On the Preprocessing of Dynamic Nuclear Medicine Images

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Abstract – **In this paper an approach for pre-processing of dynamic nuclear images is proposed. The method is based on conventional threshold level detection, applied on adequately pre-processed set of dynamic images. A few raw and a few pre-processed nuclear medicine images are provided.**

Keywords – **Correlation, nuclear medicine image, denoising.**

I. INTRODUCTION

Nuclear Medicine (NM) images are diagnostic digital images, which present the projection of the distribution of radioisotope(s) in a body of a patient after injection of adequate dose of radioisotope(s). They are captured via computerized gamma cameras by accumulating the emitted gamma rays from the patient. The diagnostic images could be captured either in sets (series of images recorded one after another), or as single frames, with predefined accumulation time and resolution. In the first case, the images are called "dynamic", since their purpose is to investigate the dynamics of the distribution of the radionuclide in the organs and tissues of the patient, while the others are called "static", since they provide information about the static distribution of the radionuclide. Therefore, the "dynamic" images usually have much shorter accumulation time and relatively lower energy than the "static" ones.

In both cases, the images are very noisy due to the nature of the gamma ray emission process and the operational characteristics of the gamma cameras [1]. Actually, each point source of radionuclide in the body of the patient contributes with a noisy, bell shaped, two-dimensional region on the image, with parameters (scattering radius, and maximum number of counts) that depend on the distance of the point source from the camera and the exposition time. Therefore, a certain image preprocessing must precede the NM image analysis, which ought to provide an accurate recognition of anatomic data of the patient (the boundaries of the various objects – organs, on the images). This process could be much diversified, since it should be adjusted to the organs and tissues, which physiology is to be investigated.

In this paper we present our approach on preprocessing of dynamic chest-region NM images, captured immediately after injection of the radioactive material into the vein of a patient (first pass study). In Section II we model the dynamic NM images creation process, and formulate the problems due which, they should be preprocessed. In Section III we propose, suitable, first pass NM images filtering technique, after which, in Section IV, we propose our method for extracting the boundaries of the anatomical data in the chest region from a set of raw sequential images. The proposed method is illustrated by real images captured with our own gamma camera upgrading system, developed at the department of NM in Bitola. At last, in Section V, we give some conclusions and propose directions for further investigation of the problem.

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II. FORMULATION OF THE PROBLEM

The process of generating the NM images starts after injection of certain, small dose (for safety reasons) of suitably chosen radioactive material,

$$Q = \int_0^T q(t)dt \tag{1}$$

into the body of a patient. The total quantity of radioactivity, the place and the way of its injection into the patient ($q(t)$ - injection flow; T - total injecting time), are determined by the weight of the patient and the type of the investigations that need to be done. The injected radionuclide will start to spread, generating some space and time varying **radionuclide density function** (r.d.f.), $\rho(x, y, z, t) \geq 0$, into the body of the patient ($t > 0$; $x, y, z \in B$, B – body of the patient).

For heart analyzes, the injecting point is the patient right arm vein. After the injection (with rather high pressure) of the radionuclide, it starts to spread and mix with the blood on its way to the heart through the vena cava superior. This results with some very complicated, fast changing r.d.f. function, $\rho(x, y, z, t)$. After passing through the heart, the blood-radioactivity mixture passes through the lungs, returns to the heart and proceeds with spreading toward each cell of the patient body through its arteries.

This process could be recorded as a set of N, NM images

$$S_k^r(i,j,t_k,\tau), \quad k = 1,2,...,N \tag{2}$$

where $i, j = 1,2,...,r$; are indexes of the image matrix that correspond to the rectangular cells of the gamma camera detector plane. Each image contains rather high level of noise caused by: a) mixing the radionuclide with the blood and the spreading of this mixture, b) hydrodynamic processes in the blood vessels caused by the pumping work of the heart, and c) by the randomness of the gamma rays emission and their detection by the gamma camera.

Each image $S_k^r(i,j,t_k,\tau)$ ($S_k^r(t_k,\tau)$ or S_k^r in the further text) is formed by counting the detected gamma rays in the

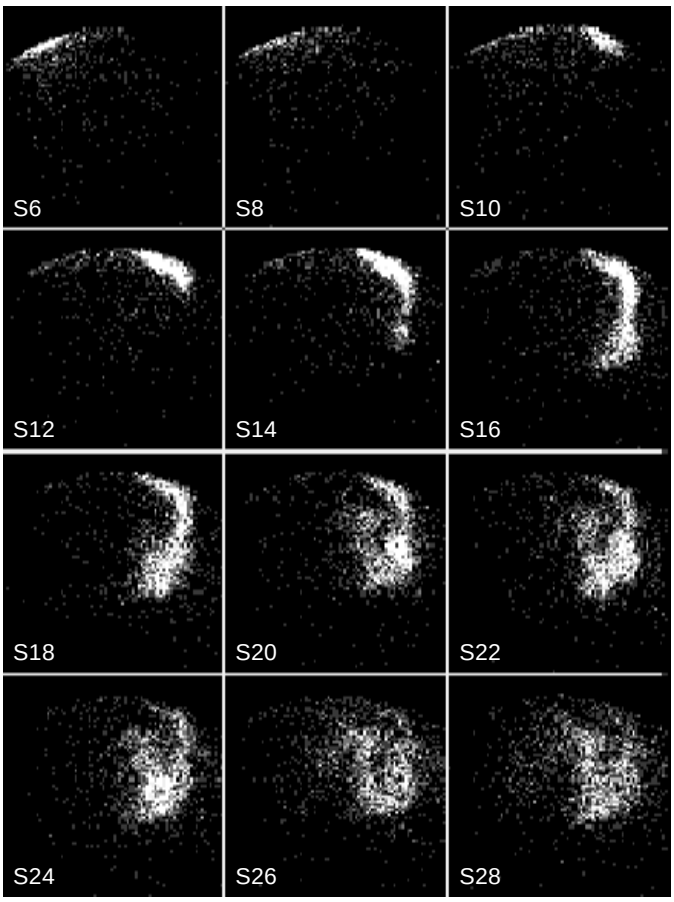

Fig. 1. Sequence of enhanced noised images (τ=0.4 s)

cells of the ($r\times r$) image matrix in the interval $[t_k,\ t_{k+1}]$ ($t_{k+1} = t_k+\tau$; $k = 1, 2, \ldots, N$; $t_1 = 0$, τ – accumulation time).

On this set of images, the following arithmetic operations can be defined:

$$S_k^{r1}(t_k,\tau) = f(S_k^r(t_k,\tau)); \qquad r1 = 0.5r \tag{3}$$

$$S_{k,j}^r(t_k, j\tau) = \sum_{i=k}^{k+j-1} S_i^r(t_i,\tau) \tag{4}$$

which helps in creation of new raw images with lower resolution and longer accumulation time (f(.) is a function for reducing the resolution of the original image by factor of two).

This type of images, usually has a very short accumulation time ($\tau \le 0.5$) in order to record the very fast spreading of the radionuclide. Therefore, the accumulated energy (counts) per image is very small. As a consequence of that, the images captured with higher resolution will have relatively lower level of image dynamics defined by

$$d_k^r = \max_{i,j}(S_k^r(i,j)) - \min_{i,j}(S_k^r(i,j)) \tag{5}$$

Since for this type of NM images, the lowest pixel intensity is 0, the image dynamics is defined by $d_k^r = \max_{i,j}(S_k^r(i,j))$.

Hence, the Eqs. (3) and (4) should be applied in creating new sets of useful raw images as a trade-of between the resolution, the level of image dynamics, and the image accumulation time.

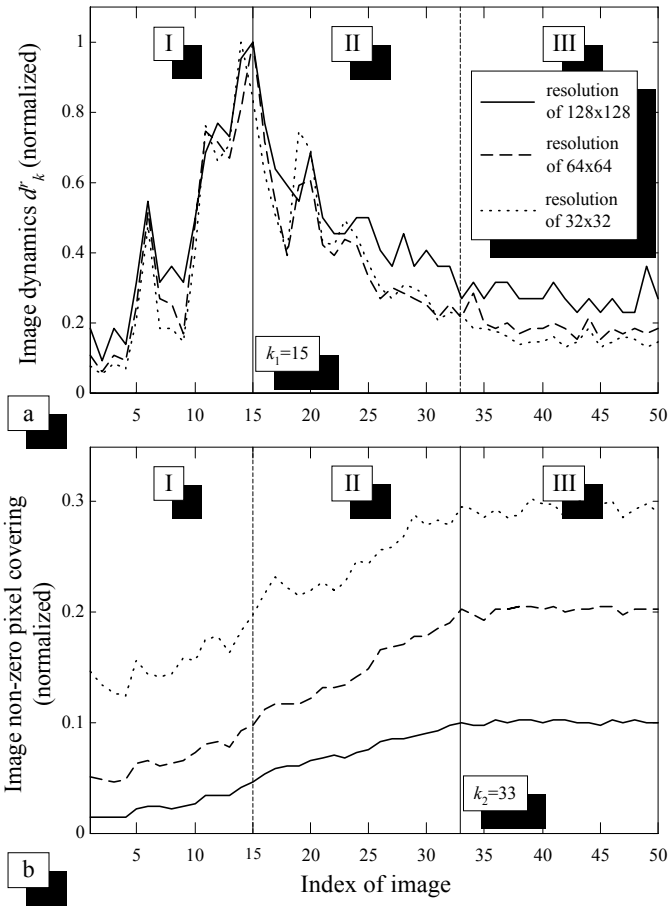

Fig. 2. Relationships between: (a) The image dynamics d^r_k and the index of the image and (b) The image surface covering with non-zero pixels and the index of the image

Considering this, the raw images should be adequately preprocessed in order to extract the anatomy information about the position of the vena cava superior and the heart. According to this information, the optimal position (and the shape) of the regions of interest (ROI's) for the heart study could be proposed [2].

III. Filtration of Dynamical Images

The process of spreading of the radionuclide can be divided in three successive phases. The first one is when the radionuclide passes through the vena and comes to the heart; the second one begins when it starts to spread through the heart and comes to the lungs; and the third one starts when the radionuclide begins to return to the heart and proceeds to spread toward each cell of the patient body.

The break point between the first and the second phase can be determined very accurately by the index, $k=k_1$, of the image S_k^r (r=128, 64, 32) with maximum image dynamics, d_k^r, as illustrated in Fig. 2a.

This maximum happens when the main quantity of the injected radionuclide is temporally stopped at the entrance of the heart by its pumping rhythm. After that, the radionuclide starts to spread through the heart, which affects on reducing its maximal concentration in the vena. We use this fact to

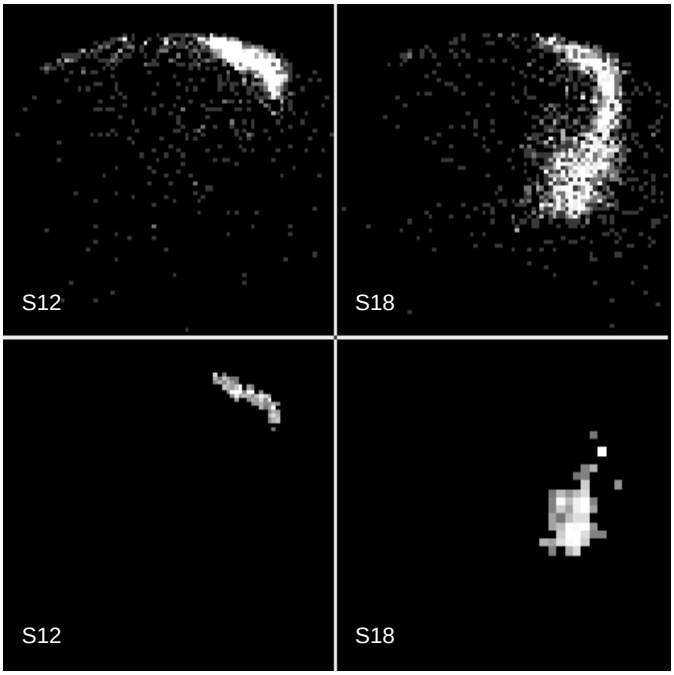

Fig. 3. Original and filtered images S_{12}, S_{18}

determine (estimate) the projection of the entrance of the vena in the heart as a region (in the neighborhood) of the image S_k with maximum image intensity.

The break point between the second and the third phase can be determined by the index, $k=k_2$, of the image S_k^r (r=128, 64, 32) on which the end of the spreading trend of the distribution of the radionuclide in the chest region can be recognized. This moment can be recognized on the graph which depicts the covering of the image surface, S_k^r, with nonzero intensity pixels as illustrated in Fig. 2b.

The images recorder in phase one, shows the spreading of rather compact mass of radionuclide through the vena. In spite of that, these images contain high level of spatially distributed noise in a form of isolated pixels in the neighborhood of the vena (Fig. 1.).

After a dozen of experiments we have concluded that the best method for removing the noise from this group of images is to use the autocorrelation low-pass filtering technique defined by

$$S_{fk}^r = S_k^r \otimes \psi(S_k^r, l_x, l_y) \tag{6}$$

where: S_{fk} is filtered image; ψ – is a raw image shifting operator defined by

$$\psi(S_k^r, l_x, l_y) = \begin{cases} S_k^r(i+l_x, j+l_y) & i+l_x, j+l_y \in [1,r] \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

and $\otimes$ is a pixel by pixel operator, defined by:

$$S_k^r(i,j) \otimes B(i,j) = \begin{cases} S_k^r(i,j) & \text{for } B(i,j) > 0 \\ 0 & \text{for } B(i,j) = 0 \end{cases} \tag{8}$$

We have used this technique eight times recurrently (by shifting the raw image S_k one pixel right, right-up, up, up-left, left, left-down, down and down-right) and obtained results as illustrated in Fig. 3. The main motivation to apply this technique was our assumption that there is a bigger chance for any isolated pixel to be a part of the noise than to be a part of the image information.

The images recorded in the beginning of the second phase consists two objects: the vena and the heart. Later, the vena disappears, and only the heart remains. The projection of the heart in this phase is the best, but still its boundaries remain poorly shaped due to the lower concentration of the radionuclide in it. Also, the heart pulsation has NM image degrading effects. Hence, the correlation technique can not be successfully applied on the whole image. Therefore, this group of images must be preprocessed as follows:

- Decomposing the set of images into two subsets: subset with images of the vein (I phase, indexes 5-14) and subset with images of the vena, the heart and the lungs (II phase, indexes 15-28);
- Applying the autocorrelation technique (Eq. 6) to the images from the first subset;
- Superposition of the images from the first subset and obtaining a final image about the vein;
- Extracting the segment with the heart from the images of the second subset using the final image about the vein;
- Reducing the resolution of the extracted segment from 128x128 to 64x64;
- Applying the autocorrelation technique (Eq. 6) to the images obtained in the previous step;
- Increasing the resolution of the filtrated images from 64x64 to 128x128;
- Superposition of the images obtained in the previous step and obtaining a final image about the heart.

IV. Anatomical Data Extraction

The conventional way for extracting anatomic information is by summing a number of sequential raw images according to the Eq. (4). In some cases this approach gives sufficiently good results, but in many situations the objects on the resultant image appear enlarged and deformed (Fig. 4.). Therefore, we have experimented with a modified approach based on superposition of the parts of the filtered images.

Intuitively, it is obvious that each filtered image S_{fk} contains a part of global information about the anatomy of the body of the patient. In order to extract the desired information out from the image S_{fk}, we define and determine the image energy zone with energy above certain threshold (say $0.8 \cdot d_k$), and the image zone below the same threshold.

Actually, we decompose the filtrated image into two sub-images:

$$S_{fk}^r = S_{hfk}^r + S_{lfk}^r \tag{9}$$

(S_{hfk}^r -high energy sub-image, S_{lfk}^r -low energy sub-image), after what we proceed with the composition of the resultant image according the following formula:

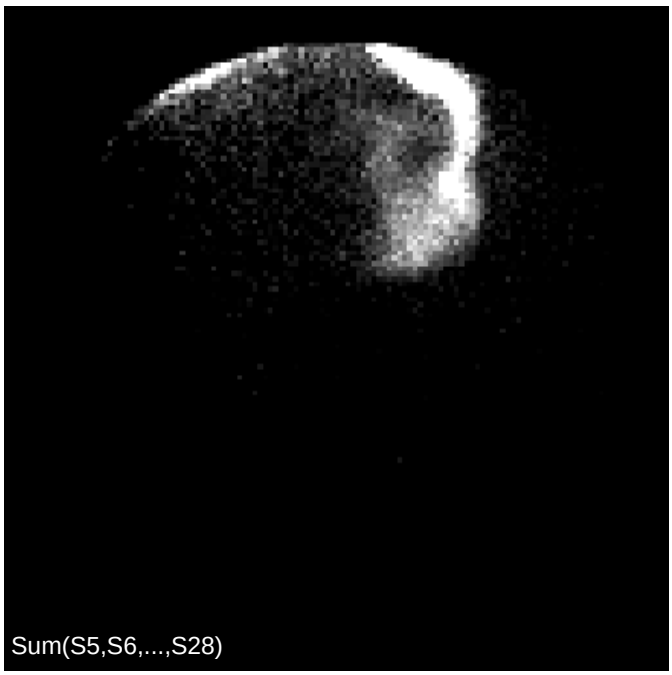

Fig. 4. The vena and the heart (conventional approach)

Fig. 5. The final image of the vena and the heart (our approach)

$$S_{af}^{r} = \sum_{k=0}^{k_3} \frac{d_{k_1}^{r}}{d_k^{r}} S_{hfk}^{r} + \omega \sum_{k=0}^{k_3} \frac{d_{k_1}^{r}}{d_k^{r}} S_{lfk}^{r} \qquad (10)$$

where $0 < \omega < 1$ and $k_3 = k_1 + \varepsilon(k_2 - k_1)$; $0.6 < \varepsilon < 0.8$. We choose the coefficient ε to lie in the interval [0.6, 0.8], because we want to process the images with the heart only, not the images with the heart and the lungs together.

The resultant image about the vena and the heart (obtained from 24 sequential images, with indexes 5-28) is shown in Fig. 5. The process of decomposition could be continued with decomposing the sub-image S_{lfk}^{r} into two new sub-images.

Discussion. From a visual aspect, the image obtained by proposed method has lower quality than the image obtained by conventional approach. But, if the images are compared from an aspect of designing an expert system for determining regions of interest and positions of the organs in patient body, the proposed approach has advantage above the conventional one. With proposed approach, the position of the vena cava superior could be quite precisely determined, but the position of the heart could be determined with some dose of uncertainty due to its pumping work and the fact that in this phase the radionuclide is distributed only in the heart cavities (not in the heart muscles). The image in Fig. 5 is filtrated from the noise, but it contains certain deformation of the shape of the heart due to the increasing of the resolution of the images.

V. CONCLUSION

In this paper we present our approach for preprocessing of dynamic nuclear images. The proposed method is based on conventional threshold level detection, applied on adequately preprocessed set of dynamic images, (nonlinear enhancement of the originals and their low-pass filtrations). The presented results are illustrated in few NM images recorded and processed by our own gamma camera upgraded system, developed at the department of NM in Bitola. The obtained results could be utilized an expert system to be created. This system would offer regions of interest to a medicine person. Analyzing these regions the medicine person would be able to make physiological investigation.

The problem of noise removal in photon imaging systems also can be considered in wavelet-domain. Several authors have proposed wavelet-domain algorithms to determine a threshold for removing noise from a NM image. Utilizing wavelets as a tool for analyzing the NM images, the position of the heart could be determined more precisely.

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