical studies of algorithms for processing image realizations generated by doubly stochastic models. So, one can also process the real images.

The Filtration.m script is developed to investigate filtering algorithms based on a non-linear Kalman vector filter for doubly stochastic RFs, Wiener filter for doubly stochastic RFs, and Kalman and Wiener filters for AR RFs. Fig. 9 shows the algorithm of the script.

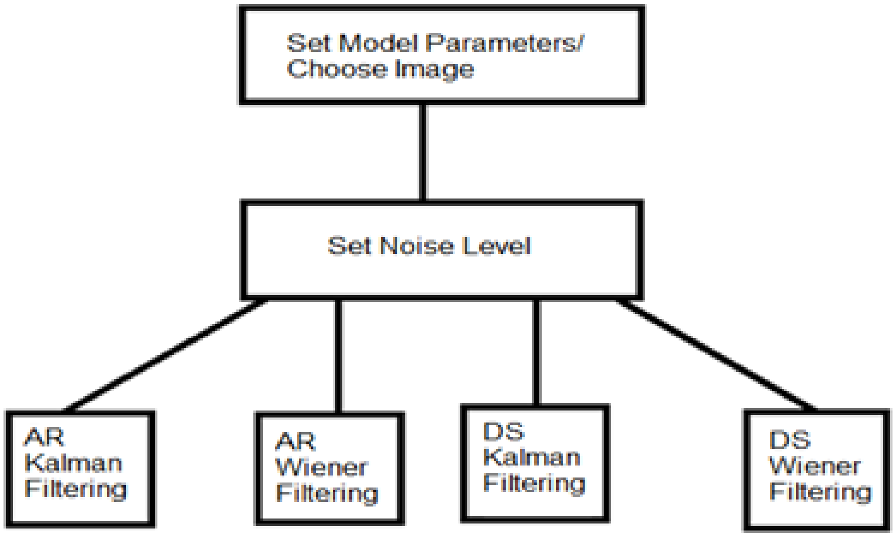

Fig. 9. Algorithm of the Filtration.m script

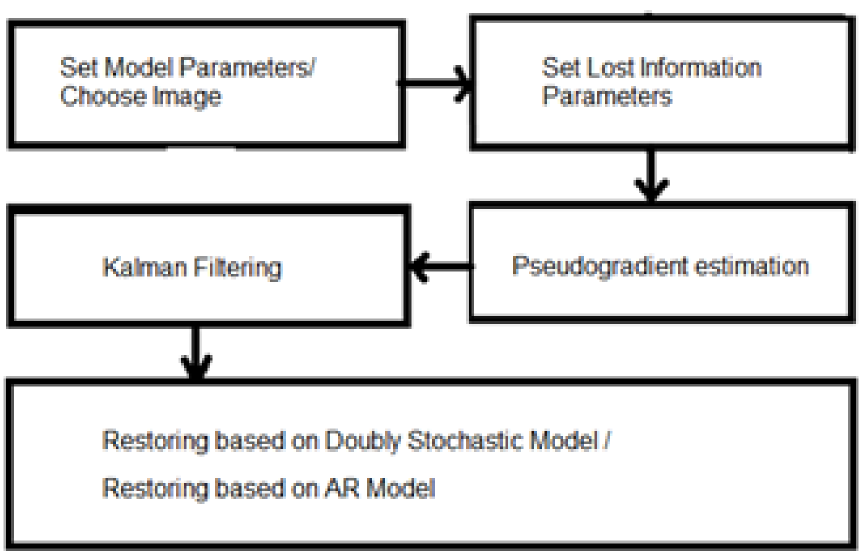

Fig. 10. Algorithm of the PGEstimationAndRestore.m script

The PGEstimationAndRestore.m script is intended for joint application of the Kalman filtering algorithms and pseudo-gradient estimation of the internal model parameters. The pseudo-gradient search estimates are used for filtering and for image restoring. The principle of its operation is similar to the principle of the filtering script. Fig. 10 shows the algorithm of the script.

Finally, to study the problem of detecting signals on the background of images generated by doubly stochastic models and real images, the RealImageDetection.m script was developed. This program allows one to generate long signals of square and round shape on the simulated or real images and to investigate the effectiveness of detecting such signals, for the given probability of false alarm. Fig. 11 shows the algorithm of the script operating.

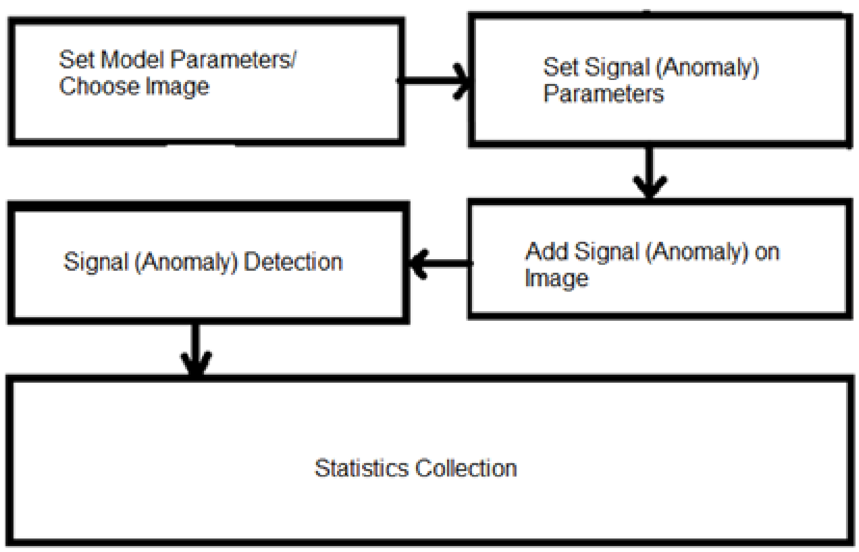

Fig. 11. Algorithm of the RealImageDetection.m script

Thus, the developed software package in the MATLAB environment includes not only the part with the graphical user interface, but, also, the script part, which is represented in the form of files with the extension ".m". All scripts can be changed at any time and reconfigured, as these files have open source code, and can be edited with the Notepad.exe. Together with the graphic part, a software was obtained, which can be used both for studying simulated images and signals and for processing real data.

5 Conclusion

We considered the software that can be conditionally divided into two blocks:

— GUI-applications in MATLAB, which can be used to study doubly stochastic RF models and do not require special skills and knowledge of programming languages from the user;

— script-applications in MATLAB implementing the complex image processing algorithms based on the doubly stochastic RF models and used not only to process simulated material, but also real images; these applications require users to have a basic knowledge of the Matrix Laboratory environment.

The developed software package for the study of image modeling algorithms allows simulating multidimensional RFs based on doubly stochastic models with different correlation parameters. Also, algorithms of filtering and segmentation of doubly stochastic RFs are included in the software package.

In addition, it is possible to generate images that are close to real based on a model with varying statistical parameters.

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