AN AUTOMATIC SEGMENTATION METHOD FOR FAST IMAGING IN PET

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ABSTRACT

A new segmentation method has been developed for PET fast imaging. The technique automatically segments the transmission images into different anatomical regions, it efficiently reduced the PET transmission scan time. The result shows that this method gives only 3 min-scan time which is perfect for attenuation correction of the PET images instead of the original 15—30 min-scan time. This approach has been successfully tested both on phantom and clinical data.

Keywords: PET TR imaging Segmentation Clustered segmentation method Pyramid Fast imaging Pyramid structure

1 INTRODUCTION

As the newest generation of the imaging instrument using nuclear radiation, the positron emission tomography (PET) has more advantages such as on resolution, uniformity, *etc*. than the single photo emission computer tomography (SPECT). But the longer transmission (TR) imaging time limits the clinical use, especially in chest or whole body tests of the PET. Simply reducing the TR sampling time seems available, but the statistic noise will be very high[1,2], and the PET quantitative analysis will become unreliable.

A segmented attenuation correction technique has been developed for PET which automatically calculated attenuation correction factors in the image reconstruction. The technique segments the transmission image into anatomic regions by average values of attenuation correction factors derived from the clustered segmentation image. The phantom studies and the clinical cardiac studies in patients showed that this approach is able to reduce the noise and keep the resolution of the image taken from 3 min transmission imaging time.

2 METHOD

A pyramid structure for 2D images is a layered arrangement of square arrays in which each array is half as long and wide as the next array below it[3].

The pixels in the pyramid array are defind by $P(x,y,l)$, where x and y are spatial coordinates, l is the layer number in the pyramid. In the initial statues, each pixel hold the average value of the nearby pixels in the layer below. The bottom layer contains the image to be processed. Pixels are clustered into a regions by a procedure between nodes in adjacent layers such that all descendants of a pixel are considered to be in the same segment (Fig.1)

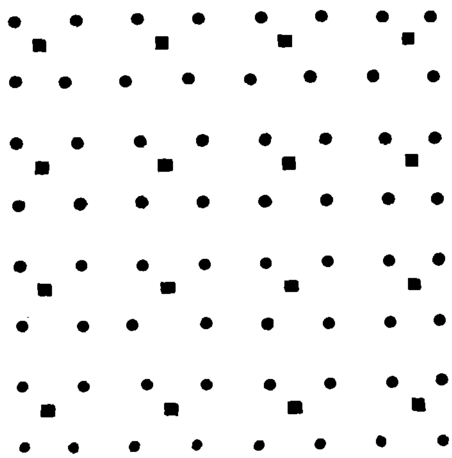

Fig.1 The relative spatial position of the elements in two adjacent levels of a pyramid

Dots represent the elements on the lower level. Rectangulars show the elements located in high level.

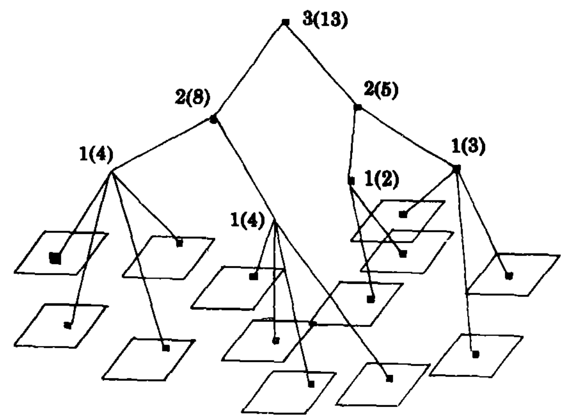

Fig.2 The 3−dimension structure of pyramid

Each element is labelled with its level number and with the total area of its ground level descendants. The ground level is shown by squares

For a $2^N \times 2^N$ original image, the maximum number of pyramid layers of the structure is N-1. The initialization of the pyramid is an upward process in which the local image value of each element is defined by an unweighted average process using a subset of its sons. On the bottom the element of the pyramid has the same meaning as the pixel of the image and its value equals to the original pixel value of the transmission image in the initialization step.

Assume the transmission image function is $T(x,y)$, then in the pyramid structure $[i, j, l]$, the function $T(x,y)$ is defined by

$$f(i,j,0) = T(x(i,0), y(j,0)) \tag{1}$$

here $i = j = 2^N$, $l = 0$. On the higher levels, $0 < l < N$.

The initialization of the pyramid is a procedure of convolution of the image $f(i,j,0)$ with operators of increasing size. The operators are centered around the elements and overlap by half both horizontally and vertically:

$$g(i',j',l) = \Sigma_A (f(i,j,l-1)) / A(k,l) \tag{2}$$

where $A(k,l)$ is the area on which the links between father and its sons established (Fig.2), here

$$0 < k \leqslant (2^{N-1}-1)^2 \tag{3}$$

In this procedure, each son is allowed to choose four candidate fathers and the evaluation of the relationship between father and its sons usually by following function:

$$| g(i',j',l) - f(i,j,l-1)| < S(i,j,l) \tag{4}$$

where $f(i,j,l-1)$ located on the l-1 level in pyramid structure, $S(i,j,l)$ is defined by the local standard deviation on $A(k,l)$.

Assume $f'(i,j,l)$ linked with their father on subarea $A'(k,I)$, $A'(i,I) < A(k,I)+1$, then

$$f'_{A'}(i,j,l) = \Sigma_{A'} f(i,j,l) / A'(k,I) \tag{5}$$

$$f'_{A-A'}(i,j,l) = \Sigma_{A'} (f(i,j,l) \times w'(i,j,l)) / A(k,I) \tag{6}$$

where I is the iteration index, l is the number of layers, $w'(i,j,l)$ is the weight factor for the elements located in $A-A'$.

If $A'(k,I)=0$, $f(i,j,l)$ defined by

$$f'(i,j,l) = \Sigma_A (f(i,j,l) \times w'(i,j,l)) / A(k,I) \tag{7}$$

The new value of the $f(i,j,l)$ is determined by (7), (8), (9) in the I-th iteration. The relationship between $f(i,j,l)$ and $f(i,j,l-1)$ depends on the value $S(i,j,l)$ explained below:

$$S(i,j,l) = [\Sigma_{A(k,I)} (f(i,j,l) - \bar{f}(i,j,l))^2 / A(k,I)]^{1/2} \tag{8}$$

where $$\bar{f}(i,j,l)/A(k,I) = \Sigma_A f(i,j,l) / A(k,I) \tag{9}$$

Consider that if the links have been established, then the subarea $A'(k,I) > 0$, furthermore:

$$f'(i,j,l)/A'(k,I) = \Sigma_{A'} f(i,j,l) / A'(k,I) = \bar{f}(i,j,l) / A'(k,I) \tag{10}$$

From (8), one has

$$S_I(i,j,l) = [\Sigma_{A(k,I)} (f(i,j,l) - \bar{f}(i,j,l))^2 / A(k,I)]^{1/2} \tag{11}$$

after $I+1$ th iteration:

$$S_{I+1}(i,j,l) = [\Sigma_{A(k,I+1)} (\bar{f}(i,j,l)/A(k,I+1) - \bar{f}(i,j,l) / A'(k,I+1))^2 / A(k,I+1)]^{1/2} \tag{12}$$

Assume $A'(k,I+1) = A'(k,I)+d$, $d < p(k,I) - p'(k,I+1)$, therefore

$$\bar{f}(i,j,l) / A'(k,I+1) = [\Sigma f(i,j,l)/A'(k,I) + \Sigma_d f(i,j,l)] / (A'(k,I)+d) \quad (13)$$

Else, if the value $d=0$, that means no more sons could be linked, then

$$\Sigma_d f(i,j,l)=0 \quad (14)$$

According to (13), one has

$$\bar{f}(i,j,l) / A'(k,I+1) = \bar{f}(i,j,l) / A'(k,I) \quad (15)$$

Considering (8) one can get:

$$S_{l+1}(i,j,l) = S_l(i,j,l) = \text{const} \quad (16)$$

Obviously, for $A=A'$, under the same condition, $S_l(i,j,l)=0$. After the last iteration one gets the pyramid image.

2.1 Probability segmentation

After processing with pyramid procedure, the new distribution of the image already has been set on the level 0. Assume Df represents the cluster distribution, then Df$<2^N$.

Define r is the segmentation number we choose, then $0< r< 2^N$. If the maximum probability is $P(xm)$, xm is the gray level which has the maximum probability of the pixels on pyramid image, then in the region Ui the maximum probability will be $P_i(xm)$.

If the subimage $i(xm)$ represents one group that has the value $P(xm)$, then the subprobability will be Ib_1, Ib_2, ⋯ Ib_i, ⋯ Ib_r.

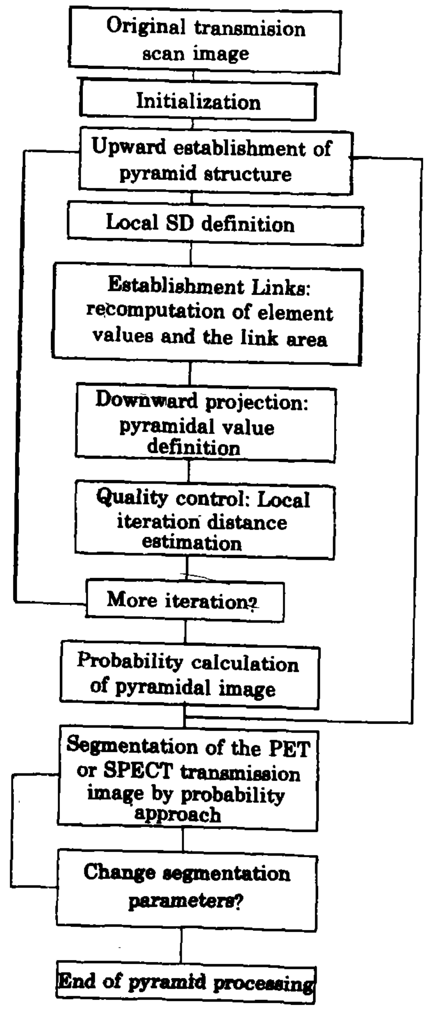

Fig.3 The flow chart of the pyramidal segmentation program

Finally, the segmentation image $I_{seg}(i,j)$ is set equal to that of the sum of all the subprobability distribution functions:

$$I_{seg}(i,j) = \Sigma_{i=1}^{r} (Ib_i) \quad (17)$$

In fact, for the purpose of attenuation correction the segmentation number depends on pyramid structure. For example, on the certain level l, $-1< l< N+1$, if the node number is C_n, $A'<A<C_n$, the maximum segment number is limited by the C_n.

2.2 Flow chart

For summary of the procedure with pyramid approach to segment the transmission image in PET, the program flow chart is shown in Fig.3.

3 RESULT

Fig.4 shows the study of the IAEC 3- D chest phantom before and after processing with this method. Usually, 15—30 min acquisition time to the transmission imaging is necessary in PET study. Here we choosed only one minute for PET TR- acquisition in order to creat an image with very low N/S value for testing our approach (see Fig.4a).

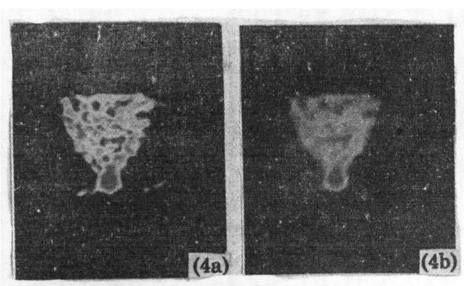

Fig.4 The transmission image with 1 min sampling time using IAEC standard 3—D human chest phantom

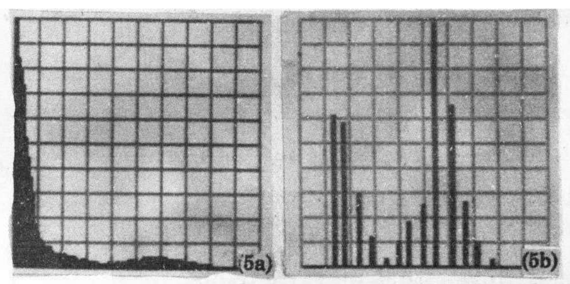

Fig.5 Histogram of the gray probability distribution of the phantom

4a,5a) Before processing 4b,5b) After processing

Fig.4 (a) indicates that there are very high noise and image distortion. (b) shows the processed result and the obvious implementation to the distortion of the count distribution as well as the chest edge. The further analysis is explained by the histograms of the gray probability distribution. Fig.5 shows the histograms before and after processing, Fig.5(a) shows that the maximum effective signal amplitude is only a tenth part of the background. Fig.5(b) is the result after implementation with this method. It is obvious that the background has been suppressed and the effective signal is greatly increased using this method. The figure also indicates that there is not any shift in the signal distribution map, which is very helpful to the image quantitative

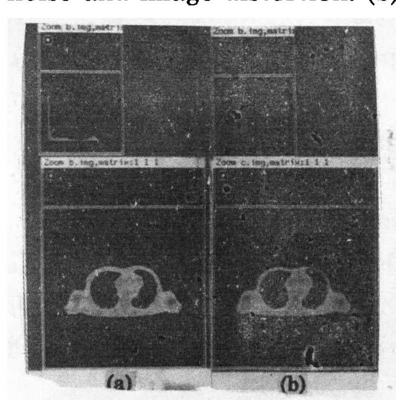

Fig.6 The result of processing for a patient with cardiac disease

a) Before processing b) After processing problem.

Usually the TR sampling time is 15—30 min but 3 min is sufficient if the pyramid segmentation is used. Fig.5 shows a chest TR tomography of a patient with cardiac disease. Sampling time is 3 min. Fig. 6(a) and (b) are images before and after processing with 3 min sampling time, the histograms are located at the left up corner of these images respectively.

4 DISCUSSION

Clustered segmentation method is an effective method for the computer processing of the images with very high noise[4,5]. It is useful to implement local count distortion through the clustering procedure to the relative groups of the image elements. Such kind of methods is usually choosed in order to keep the image resolution as well as the morphology feature, for instance the organ edges, the geometrical relations between two different regions and so on[6,7]

Pyramid structure is one of the successful clustering approaches. We modified the standard pyramid technique[5] and gave the mathematical model according to the features of the PET image to get shorter processing time. The clinical tests indicated that the average transmission image sampling time can be reduced from 15—30 min to 3 min.

The methodology of high noise image processing has been greatly developed as the imaging equipment is playing more important role in clinical diagnosis[8-10]. This approach in the paper has reduced both the radiation dose and the testing time to the patients so that it is very helpful to the children as well as the patients who could not be able to bear a long time PET tests during the clinical image diagnosis.

REFERENCES

1 Kenny D N, Phelps M. IEEE Trans Med Imaging, 1989; 8(1):291
2 Xu E Z, Mullani N A, Gould K L *et al.* J Nucl Med, 1991; 32:161
3 Willian I. IEEE Trans Pattern Anal, 1986; PAMI- 8:639
4 Jiang T, Merickel M B, Parrish A. IEEE Trans, Pat Anal, 1988; PAMI:689
5 Baronti S, Toet A. Comp Vision Grap & Image Proc, 1990; 49:346
6 Hong T H, Narayanan K A, Peleg S *et al.* IEEE Tran Sys Man and Cyb, 1982; SMC- 12(5):611
7 Burt P J, Hong T H, Rosenfeld A. IEEE Tran Sys Man & Cyb, 1981; SMC- 11(12):802
8 Ostertag H, Wolfgang K, Doll J *et al.* Eur J Nucl Med, 1989; 15:722
9 Guerrero T M. IEEE Tran Nucl Sci, 1990; 37(2):676
10 Turrin A. J Nucl Med Allied Sci, 1988; Y(8)