MATHEMATICAL METHODS OF MOTION CORRECTION IN RADIONUCLIDE STUDIES

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Detection and correction of patient motion during the acquisition of diagnostic data is an important step in the processing of radionuclide studies, since even a small shift of the patient's body at this moment can affect to the accuracy of diagnostics results. Motion correction in single photon emission computed tomography (SPECT) and dynamic scintigraphy are considered. Mathematical methods of motion correction based on the use of cross-correlation function are implemented.

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INTRODUCTION

Motion correction problems exist for diagnostic studies [5], as well as for planning radiation therapy [4]. Radionuclide diagnostics is one of the modern radiology methods for the estimation of the functional status of the various organs and body systems. This method is based on the injection of the indicator quantities of radioisotopes in the target organs and body systems. The method of the radioisotopes visualization includes a number of methods for obtaining images showing distribution of the labeled radionuclides substances in the body. These substances are called radiopharmaceuticals and they are designed for monitoring and evaluation of the physiological functions of organs [9, 11].

Detection and correction of the patient motion are one of the most important steps of the processing of radionuclide studies. Even small displacement of the patient or of the target organ during the process of data collection may affect accuracy of diagnostic results [2, 5, 13, 15, 17]. It is impossible to avoid the position changing of the patient or its target organs during data acquisition.

1. MOTION CORRECTION IN SPECT

1.1. PROBLEM STATEMENT

The camera turns around patient, during the data collection of the single photon emission computed tomography (SPECT) [1, 6]. This fact must be taken into account for motion correction.

Let's introduce two coordinate systems (Fig. 1). The moving system of coordinates (x, y), associated with the detector, which rotates in a circular orbit around the center of fixed coordinate system (x', y', z'). This system is associated with the gamma camera gantry.

Let's the point P' has coordinates (x', y', z'), in the fixed coordinate system, i.e. $P' = P'(x', y', z')$. The point P is its projection into the plane (x, y). The coordinates of the point P are (x, y), i.e. $P = P(x, y)$. The relationship between the points P and P' will be defined as follows:

$$\begin{cases} x = A\sin(\theta - \omega) \\ y = z' \end{cases},$$

where $\omega = arctg(y'/x')$; θ – viewing angle; $A = \sqrt{x'^2 + y'^2}$.

Let's consider relative motion of a point in the projection coordinates between two consecutive frames

$$\begin{cases} \Delta x = A\cos(\theta - \omega)\Delta\theta, \\ \Delta y = 0. \end{cases} \quad (1)$$

We can see, that in the case of absence of motion the trajectory of the point projection (x', y', z') must be sinusoidal relative to the axis x and the line relative to the axis y.

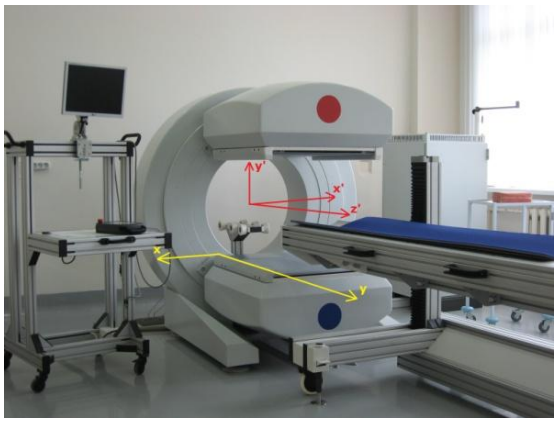

Fig. 1. The coordinate systems. The yellow color defines the moving system and the fixed system is defined by the red color

The transverse motion is the position displacement of the examined organ parallel to the plane (x', y'), and a longitudinal one – parallel to the axis (z').

The method of the cross-correlation function is used for the determination and subsequent motion correction.

1.2. THE MOTION CORRECTION BASED ON THE METHOD OF THE CROSS-CORRELATION FUNCTION

This method is based on the analysis of cross-correlation function defined for successive planar images. Discrete cross-correlation function $F(s)$ between the two one-dimensional data sequences A and B may be written as

$$F(s) = \sum_{p=1}^{m} A(p)B(p+s),$$

where m – dimension of sequences, $s \in Z$ – displacement of one sequence relative to the other, $-K \le s \le K, K \in N$ – maximum displacement, $B(p+s) = 0$, if $p+s<1$ or $p+s>m$.

Let's the initial data of tomographic studies are N projection images of size $n \times n$ pixels. Thus, we have a set of matrices $P_k(i, j), k = \overline{1, N}, i, j = \overline{1, n}$, the elements of which are the values of density distribution of the radiopharmaceutical at the points (x_i, y_i).

We use total profiles of data set for the analysis of the projection images [3]. We obtain these profiles from the planar images for each of the angles of observation:

$$C_{jk} = \sum_{i=1}^{n} P_k(i, j), j = \overline{1, n}, k = \overline{1, N},$$

$$D_{ik} = \sum_{j=1}^{n} P_k(i, j), i = \overline{1, n}, k = \overline{1, N},$$

where C_{jk} and D_{ik} – total profiles along the x and y axes respectively.

We consider the correlation between the two planar images. Thus, the cross-correlation functions for two successive planar images with indices k and $k+1$ have the forms

$$fx_k = \sum_{j=1}^{n} C_{jk} C_{j+s,k+1}, -K \le s \le K, K \in N, \quad (2)$$

$$fy_k = \sum_{i=1}^{n} D_{ik} D_{i+s,k+1}, -K \le s \le K, K \in N, \quad (3)$$

where $C_{j+s,k+1} = 0$, if $j+s<1$ or $j+s>n$, and $D_{i+s,k+1} = 0$, if $i+s<1$ or $i+s>n$.

Formulas (2) and (3) represent a view of the cross-correlations function relative to the x and y profiles respectively.

1.3. SOFTWARE IMPLEMENTATION

The sinogram and linogram [10] are built for the visual detection of displacement along the x and y axes respectively.

It is necessary to determine the area of interest, before we start detecting the motion, with the purpose to increase the ratio signal-to-noise [16].

The final value of the frame displacement is determined by the parabolic approximation of the cross-correlation at the point where it reaches its maximum value and the two neighboring.

As mentioned above, a major problem of the transverse motion determining is that the motion is supposed to exist in advance. The reason of this motion is the rotation of the camera around the patient. For the solving this problem, we define the difference function along the x-axis, and then this function is approximated by the method of least squares polynomial of order 4, and the difference of these functions is taken.

Software module of motion correction is implemented on C# (Fig. 2).

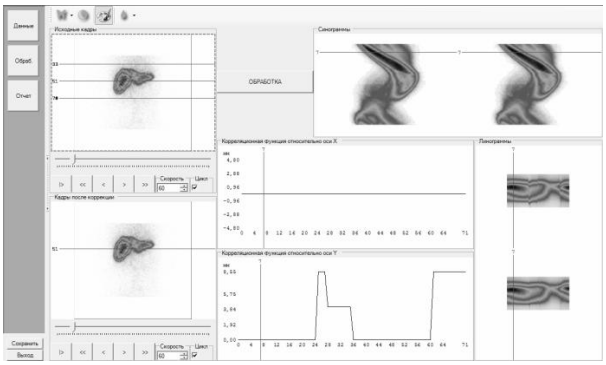

Fig. 2. The main window of the program module

The window of the module has an initial group of frames and frames after the correction presented in animation mode, sinogram (Fig. 3), linogram (Fig. 4), function of the difference value of frame relative to the x and y axes.

Area of interest corresponds to the area between the upper and lower sliders. The central slider determines the level for which the sinogram is built.

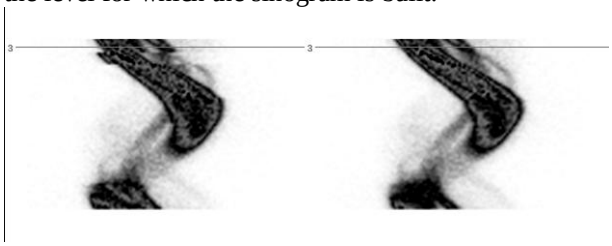

Fig. 3. Sinogram before (left) and after (right) correction

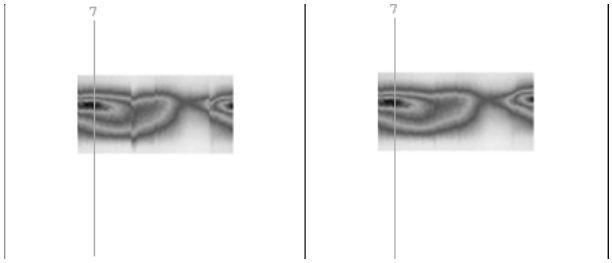

Fig. 4. Linogram before (left) and after (right) correction

We take the first frame, made by the detector, as the standard frame. Standard frame is a frame with respect to which the motion is considered. We consider the motion for each of the two groups of frames for two detectors separately.

Fig. 5. The dependence of displacement value along the y axis on the frame number

In Fig. 5, we show an example of dependence of displacement value along the y axis on the frame number.

All the figures presented here relate to the same study. For example, the linogram before the correction and function graph, shown in Fig. 5, and linogram after correction demonstrate detection and subsequent motion compensation.

2. MOTION CORRECTION IN PLANAR DYNAMIC SCANNING

2.1. PROBLEM STATEMENT

During the data collecting in the mode of planar dynamic scanning detector is stationary. A sequence of planar images with a fixed exposure is formed for each detector. We can observe the dynamic distribution of the radiopharmaceutical in the system of the body.

The obtained data is a set of planar images, which are projections of three-dimensional density distribution of the radiopharmaceuticals on the detector plane. This mode is used in the diagnostics of diseases of the kidneys, liver, gall bladder, brain, etc.

Let's the initial data of the radionuclide studies are projection images of size $n \times n$ pixels. Suppose that, there is a contour G on some frame, this contour restricts certain region of interest (ROI). The frame with this contour is called a standard. We detect the motion of the ROI on the other frames, relative to the standard frame.

Let's display the contour in the reference frame, in all other frames and state the problem of motion correction as the task of determination of the displacement vector contour bounding the region of interest.

Thus, it is required to find the displacement vector $s_k(x_k, y_k), k = \overline{1, N}$ for the each contour. Here x_k, y_k are shifts of the contour on the k frame along the x and y axes, respectively.

2.2. SOFTWARE IMPLEMENTATION

The problem is solved in two stages. At the first stage, as in the previous section, the method of cross-correlation function is used. As a second stage of the correction contour position we use a method based on finding the center of gravity of a plane figure, bounded by contour.

The point of origin is a point with coordinates $(0,0)$ in the above notation. Relative to the point of origin the radius vector is determined.

Before the start of the motion correction set the start time of visualization i.e. frames number in which the object is visualized. It is necessary because the radiopharmaceutical, which was administered to patient not immediately comes to the organ under investigation.

We obtain a great number of the images after data collection. So for clarity we draw the plots of depending function of the total counts within the selected region of interest from the frame number. The corresponding linogram are constructed for the visual detection of shifts along the x and y axes.

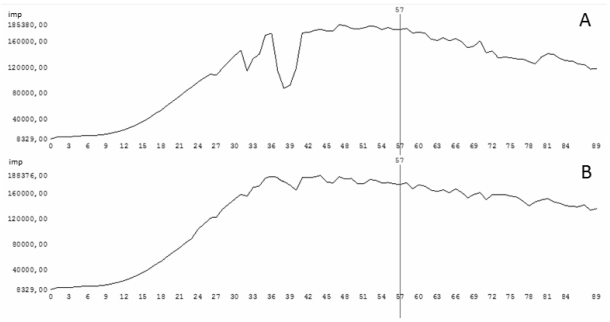

Fig. 6. The dependence of total counts of ROI from the frame number. A: Before motion correction. B: After motion correction

The example of dependence of total counts of ROI from the frame number before and after the motion correction are shown in Fig. 6.

The graph of Fig. 6,B displays the real distribution of the radiopharmaceutical per frame in the ROI after motion correction.

We can note also that the use of the approaches described in [7, 8, 12, 14] can be helpful for the motion correction as well. These approaches are based on the determination of the velocity field and can be used for the solving of motion correction problems for dynamic and tomographic studies.

CONCLUSIONS

In this paper the algorithms of motion correction based on the method of cross-correlation function are developed and implemented. The results showed that this methods can be used for the motion correction in radionuclide studies.

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МАТЕМАТИЧЕСКИЕ МЕТОДЫ КОРРЕКЦИИ ДВИЖЕНИЯ В РАДИОНУКЛИДНЫХ ИССЛЕДОВАНИЯХ

Д.А. Овсянников, Е.Д. Котина, А.Ю. Широколобов

Важным этапом при обработке радионуклидных исследований является обнаружение и коррекция движения пациента во время сбора диагностических данных, поскольку даже небольшое смещение пациента или исследуемого органа в этот момент может повлиять на достоверность результатов диагностики. Коррекция движения рассматривается для двух режимов сбора данных: однофотонной эмиссионной компьютерной томографии и динамической сцинтиграфии. Реализованы математические методы коррекции с использованием функции взаимной корреляции.

МАТЕМАТИЧНІ МЕТОДИ КОРЕКЦІЇ РУХУ В РАДІОНУКЛІДНИХ ДОСЛІДЖЕННЯХ

Д.О. Овсянников, О.Д. Котіна, А.Ю. Широколобов

Важливим етапом при обробці радіонуклідних досліджень є виявлення і корекція руху пацієнта під час збору діагностичних даних, оскільки навіть невелике зміщення пацієнта або досліджуваного органу в цей момент може вплинути на достовірність результатів діагностики. Корекція руху розглядається для двох режимів збору даних: однофотонної емісійної комп'ютерної томографії (ОФЕКТ) і динамічної сцинтиграфії. Реалізовано математичні методи корекції з використанням функції взаємної кореляції.