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OPTICAL FLOW-BASED APPROACH FOR THE CONTOUR DETECTION IN RADIONUCLIDE IMAGES PROCESSING

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Abstract
Radionuclide diagnostics requires the use of mathematical methods of processing and analysis of data obtained during the investigation. One of the main steps of data processing is region of interest (ROI) contour detection. In this paper the algorithm based on the optical flow method is considered. Radionuclide images are mainly noisy and non-smooth, that is why presented method requires pre-processing data using filters. The paper presents an example of using the proposed method for contour detection of the left ventricle (LV) in radionuclide cardiac research.

Key words
Optical flow, radionuclide images, contour detection, image sequences.

1 Introduction

Radionuclide diagnostics is the functional diagnostics of human diseases based on the registration of radioactive emissions from radiopharmaceuticals absorbed by examined organ [Grebenshikov and Kotina, 2007]. This area is actively developed today that makes creation of new mathematical models and algorithms for data processing actual [Balykina, Kolpak and Kotina, 2014; Kotina, 2012; Kotina and Ploskikh, 2012; Kotina, Ploskikh and Babin, 2013; Ostroumov et al., 2010]. Gamma-camera and gamma-tomograph are used for radionuclide emission registration and image acquisition [Arlychev et al., 2009]. In this paper the problem of detecting region of interest (ROI) contour is considered. During the process of radionuclide studies the motion of studying organs takes place. We present approach based on the concept of the optical flow [Anandan, 1989; Barron and Fleet, 1994; Horn and Schunck, 1981; Ovsyannikov and Kotina, 2012; Papenberg, 2006] in terms of processing radionuclide images. Here the optical flow is meant as two-dimensional velocity field describing displacement of image points, which occurs while represented objects moving relative to the detector of gamma-camera [Kotina and Pasechnaya, 2013].

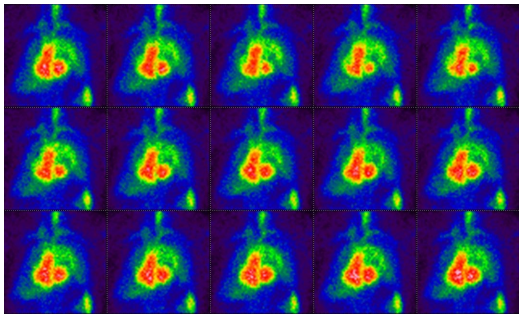


Figure 1. The distribution of radiopharmaceutical in cardiology research.

2 Problem Statement

We consider image sequences obtained in dynamic data acquisition mode. This mode allow to observe the distribution of indicator (radiopharmaceutical) in studying organism system depending on time and spatial coordinates (Figure 1). As a result we obtain radiopharmaceutical density distribution $\rho = \rho(t, x, y)$, $t \in [0, T]$, $(x, y) \in D$, or using discretization we have the sequence of matrices $\rho_1(i, j)$, $\rho_2(i, j)$, $\ldots$, $\rho_T(i, j)$, $i, j = 0, \ldots, n + 1$.

Let us suppose that we acquire sequence of radionuclide images, where the motion of examined organ occurs. The problem is to detect region of interest (ROI) contour on every image, i.e. in different moments of time.

3 Optical Flow Based Approach

So we consider the obtained image sequence of moving organ. Determining velocity field of ROI motion we construct its contour. With the aim of doing it in

this section optical flow based approach is presented. Proposing procedure involves solving special sparse linear system by iterative method. The convergence of this method is investigated.

3.1 Velocity Field Determining

To determine velocity field of region of interest (ROI) contours we propose optical flow based approach.

Let us consider system of differential equations

$$\begin{aligned} \dot{x} &= u(t,x,y), \\ \dot{y} &= v(t,x,y). \end{aligned} \tag{1}$$

Here x and y – spatial coordinates, t – time, functions u and v define velocity field.

We assume that the density distribution of radiopharmaceuticals along the trajectories of the system (1) remains constant

$$\rho_t + \rho_x u + \rho_y v = 0. \tag{2}$$

here ρ_t, ρ_x, ρ_y – partial derivatives of radiopharmaceutical density distribution with respect to x, y and t, $(u,v)^T = f$ – velocity field of the system (1).

Taking into account the above model (1), we consider the inverse problem of determining the velocity field, which in general is ill-posed. It can be solved using regularization method. According to it we fix some moment of time t and compose integral functional

$$J(u,v) = \int\limits_M (\varphi^2 + \alpha^2 \psi^2) dxdy. \tag{3}$$

where $\varphi^2 = (\rho_t + \rho_x u + \rho_y v)^2$, $\psi^2 = u_x^2 + u_y^2 + v_x^2 + v_y^2$, α^2 – regularization parameter, M – region of non-zero measure from R^2.

Then we minimize functional (3), using following system of Euler-Lagrange equations:

$$\begin{aligned} -\alpha^2 \Delta u + \rho_x^2 u + \rho_x \rho_y v &= -\rho_t \rho_x, \\ -\alpha^2 \Delta v + \rho_y^2 v + \rho_x \rho_y u &= -\rho_t \rho_y. \end{aligned} \tag{4}$$

Here Δ – Laplace operator, $\Delta u = \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}$ and $\Delta v = \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}$.

This approach reduces the problem of determining velocity field of system (1) to solving the system of differential equations in partial derivatives of second order with the appropriate boundary conditions.

Discrete nature of measurements allows us to consider radiopharmaceutical density distribution at the intersection ith row, jth column and in the kth moment of time as $\rho_k(i,j)$, $i,j = 1,\dots,n$ as it was said below. Therefore the solution of system (4) can be considered at the nodes of a square grid with a step equal to the one pixel change in the distance along any axis. In the grid point (i,j) the approximation to the solution of system (4) can be written as $u(i,j), v(i,j)$.

Laplacians in (4) then will be changed with finite differences and partial derivatives will be calculated using the density values in the neighboring grid points. So we obtain linear system of difference equations

$$\begin{cases} -\alpha^2(u(i-1,j) + u(i+1,j) + u(i,j-1) + \\ \quad +u(i,j+1)) + +(4\alpha^2 + \rho_x^2(i,j))u(i,j) + \\ \quad +\rho_x(i,j)\rho_y(i,j)v(i,j) = -\rho_x(i,j)\rho_t(i,j), \\ -\alpha^2(v(i-1,j) + v(i+1,j) + v(i,j-1) + \\ \quad +v(i,j+1)) + +(4\alpha^2 + \rho_y^2(i,j))v(i,j) + \\ \quad +\rho_x(i,j)\rho_y(i,j)u(i,j) = -\rho_y(i,j)\rho_t(i,j). \\ \qquad\qquad\qquad\qquad i,j = 1,\dots,n. \end{cases} \tag{5}$$

Functions u and v are defined on the boundary of the region, therefore in this system only $2n^2$ variables $u(i,j)$, $v(i,j)$, $i,j = 1,\dots,n$, at interior points of the grid are unknown.

System (5) can be expressed as a system with large sparse matrix

$$\begin{pmatrix} A & B \\ B & C \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} d \\ e \end{pmatrix}, \tag{6}$$

where $u = (u_1,\dots,u_{n^2})^T = (u_{11},\dots,u_{1n},u_{21},\dots, u_{2n},\dots,u_{n1},\dots,u_{nn})^T$, $v = (v_1,\dots,v_{n^2})^T = = (v_{11},\dots,v_{1n},v_{21},\dots,v_{2n},\dots,v_{n1},\dots,v_{nn})^T$; $d = (d_1,\dots,d_{n^2})^T = (d_{11},\dots,d_{1n},d_{21},\dots, d_{2n},\dots,d_{n1},\dots,d_{nn})^T$, $e = (e_1,\dots,e_{n^2})^T = (e_{11}, \dots,e_{1n},e_{21},\dots,e_{2n},\dots,e_{n1},\dots,e_{nn})^T$.

Matrices A, C – sparse and differ only with diagonal elements, i.e. $a_{sr} = c_{sr}$ and nonzero of them $a_{sr} = c_{sr} = -\alpha^2$. Diagonal elements of matrix A: $a_{ss} = 4\alpha^2 + \rho_x^2(i,j)$, matrix C: $c_{ss} = 4\alpha^2 + \rho_y^2(i,j), i,j = \overline{1,n}, s = \overline{1,n^2}$. Matrix B – diagonal, i.e. $b_{sr} = 0$, $s,r = \overline{1,n^2}$, $b_{ss} = \rho_x(i,j)\rho_y(i,j)$. Moreover for system (6): $d_{i,j} = -\rho_x(i,j)\rho_t(i,j)$, $e_{i,j} = -\rho_y(i,j)\rho_t(i,j), i,j = \overline{1,n}$.

Renaming variables, we reduce the system (6) to a form suitable for further processing

$$Hz = q, \tag{7}$$

Matrix H is block, with second order blocks. Let us rewrite it as it follows

$$H = D - E - F, \tag{8}$$

matrix D – diagonal, E and F – lower triangular and

upper triangular matrices, respectively.

$$D = \begin{pmatrix} H_{11} & 0 & \cdots & 0 \\ 0 & H_{22} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & H_{n^2n^2} \end{pmatrix},$$

$$E + F = - \begin{pmatrix} 0 & H_{12} & \cdots & H_{1n^2} \\ H_{21} & 0 & \cdots & H_{2n^2} \\ \vdots & \vdots & \ddots & \vdots \\ H_{n^21} & \cdots & H_{n^2,n^2-1} & 0 \end{pmatrix}.$$

System (7) with matrix in the form (8) is suitable for using Gauss-Seidel block iterative method:

$$H_{ss} z_s^{k+1} = -\sum_{r<s}^{n^2} H_{sr} z_r^{k+1} - \sum_{r>s}^{n^2} H_{sr} z_r^k + q_s, \quad (9)$$

$$s = 1, \ldots, n^2, \quad k = 0, 1, 2, \ldots,$$

3.2 The Convergence of Block Iterative Method

The convergence of Gauss-Seidel block iterative method (9) in the case when matrix B is diagonal and matrices A, C are sparse and differs only with diagonal elements can be shown, using the conditions obtained in [Kotina, 2012]:

$$1) a_{ss} c_{ss} - b_{ss}^2 > 0, a_{ss} > 0, c_{ss} > 0, \quad s = \overline{1, n^2},$$

$$2) \frac{a_{ss} + c_{ss}}{2} \geq \sum_{r=1, r\neq s}^{n^2} \|a_{sr}\| + \sqrt{\left(\frac{a_{ss} - c_{ss}}{2}\right)^2 + b_{ss}^2}, s = \overline{1, n^2} \quad (10)$$

and for some s $\frac{a_{ss} + c_{ss}}{2} > \sum_{r=1, r\neq s}^{n^2} \|a_{sr}\| + \sqrt{\left(\frac{a_{ss} - c_{ss}}{2}\right)^2 + b_{ss}^2},$

3) *"block" irreducible condition.*

It is easy to check conditions (10) are performed for matrix H from (7) and then block iterative method of Gauss-Seidel (9) converges for any initial approximation to the unique solution of system.

4 Contour Detection Algorithm

Based on the above, we propose contour detection algorithm (Figure 2).

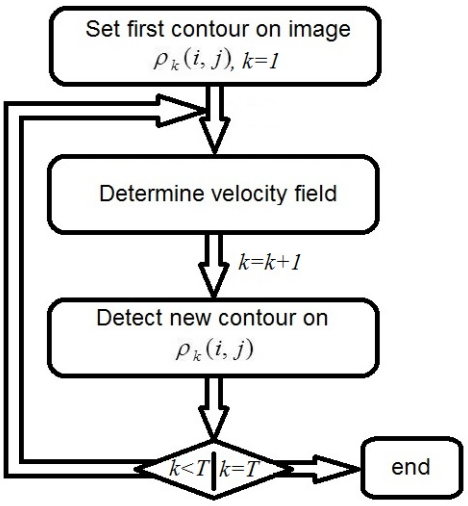
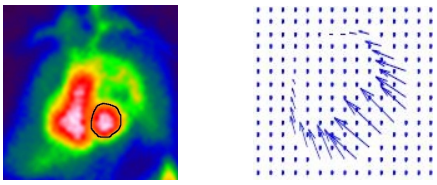


Figure 2. Block-scheme of contour detection algorithm.



a) b)

Figure 3. a) First image with contoured region of interest (ROI). b) Velocity field of contour points.

Step 1. To improve image quality before processing filters should be applied. Suppression of image noisiness can be realized applying smoothness operation. In this paper low-frequency spatial filtering with 3x3 mask is used.

Step 2. Set manually or automatically the region of interest (ROI) contour on the first image (Figure 3a)) [Gonzalez and Woods, 2005; Kotina, 2013].

Step 3. Determine the velocity field of contour points using optical flow based approach (Figure 3b)).

Step 4. According to obtained velocity field receive points of new contour – region of interest (ROI) contour on the second image.

Step 5. Using second contour and proposed algorithm, detect contour on the next image. Do it for all sequence images.

5 Example of Using the Proposed Algorithm

The proposed algorithm can be used for region of interest (ROI) contour detection for medical imaging. Here we present as an example planar radionuclide study of the heart – equilibrium electrocardiography-gated cardiac blood pool scanning (GBP) performed by gamma-camera [Canclini et al., 2001]. GBP can be used to evaluate left ventricular function. It requires contouring of the left ventricle (LV) on all images ob-

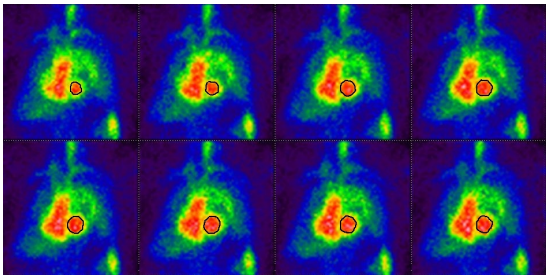


Figure 4. Images of cardiology research with countered heart left ventricle (LV).

tained at different time intervals of the representative cardiac cycle [Kotina, 2013]. It is generally considered 16 – 32 such images. This method proved to be sensitive to changes in the contours on radionuclide images. Assuming that on the first image left ventricle (LV) is contoured manually or with known method, we detect contours on other images applying the presented method. The obtained result is shown in the Figure 4.

6 Conclusion

Optical flow-based approach can be applied for contour detection on different radionuclide images. It can be also used for motion correction [Kotina and Maximov, 2011; Ovsyannikov, Kotina, and Shirokolobov, 2014] for radionuclide studies as well as for planning radiation therapy [Elizarova, Ovsyannikov and Cheremisin, 2007].

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