JOINT INSTITUTE FOR NUCLEAR RESEARCH

FINAL REPORT ON THE INTEREST PROGRAMME

Application of semiconductor pixel detectors from the Timepix family in nuclear medicine tasks (SPECT, CT)

Supervisor:
Dr. Vladislav Rozhkov

Students:
Kokurina Elina
Kazan Federal University, Kazan, Russia
Mohamed Elsabagh
Zewail City of Science and Technology,
Giza, Egypt
Suren Kathirvel
Institute of Chemical Technology, Mumbai.
IndianOil -Bhubaneswar Campus
Stanislau Murashka
Belarusian State University, Minsk, Belarus.

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Abstract

In this project, we have studied the work of semiconductor pixel detectors from Timepix family and their application in tasks of nuclear medicine. These detectors such as SPECT (Single photon emission computed tomography) and computed tomography (CT) due to their high sensetivity to ionizing radiation are the great interest for diangnostis and treatment of radiatiom-related deseases [1]. The main goal of our internship was the data acquisition and processing, finished with the creation of a 3D tomographic reconstruction. The results were processed in ImageJ program, including Astra Toolbox. After the reconstruction, we got the whole image of the object.

Introduction

The **SPECT** is a nuclear medicine imaging modality that tomographic slices of internally distributed radiopharmaceuticals. SPECT is used to detect tumor and diagnosis of artery disease. The single photon emission computed tomography produces a 3-dimensional image of the distribution of a radioactive probe which is then injected into the blood stream. Then some certain tissues are subsequently taken. It's a nuclear imaging modality that involves the injection of a radioactive, which emits gamma rays [2]. These gamma rays are also detected by a gamma camera, allowing for the creation of detailed images. These gamma rays are then detected by a gamma camera, allowing for the creation of detailed images. The gamma ray cameras are rotated around the patient to get the information of the radionuclide within the tissue. By using these gamma cameras, we can increase the efficiency of the detector and spatial resolution.

Material and Methods

There are components are needed for 3D-SPECT imaging: a collimator, a radio-labeled tracer that is used for the target tissue, and a rotating multi-headed gamma camera [3]. The camera's main job is to detect photons released from the patient in all directions due to the tracer compound's gamma decay. These photons are filtered by the collimator so that only particles parallel to the detector pass through. Thus, the collimator concentrates the radiation, and the choice of collimator affects the resulting image's sensitivity and resolution. The data which we attained from the cameras are also reconstructed into 3-dimensional images in axial slices. By using the SPECT/CT the attenuation correction and advanced resolution anatomical localization can be achieved. The information emitted by the gamma rays and displays it on the CT cross-section are collected from the computers. Combining the cross-sections together forms a 3D image of your brain.The radioisotopes generally used in SPECT are iodine-123, technetium-99m, xenon-133, thallium-201, and fluorine-18. These radioactive forms of natural rudiments will pass through your body and be detected by the scanner. colourful medicines and other chemicals can be labeled with these isotopes [4]. Its ability to provide functional information enhances its diagnostic capabilities, making it an integral part of modern medical imaging. Overall, SPECT remains an important modality for functional imaging in various medical disciplines. SPECT imaging stands as a pivotal development in medical diagnostics, harnessing the power of gamma cameras to enhance the effectiveness and clarity of detectors. Central to this process are three key elements: a collimator, a radiolabeled tracer, and a gamma camera with rotating heads. The primary role of the gamma camera is to capture photons emanating from all directions around the patient. These photons are then selectively filtered by the collimator, allowing only those aligned with the detector to pass, thus concentrating the radiation and improving the image's sensitivity and resolution.

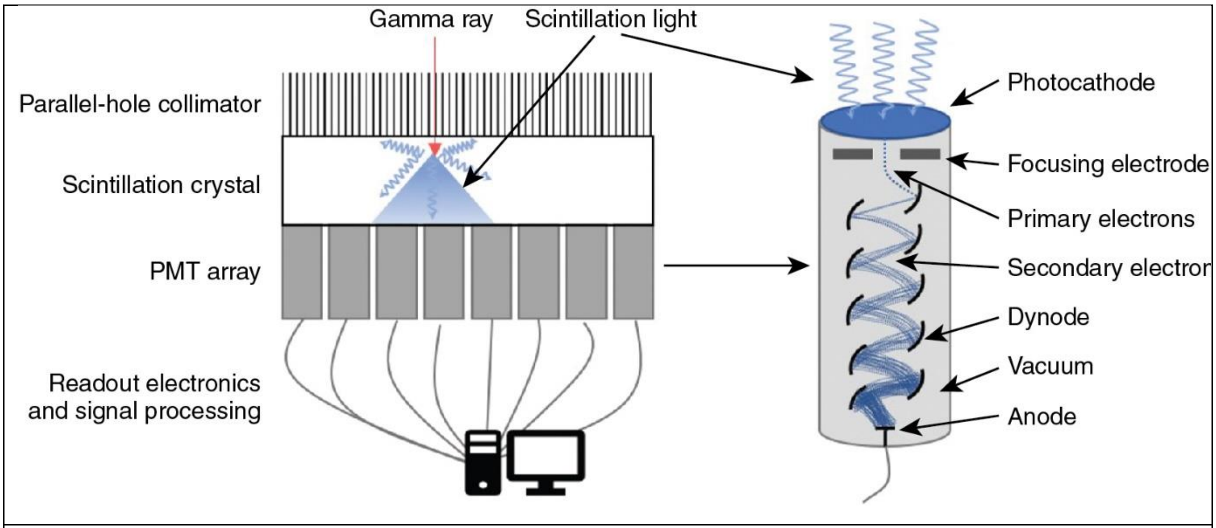


Figure1: the sceme of the SPECT detecor

In short, there are how the detection works: To achieve the high resolution, in the SPECT systems there are most commonly used scinatillating crystals, that emit low energy photons when they intersects with gamma rays, which are should be detected by the light sensor and converted into the electronic signal [5].

The light sensor is also called "photomultiplier". Photomultiplier is a device, which contains the diodes and a cathode. The principal of the detection system is next: the photocathode absorbs the emission light and produces the ionized electrons, which energy depends on the energy of light. These photons move to the first dynode in photomultiplier device, where their kinetic energy ionizes the secondary electrons. In the sensor the local electromagnetic field accelerate these electrons, through the diode series. Therefore, the produced electric signal is proportional to the emission we from scintillating crystal light, which is consequently, proportional to the energy of gamma rays. Regular SPECT system consists around 7-9 examples of diode.

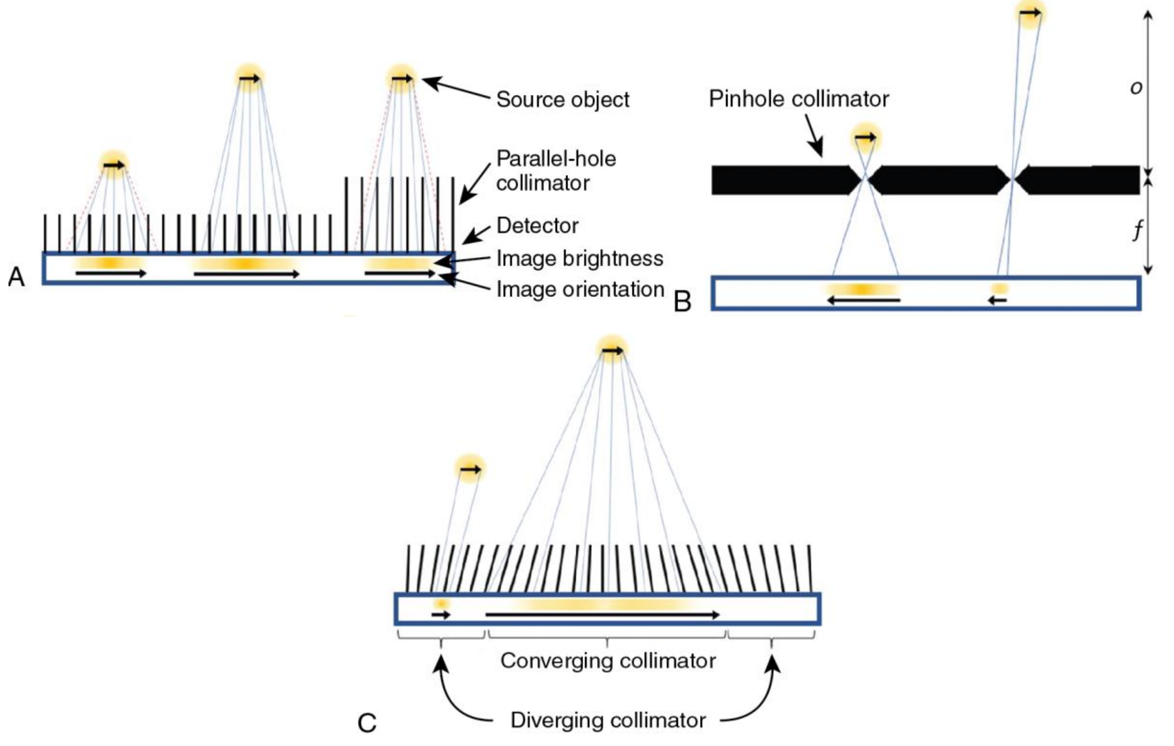


Figure 2: the explanation of collimator response

The light from scintillating crystals is radiated from it is, and it's intensity depends on the distance from the point of interaction to the detector. Thus, we could measure this distance and reconstruct the shape of the object, knowing the intensity (energy of the photons) registered by the detector. This step, the picture is pretty blurred. To create the more detailed picture there are used collimators. Collimators provides the contests of the angle, which photon travels the distance. This way we could know not only the energy of emitted photons, but also it’s trajectory which is essential for our reconstruction.

Mostly there are used the parallel collimator detectors. These detectors have a dense package of the parallel holes on high-density material. The resolution of the object depends on the diameter of the hole. The smaller holes creates the better resolution and the ones with higher sensitivity to gamma rays

What makes SPECT unique are the tracers, consisting of radioisotopes like iodine-123, technetium-99m, xenon-133, thallium-201, and fluorine-18, injected into the patient's bloodstream. These isotopes, easily spotted by the scanner, are employed to tag various drugs and chemicals. The specific tracer selected is based on the diagnostic objective, such as using radiolabeled glucose for analyzing tumor metabolism.

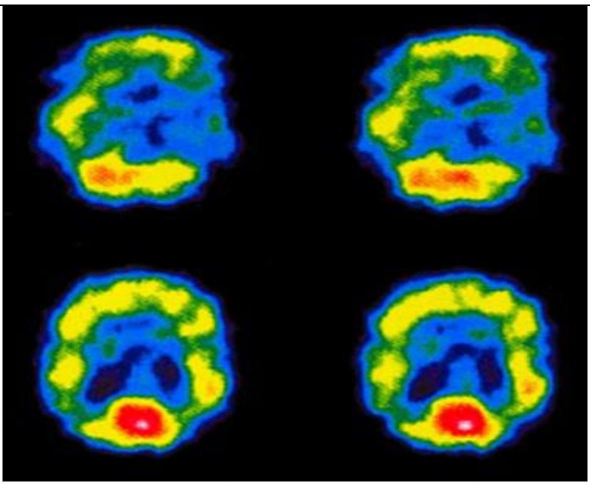


Figure 3: a SPECT scan of a patient with complex partial seizures, highlighting reduced blood flow in the left temporal lobe compared to the right, aiding the surgeon in pinpointing the seizure-causing brain area.

A notable distinction of SPECT, compared to PET scans, is that its tracers linger in the bloodstream, illuminating regions with active blood flow. This attribute renders SPECT scans especially adept at detecting brain injuries, stroke-related ischemic regions, and tumors. Moreover, SPECT's affordability and wider availability make it a more accessible choice over PET scans in many scenarios. It's also invaluable for pre-surgical assessments of seizures, providing vital information on blood flow during different seizure phases.

Overall, the fusion of SPECT with CT technology paves the way for sophisticated anatomical localization and attenuation correction. The data collected is meticulously reconstructed into detailed three-dimensional images. This marriage of functional and anatomical imaging significantly bolsters the diagnostic power of SPECT, cementing its indispensable role across various medical specialties.

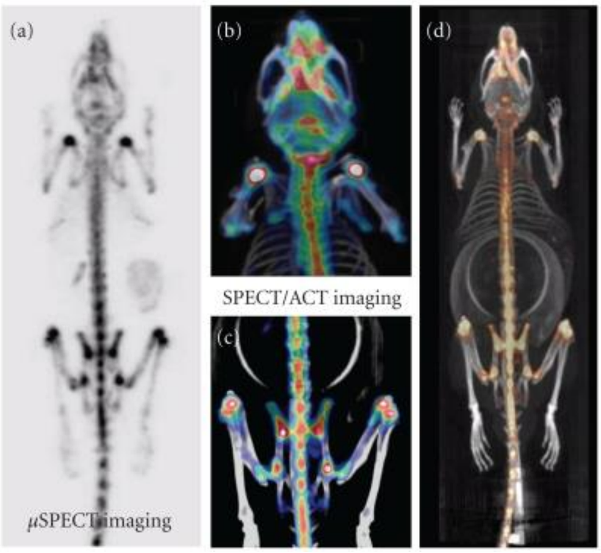


Figure 3: Invivo SPECT and SPECT/CT with 99mTc-MDP in C57BL/6 mice.

Task and results

The task of our project is centred around processing and cleaning the image in ImageJ program. Various reconstruction algorithms support projection data and reconstruction volume masks. Astra Toolbox is a special ttolbax, based on MATLAB and Python for the high-resolution performances for imaging 2D and 3D tomography. We used it to cleaned our images and find the best conditions for preprocessing our image.

The projection data elements corresponding to locations with Sinogram Mask value 0.0 will be ignored during the reconstruction. Similarly, the reconstruction data elements corresponding to locations with Reconstruction Mask value 0.0 will be ignored during the reconstruction, and their values will be preserved [6].

The algorithm will behave as if the rows and columns corresponding to the masked voxels and projection data elements have been removed from the projection matrix entirely [7]. In other words, it will iteratively try to match the projection of the non-masked voxels to the non-masked projection data elements.

NB: Min Constraint/Max Constraint will affect even masked voxels.

There were 11 darkfield images and 11 lightfield images in total. To clean the images we followed next steps:

1. Darkfield: If a pixel "reacted" more than n=1 times, it was added to the mask.

2. Lightfield: If a pixel always had a value of 0 it was added to the mask.

If a pixel in any of the lf images had a maximum value, it was added to the mask, because in this case it was overexposed or the pixel was dead.

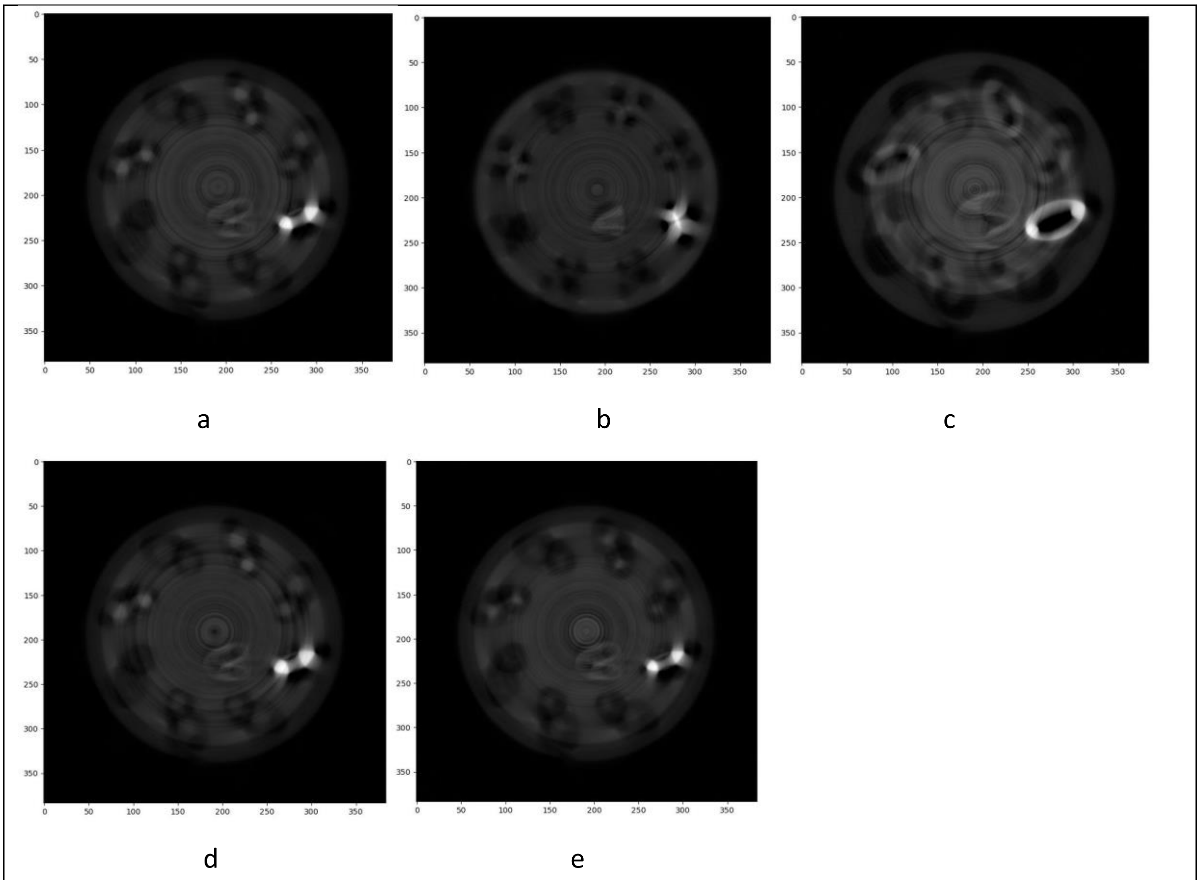
3. Lightfield – Darkfield: If the confidence interval of the mean "Lightfield-Darkfield" value crossed the value <=0, the pixel was considered noisy and added to the mask.

4. Projections: If $\int \mu dl = \pm\infty$, pixel was added to the mask, where μ is so koiffiecient of absorbtion. If $\int \mu dl$, is less than zero (but not $\pm\infty$), for example, because of photon scattering, then the value 0 was kept in the projection.

Due to PC limitation, the size of the projections was reduced by a factor of [5,4] to 768*64.

Constraints on the minimum (0) and maximum (1) voxel values were applied.

Due to computer limitations, it was not possible to apply the mask. Instead, the value of masked pixels was set through bicubic interpolation.



a b c

d e

Figure 5: Reconstructed images of the object. Figure 5a shows a 15-slice reconstruction with centreed detector. Figures 5b,5c,5d,5e show renonstructions with detector shift to the left, right, up, and down, respectively

An example of preliminary reconstruction is presented in the figure 5a. It has been suggested that smearing artifacts are caused by displacement and rotation of the detection matrix relative to the main axis of the X-ray tube beam. In the Astra Toolbox it is possible to add a detector offset along OX and OY (Figures 5b-e). However, the values of ΔX and ΔY at which smearing artifacts are leveled out could not be determined. There are also a few of circle artefacts, which are caused be the heterogeneity of detection. In the SPECT systems the center of the detector is placed on the axis of x-ray tube, but in our system the center is displaced comparing the origin. Probably, this peculiarity is caused the blurring effect.

Conclusion

Using the SPECT system, we processed the data from Timepix detectors and cleaned the images from the noises and corrupted pixels in ImajeJ program, including Astra Toolbox. In the result, we created the full 3D tomographic reconstruction of the object. However, we also wrote the Python code which cleans all the pictures from the detectors authomatically, instead doing it manually. Furthermore, we also found some peculiarities in the pixels on the pictures, which was significant for our cleaning. We purposed the explanation, that the blurring effect of the images could be caused by the detector position properties, but the Astra Toolbox possibilities was not enough to get rid of the displacements. Anyway, we proceed the images and got the reconstruction which could be compared with the real image of the object.

Acknowledgments

We would like to thank INTEREST for the organisation of this project, which gave us an opportunity to make an acquaintance with the Timepix detectors family and gain a new experience with data preprocessing. We also want to thank our supervisor, Vladislav Rozhkov, for his help and guidness. We hope that in future we will have a chance to participate in the program’s projects.

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