SIMULATION OF MOVING MICROOBJECTS ON DYNAMIC BACKGROUND AND ITS TRAJECTORIES VISUALIZATION

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Abstract: Presented investigation is dedicated to the technique, algorithms and software development for tracking of the moving micro-objects images on random dynamic background. The results allow estimating parameters of motion behavior and objects interactions for micro- and nano-technologies development.

1. Problem formulation

The development of special measuring systems and techniques of data processing is necessary for trajectory visualization of moving microobjects on the basis of use of microscopes with high resolution. Application of such technologies is especially effectively in the field of materials science and molecular biology that promotes working out of the newest materials and medical preparations. In these directions visualization and manipulation processes on molecular and cells levels will play defining role [1, 2].

The goal of this investigation consists of developing a method, algorithms and the software for automatic processing of dynamic images with moving microobjects with the purpose of their characteristics and movement interactions investigation. This work includes two parts:

- the development of image models composed of nonhomogeneous dynamic random background and moving microobjects;
- the development of a filtering, tracking and visualization methodology for trajectories of moving microobjects.

2. Image model

The technique of background fields simulation is based on their representation by multidimensional Markovian random sequences [3]. It allows to set their spatial covariance functions (during the fixed point of time) and time autocorrelation functions (in the fixed point of the image) in a wide range of possibilities.

The background model is supposed to be a dynamic random field discrete in time and space described by a set of stochastic finite-difference equations with the following vector-matrix notation:

$$\boldsymbol{x}_{k+1} = \boldsymbol{A}_k \boldsymbol{x}_k + \boldsymbol{u}_k + \boldsymbol{w}_k , \tag{1}$$

where $k = 0,1,2,\ldots$ — discrete time; $\boldsymbol{x}_k$ — time-dependent background fields vector; $\boldsymbol{A}_k$ — matrix that specify the spatial covariance and time autocorrelation characteristics of the field; $\boldsymbol{u}_k$ — regular composition determining expectation value of the field; $\boldsymbol{w}_k$ — white noise with zero expectation value and covariance matrix $\boldsymbol{Q}_k$.

Images of microobjects can have the complicated configuration changing in time. Such objects are simulated by means of casual clusters and their trajectories – by random Markovian processes with limited number of positions. The trajectories of objects are described by the following stochastic equations:

$$\begin{aligned} r_{ik+1} &= b_{ik} r_{ik} + t_{ik} T + \tfrac{1}{2}(l_{ik} + \xi_{ik}) T^2; \\ t_{ik+1} &= c_{ik} t_{ik} + (u_{ik} + \xi_{ik}); \\ 0 &< b_{ik}, c_{ik} < 1,\ i = 1,2. \end{aligned} \tag{2}$$

In these equations variable r_{ik} denotes the two dimension coordinates of the object, t_{ik} — the rate of change of the corresponding coordinate. The acceleration is supposed to be a discrete Gaussian noise ξ_{ik} with variance σ_{ik}^2 and expectation value l_{ik}. In vector form these equations is given by the expression

$$\boldsymbol{r}_{k+1} = \boldsymbol{B}_k \boldsymbol{r}_k + \boldsymbol{l}_k + \xi_k, \tag{3}$$

where the following notations for vectors are used:

$$\boldsymbol{r}_k = \left[r_{1k}, r_{2k}, t_{1k}, t_{2k} \right]^T;$$

$$\boldsymbol{l}_k = \left[\tfrac{1}{2}T^2 l_{1k}, \tfrac{1}{2}T^2 l_{2k}, l_{1k}, l_{2k} \right]^T;$$

$$\xi_k = \left[\tfrac{1}{2}T^2 \xi_{1k}, \tfrac{1}{2}T^2 \xi_{2k}, \xi_{1k}, \xi_{2k} \right]^T.$$

Matrix $\boldsymbol{B}_k$ has the form:

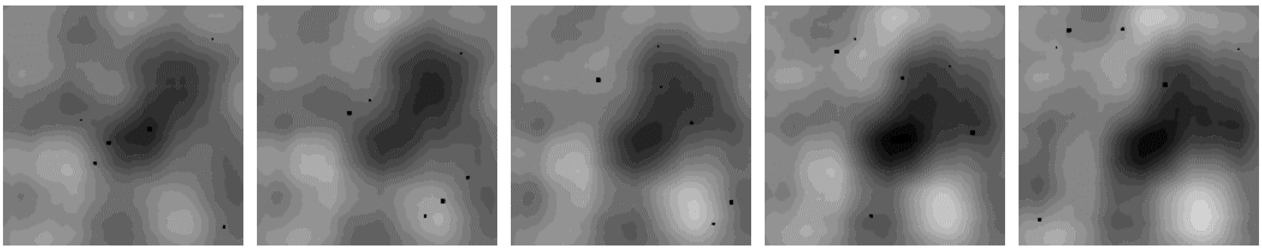
$$\boldsymbol{B}_k = \begin{bmatrix} b_{1k} & 0 & T & 0 \\ 0 & b_{2k} & 0 & T \\ 0 & 0 & c_{1k} & 0 \\ 0 & 0 & 0 & c_{2k} \end{bmatrix}.$$

The model for fluctuation of the intensity $i_{r_1 r_2 k}$ is also represented in the context of random Markovian processes and is given by

$$\begin{aligned} &i_{r_1 r_2 k+1} = \alpha_{r_1 r_2 k} i_{r_1 r_2 k} + j_{r_1 r_2 k} T + \tfrac{1}{2}(v_{r_1 r_2 k} + \eta_{r_1 r_2 k}) T^2; \\ &j_{r_1 r_2 k+1} = \beta_{r_1 r_2 k} j_{r_1 r_2 k} + (v_{r_1 r_2 k} + \eta_{r_1 r_2 k}); \\ &0 < \alpha_{r_1 r_2 k}, \beta_{r_1 r_2 k} < 1. \end{aligned} \tag{4}$$

In these equations $j_{r_1 r_2 k}$ is the rate of change of the intensity, while the acceleration $v_{r_1 r_2 k} + \eta_{r_1 r_2 k}$ is a discrete Gaussian noise with regular component . $v_{r_1 r_2 k}$.

As an example figure 1 shows a set of images realizations of moving microobjects on a dynamic background for different time points k.



$k = 20$ $k = 40$ $k = 60$ $k = 80$ $k = 100$

Fig. 1. The image of moving microobjects on a nonhomogeneous dynamic background

The general methodology of dynamic images processing is resulted in the authors monograph [3]. Developed approach is adapted for formulated problem conditions and corresponding processing algorithms and software are developed. The processing technology includes next stages: a preliminary intraframe filtration; a background compensation; a threshold filtration; a clasterization; objects current coordinates estimation and trajectories visualization.

3. Algorithm description

Algorithm is available for filtering, detection, selection, tracking and classification of moving microobjects against the complex background taking into account measurement noises. Algorithm structure and characteristics allows to adopt it for a different types of problems. The algorithm flowchart is presented in figure 2.

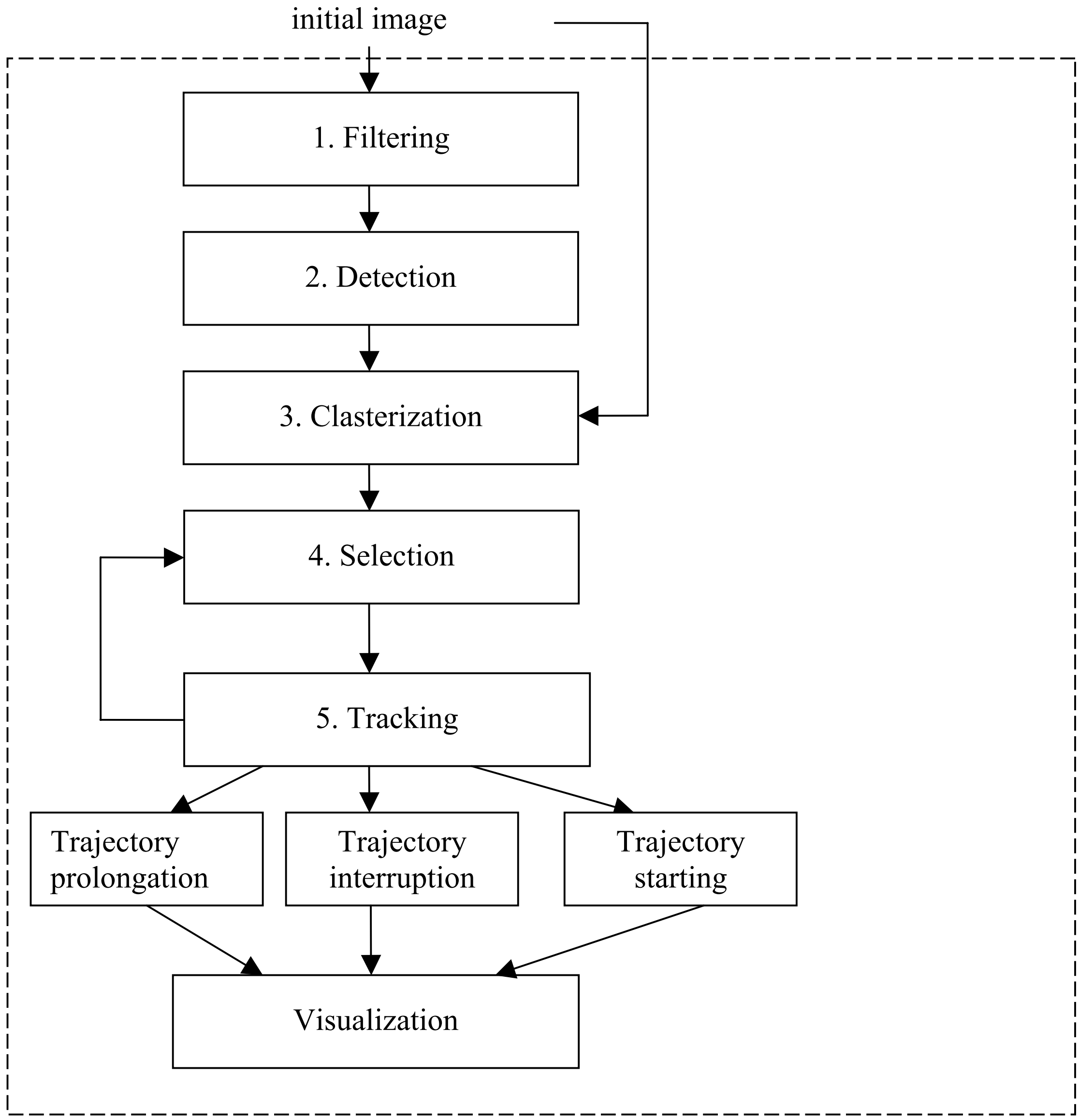
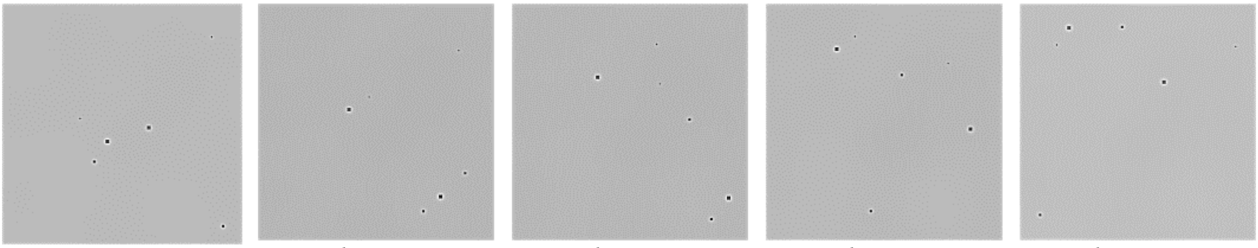


Fig. 2 Algorithm flowchart

On the first stage initial image is processed by four-channel spatial wavelet-filter. With the help of this procedure low- and high-frequency spectrum components of the image are suppressed. The filtering in each channel is processed by convolution of image with difference of Gaussians (DoG) wavelet [4]. This wavelet is generated by the difference of two 2D-Gaussian functions and its impulse response can be expressed as

$$H(x,y)=G(x,s_1)G(y,s_1)-G(x,s_2)G(y,s_2)\,, \tag{5}$$

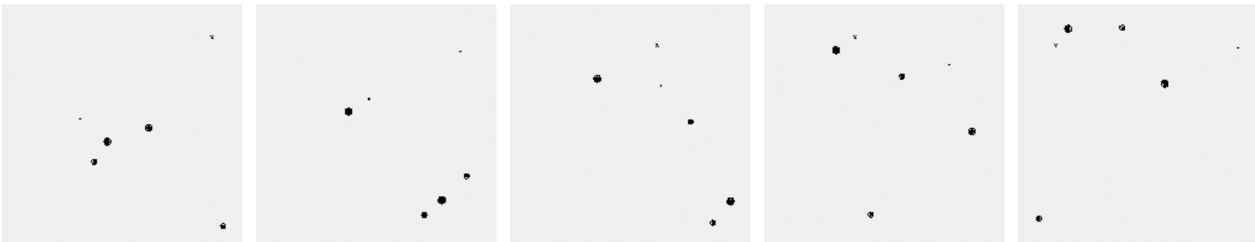
with $G(x,s)=\dfrac{1}{\sqrt{2\pi s^2}}\exp\left(\dfrac{x^2}{2s^2}\right)$.Thus, the convolution operation can be computed separately along rows and columns of an image. In figure 3 the result of spatial filtering of the initial images (see figure 1) is shown.



$k = 20$ $k = 40$ $k = 60$ $k = 80$ $k = 100$

Fig. 3. Example of spatial filtering of the images of moving microobjects on a dynamic background

On the second stage the resulting image is squared and thresholded. The threshold level is chosen adaptively for the each image pixel due to the given detection and false alarm probabilities. The filter output are the binary images shown in figure 4.



$k = 20$ $k = 40$ $k = 60$ $k = 80$ $k = 100$

Fig. 4. Binary images as a result of detection of moving microobjects

Clusterization procedure consists in grouping image pixels belonging to the particular object. The clusterization criterion includes the distance between pixels and the difference of pixels intensity. On the output we have a list of clusters.

Cluster selection is realized exploiting three signatures: lengthening, compactness and density. The lengthening is defined as a square root of ratio of principal second moments of the cluster:

$$\varepsilon_{lq} = \sqrt{\frac{m_{11q}}{m_{22q}}}\,. \tag{6}$$

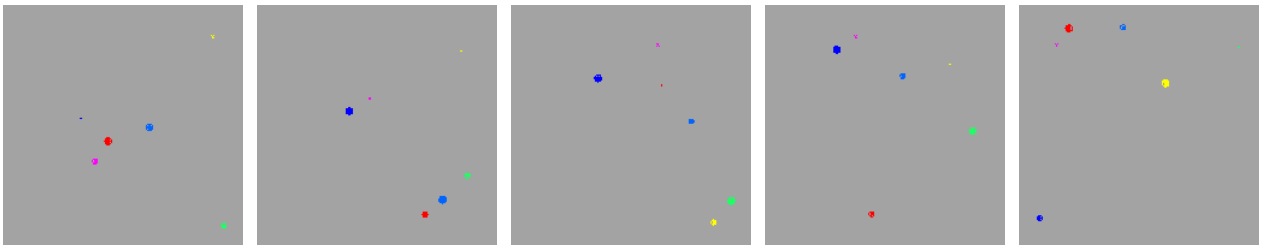
The compactness is specified by the ration of square of perimeter length to the area of closed boundary of the cluster:

$$\varepsilon_{cq} = \frac{\pi_q^{\,2}}{s_q}\,. \tag{7}$$

The density is defined by the ratio of number of cluster pixels to the area of closed boundary of the cluster:

$$\varepsilon_{d\,q} = \frac{n_q}{s_q}\,. \tag{8}$$

Selected clusters are accepted as objects images. Their parameters are delivered to the tracking and classification blocks. The outcome of clusterization and selection stages is shown in figure 5. Clusters on the picture are shown by different colors.



$k = 20$ $k = 40$ $k = 60$ $k = 80$ $k = 100$

Fig. 5. Images of the moving microobjects after clusterization and selection stages

At the last stage the trajectories of moving microobjects are obtained. Current frame clusters are matched with clusters on the previous frame. There exist three variants of matching: presence of similar clusters in both frames; the absence of similar cluster in the following frame; new cluster appearance. As a result the three trajectory types can be realized: trajectory prolongation; trajectory interruption; trajectory starting. The tracking algorithm fulfils smoothing, interpolation and extrapolation operations exploiting the Kalman filter or mean square technique. The example of trajectories of moving microobjects are presented in figure 6.

$k = 20$ $k = 40$ $k = 60$ $k = 80$ $k = 100$

Fig. 6. Trajectories of moving microobjects

4. Conclusions

The proposed algorithm was tested for processing of the microscope images of biological cells. The following figure 7 represents an example of the initial image with set of different cells and the resulting image with the estimated coordinates of the objects.

a) b)

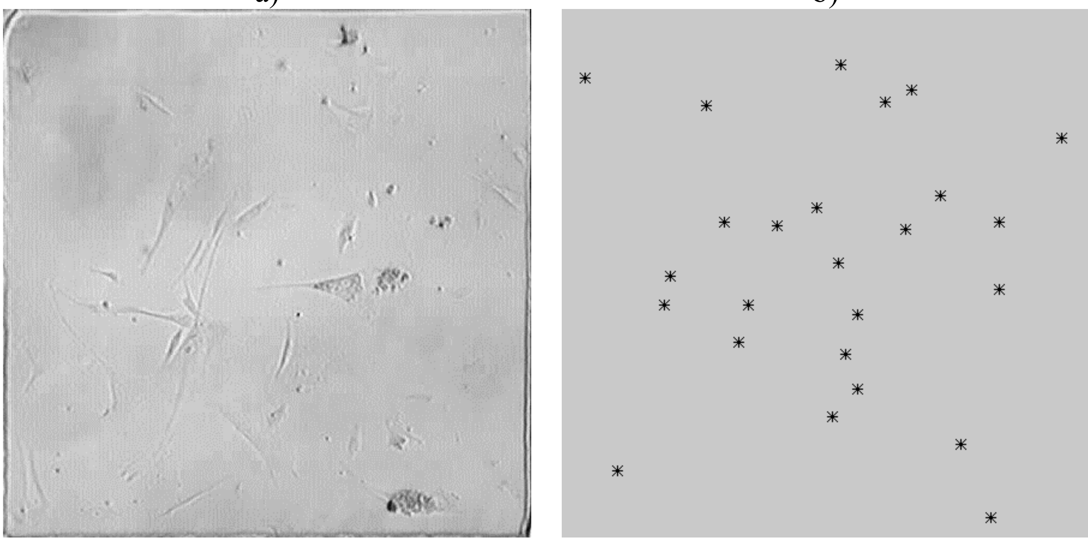


Fig. 7. The microscope image of biological cells (a) and result of estimation of their coordinates (b)

Obtained results can be used for estimation of motion behavior and objects interactions parameters. In the future authors suppose to use describe technique for investigation the self-assembly dynamic properties of biological cells.

References

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