

Precision tomoghaphic system based on annular scintillation detector and Multi Pin-hole collimator

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Theoretical investigations have made it possible to derive an algorithm of 3-dimensional tomographic reconstruction for a cylindrical gamma-ray camera with a pin-hole type collimator. The optimum number of the pin-hole collimators has been found providing the image formation on the whole surface of the cylindrical detector. Formulas have been derived correlating the tomographic projections in the planar and cylindrical geometry. A precision tomographic system has been designed and constructed basing on an annular scintillation detector and a Multi Pin-hole collimator. The space resolution of the system amounts 1 mm.

Проведенные теоретические исследования позволили создать алгоритм трёхмерной томографической реконструкции для цилиндрической гамма-камеры с коллиматором типа Pin-hole. Найдено оптимальное количество pin-hole коллиматоров для формирования изображения на всей плоскости цилиндрического детектора. Выведены формулы, связывающие томографические проекции в плоской и цилиндрической геометрии. Спроектирована и изготовлена прецизионная томографическая система на базе кольцевого сцинтилляционного детектора и Multi Pin-hole коллиматора. Пространственное разрешение прецизионной системы составляет 1 мм.

The radionuclide diagnostics takes today stable fourth place among the medical visualization methods after X-ray, ultrasound, and magnetic resonance diagnostics [1]. Its unique feature consists in that it is the only method among the above-mentioned ones providing the data collection on the functional state of the organs and systems being under study. All other medical visualization methods provide an image of the organism's morphologic structure. The essence of the nuclear medicine consists in that a pharmaceutical preparation connected with a radionuclide label is administered to a patient. The radiolabeled pharmaceutical preparation (RPP) is accumulated in one organ or other, depending on its nature. The label bound chemically with the pharmaceutical preparation emits gamma quanta and thus is the indicator of the preparation distribution [2, 3]. The gamma camera is intended to register the gamma quanta emitted by the label, to recover the RPP distribution in the patient's body using those data and to provide a necessary instruments for processing of the medical images and making the diagnosis [4, 5].

A low resolution is the main drawback of the radionuclide method [6, 7]. It amounts 3 to 4 mm for commercial gamma cameras. Such resolution is sufficient when human organs of those of large animals are to be studied but is unsatisfactory when the study of small laboratory animals is in question that have the overall body size of several centimeters (e.g., mice). That task is actual in clinical investigations of novel pharmaceutical preparations. The pharmacologists should have as much information as possible on the state of the experimental

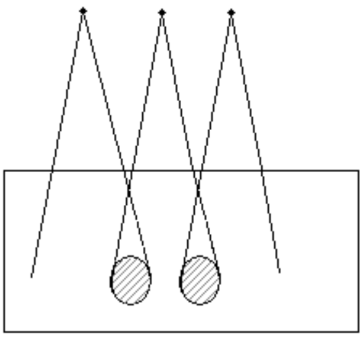

Fig. 1. Pin-hole collimators and flat detector.

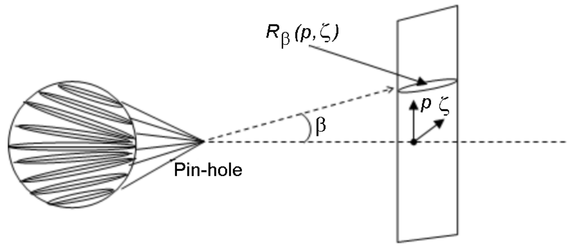

Fig. 2. Scanning scheme.

animals, including the function of their internal organs.

Thus, the development of a precision scintillation system to investigate the action of pharmaceutical preparations onto small experimental animals takes a significant actuality.

To solve the problem of low resolution, a pin-hole type collimator is used in the developed system. Such a collimator is similar to a camera Obscura in its operation principle. The collimator is a small diameter hole in a lead plate. The plate absorbs all the gamma rays hitting it. Thus, the image will be formed only by the rays passing the collimator hole. Such rays form spatial cones having the vertices at the hole and propagating towards the image [8].

However, the use of a pin-hole collimator results in a sharp drop of the system sensitivity as compared to a common type one, that is, of the gamma ray intensity that forms the image in the detector. In order to compensate that loss, several pin-hole collimators have been proposed to be used simultaneously. However, if a standard flat detector will be used in that case, we will confronted with the problem of crossing images from different holes at the detector surface (see Fig. 1) [9].

To solve that problem, a cylindrical detector was proposed for use. The cylindrical shape of the detector surface makes the algorithm of the image reconstruction more sophisticated but it provides the simultaneous use of several pin-holes without overlapping. Moreover, only the collimator but not the whole detector should be displaced in the cylindrical camera to obtain a new projection. Thus, no errors connected with the detector positioning will be made when using a common camera with a flat detector. However, it is to keep in mind that the projections obtained with a cylindrical detector will differ from those provided by a flat one. To take into account the specific geometry of the cylindrical detector, the set of cylindrical projections will be transformed in a set of planar ones.

Fig. 2 presents the geometric scheme for development of tomographic projections in our case.

The solution of the tomographic problem consists in derivation of a 3-dimensional distribution function of an RPP within the object under study. Using the mathematical analysis of the system, it is possible to obtain a formula for distribution $g(t,s,z)$ from the measured projections $R_\beta(p,\zeta)$.

$$g(t,s,z) = \frac{1}{2}\int_0^{2\pi} \frac{D_{so}^2}{(D_{so}-s)^2} \int_{-\infty}^{+\infty} R_\beta(p,\zeta)\cdot h\left([\frac{D_{so}\cdot t}{D_{so}-s}-p]\right) \times \frac{D_{so}}{\left(D_{so}^2+\zeta^2+p^2\right)^{\frac{1}{2}}} dp d\beta. \quad (1)$$

Here, $R_\beta(p, \zeta)$ is the projection of the object being studied onto a flat detector; $h(p) = \int_{-W}^{W} |\omega| e^{i\omega p} d\omega$, the reverse Fourier transformation from the Ramp filter; D_{so}, the distance from the coordinate center to the pin-hole.

It is to note that the formula (1) is similar in its structure to the classical formula of convolution and reverse projection. The main distinction is that Eq.(1) expresses the 3D function of the object in terms of 2d functions of projections while the classical formula associates the 1D projections with a 2D object. Moreover, the derived formula comprises complex geometric factors.

The Eq.(1) makes it possible to solve the tomoghraphic reconstruction problem basing on planer projections. A cylindrical detector is used in our system. Thus, the projections collected by the cylindrical detector should

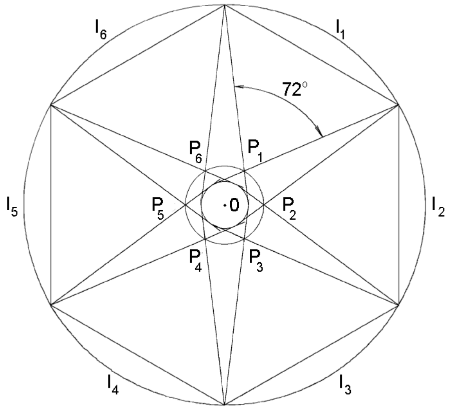

Fig. 3. Scheme of a multi-pin-hole collimator. P_1–P_6, pin-holes;, I_1–I_6, the corresponding images.

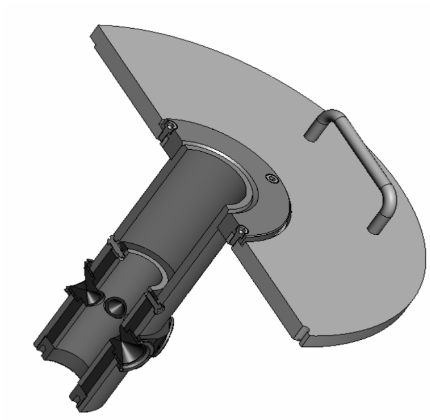

Fig. 4. 3D model of multi-pin-hole collimator.

Fig. 5. The main assembly of multi-pin-hole collimator.

Fig. 6. A 3D image of a variable pitch helix. The diameter of the tube bent into helix is 1 mm.

be transformed into those collected by imaginary flat one. The problem of projection transformation was considered by us in a preceding work [10]. The transformations result in the following expressions:

$$y' = \left(\frac{\sqrt{y^2 + R^2 \times \sin^2 \frac{x}{2 \times R}} \times r}{r - 2 \times R \times \sin^2 \frac{x}{2 \times R}} \right) \times \cos \left[\operatorname{arctg} \left(\frac{R \times \sin \frac{x}{R}}{y} \right) \right],$$

$$x' = \left(\frac{\sqrt{y^2 + R^2 \times \sin^2 \frac{x}{2 \times R}} \times r}{r - 2 \times R \times \sin^2 \frac{x}{2 \times R}} \right) \times \sin \left[\operatorname{arctg} \left(\frac{R \times \sin \frac{x}{R}}{y} \right) \right]. \quad (2)$$

Here R is the cylindrical detector radius; r distance from the pin-hole collimator to the detector center; (x, y), the flash coordinates in the cylindrical detector; (x', y'), those in the corresponding flat one.

As mentioned above, several pin-hole collimators are used in the system to improve the sensitivity as is shown in Fig. 3. In this case, a problem is to find the optimum number of pin-hole collimators forming simultaneously image in the detector with the proviso that the images formed by different collimators should not overlap. The solution of that problem resulted in the expression:

$$Count\_pin\text{–}hole = \frac{\pi}{\arccos \left(\frac{AB + \sqrt{A^2 - B^2 + 1}}{A^2 + 1} \right)} \quad (3)$$

Here A is the ratio of the object radius to the distance between the object center and the pin-hole collimator; B, is the ratio of the object radius to the distance between the object center and the detector. Since the number of collimators is an integer, the integer part of the value calculated using (3) should be taken.

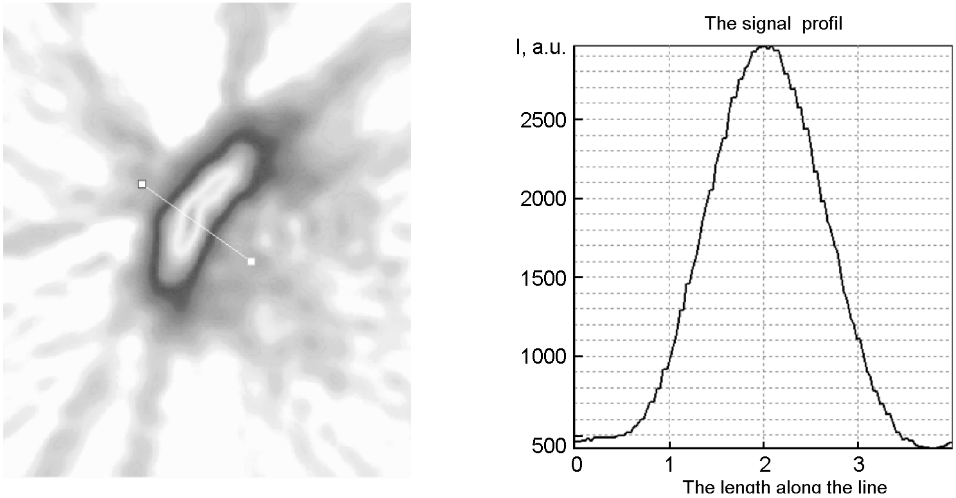

Fig. 7. Signal profile I V.S. length of transection line.

The obtained investigation results made it possible to design a multi-pin-hole collimator for a gamma camera with a cylindrical detector. In Fig. 4 presented is the device drawing and Fig. 5, photo of the main assembly.

The developed software provides visualization of the reconstructed 3D structures. Such an image is shown in Fig. 6. The signal profile can be also analyzed. In Fig. 7, presented are the helix transversal section and the profile along a line perpendicular to the tube.

To determine the resolution, let Fig. 7 be used. The signal width at half-height is 1/9 mm. The diameter of the tube of which the phantom is made is 1 mm. Thus, the broadening of the tube image with the phantom as compared to its real size is 0.9 mm. That is just the resolution of that device [11].

To conclude, a tomographic reconstruction algorithm has been developed for a cylindrical gamma camera with a multi-pin-hole collimator. A precision tomographic system basing on the multi-pin-hole collimator has been designed and constructed. The new system will contribute to studies of functional state both of moderate size animals in combination with the classic parallel collimator and of small animals in combination with a multi-pin-hole collimator. The space resolution of the precision system is less than 1 mm. Thus, the system developed provides all the necessary radionuclide investigations on laboratory animals in pharmacology.

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Прецизійна томографічна система на основі кільцевого сцинтиляційного детектора та multi-pin-hole коліматора

О.В.Дьомін, О.П.Скибін

Виконані теоретичні дослідження дозволили створити алгоритм тривимірної томографічної реконструкції для циліндричної гамма-камери з коліматором типу pin-hole. Визначено оптимальну кількість pin-hole коліматорів для формування зображення на всій поверхні циліндричного детектора. Виведено формули, які пов'язують томографічні проекції у площинній та циліндричній геометрії. Спроектовано та виготовлено прецизійну томографічну систему на основі кільцевого сцинтиляційного детектора та multi-pin-hole коліматора. Просторове розрішення прецизійної системи становить 1 мм.