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AUTOMATIC CONTOURING OF SEGMENTED HUMAN BRAIN ISCHEMIC STROKE REGION ON CT IMAGES[1]

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ABSTRACT

Investigation of the relationship between stroke area size and patient status implies evaluation of the stroke area location, volume and shape. Computed tomography (CT) examination became very popular in such type of investigations due to its moderate price and less discomfort for patient in comparison with other techniques.

We propose an algorithm for segmented CT images post-processing, which consists of several stages: filtering of CT slices, smoothing and extension of stroke region boundary, filling of stroke space, and computing of stroke volume via all slices. Post-processing of several CT images using this technique showed that all accidental points can be filtered successfully and therefore the aim of ischemic stroke area determination can be reached. We are convinced that the quality of initial information (results of stroke area segmentation) plays a crucial role for later image processing.

Key words: computed tomography, ischemic brain stroke, images post-processing

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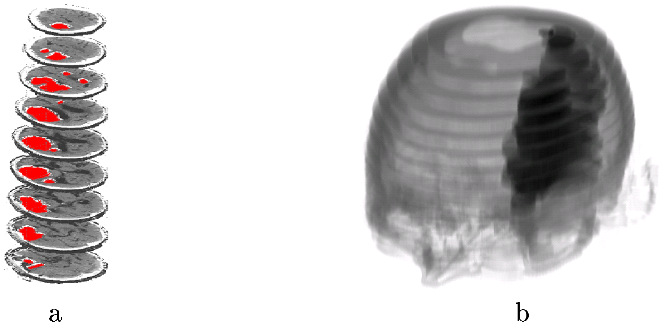

Figure 1. Automatically segmented stroke region in CT slices (a) and their reconstruction by exposing stroke volume (b).

1. INTRODUCTION

Computed tomography (CT) is a common procedure to exam patients with ischemic stroke in the head brain. Due to its moderate price and less discomfort for patient in comparison with more detailed Magnetic Resonance Imaging (MRI) technique, CT examination became very popular in such type of investigations.

It is necessary to determine ischemic stroke volume for investigation of the relationship between stroke size and patient status. While there were presented only techniques for object recognition [4] and for stroke analysis [5] in brain CT images in up to date literature, a huge amount of various algorithms have been developed for brain segmentation of MRI images ranging from semi-automated to fully automated methods [2; 3; 6; 7].

Although MRI gives more detailed pictures of the brain, CT is a fundamental branch point in the stroke evaluation. Disadvantages of MRI include its high cost, lack of ready availability at most hospitals. An MRI can be performed afterwards if finer details are required for making further medical decision [1].

Usually radiologist himself must define stroke region in the CT slice. Such work is time and attention consuming. So there is a need to automate segmentation of human brain stroke by using non expensive personal computer.

This article will continue investigation of human brain ischemic stroke recognition in the CT slices started several years ago (Fig. 1 shows automatically segmented stroke regions in CT slices and its reconstruction).

Since there are several methods of image analysis such as Histogram, Grey Level Co-occurrence Matrix, Artificial Neural Network [8; 9], and all of them give approximate results only, there is a need to develop additional technique to correct automatically detected stroke area boundary.

Objectives of investigation were to eliminate false stroke segmentation elements, to determine the stroke area contour, to mark true stroke and true non-stroke regions in the image, and to compute stroke volume through all CT slices. Here it will be discussed how to determine inner and outer stroke space by smoothing and extending the detected segmented stroke area boundary. It is believed that the inner stroke area will represent true stroke region, outer stroke area – true non-stroke region, and intermediate area – undeterminable stroke region. Finally a simple algorithm will be given for the stroke volume evaluation.

In this paper images are represented as matrices $\mathbf{I}$ with elements $I_{m,n}$, which characterize gray level value in the pixel with coordinates m, n.

2. SUCCESSIVE STAGES OF THE CT IMAGES POST-PROCESSING ALGORITHM

2.1. Filtering

The objective of image filtering was elimination of the false stroke segmentation by averaging the images in adjacent slices. This was implemented by the following averaging formula:

$$I^{OUT}_{k,m,n} = \frac{1}{P} \sum_{g=-G}^{G} \sum_{i=-I}^{I} \sum_{j=-J}^{J} I^{IN}_{k+g,\, m+di,\, n+dj}, \tag{2.1}$$

where I^{IN}, I^{OUT} are an input and filtered images respectively, $k = 1, 2, \ldots, K$ (K – the number of CT slices); $m = 1, 2, \ldots, M$ (M – the length of CT slice); $n = 1, 2, \ldots, N$ (N – the width of CT slice); G is the number of adjacent slices in top and down directions; I, J are the numbers of pixels in the x and y directions; d is the distance between adjacent slices in mm, and $P = (2G+1)(2I+1)(2J+1)$.

Figure 2a shows the results of segmented input image filtering with $K = 8$, $M = 512$, $N = 512$, $G = 1$, $I = 1$, $J = 1$, and $d = 4$. All small-size wrong segmented regions were filtered successfully (see Figure 2b).


a b

Figure 2. Segmented input image (a) and the filtered image (b).

Figure 3. Founded centers (white dots) of stroke regions from 6th (a) and 9th (b) slices.

2.2. Finding Centers

The geometrical centers of the stroke in each slice were needed to draw the inner and outer rays in order to detect stroke area boundary points:

$$m_c(k) = \frac{1}{L}\sum_{m=1}^{M}\sum_{n=1}^{N} m \times id(\text{strokearea}), \tag{2.2}$$

$$n_c(k) = \frac{1}{L}\sum_{m=1}^{M}\sum_{n=1}^{N} n \times id(\text{strokearea}), \tag{2.3}$$

where

$$id(\text{strokearea}) = \begin{cases} 1 & \text{if } (m,n) \in \text{stroke area}, \\ 0 & \text{if } (m,n) \notin \text{stroke area}; \end{cases}$$

m_c is the center row of the stroke region; n_c is the center column of the stroke region; L is the number of stroke region pixels.

Figure 3 shows several founded centers of different stroke regions.

2.3. Detection of Boundary Points

The lines were drawn from the stroke region center as inner rays (Fig. 4 a), and to stroke region center as outer rays (Fig. 4 b). These rays are necessary to find contour points for stroke region definition.

The points of inner rays satisfy the following equation:

$$m = m_c + tg(\alpha_r)(n - n_c), \tag{2.4}$$

where $n = n_c, n_c + 1, \ldots, N - 1, N$, α_r is an angle between the ray and the horizontal axis: $\alpha_r = \frac{2\pi}{R}(r-1)$, $r = 1, 2, \ldots, R$ (R is the number of rays).

The equation for outer rays can be written in a similar way.

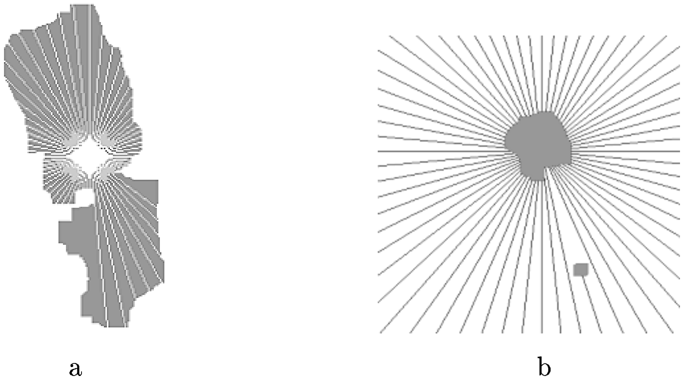

Figure 4. Inner (a) and outer (b) rays ($R = 64$) in the stroke region of 7th and 6th slices, respectively.

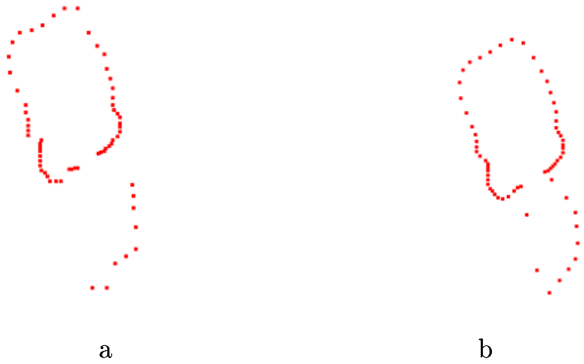

Figure 5. Smoothing result (inner rays): $R = 64$, 7th slice, a — input boundary, b — smoothed boundary).

2.4. Boundary Smoothing

The smoothing operation was performed for the boundary fitting by the weighted moving mean algorithm. Figure 5 shows smoothed stroke region boundaries according to the rays type (inner or outer space).

2.5. Extension of the Smoothed Boundary

The extension algorithm was implemented for boundary shape reconstruction by homothetic transformation (Fig. 6):

$$x \to kx, \tag{2.5}$$

where x is the length of the ray, corresponding to smoothed contour.

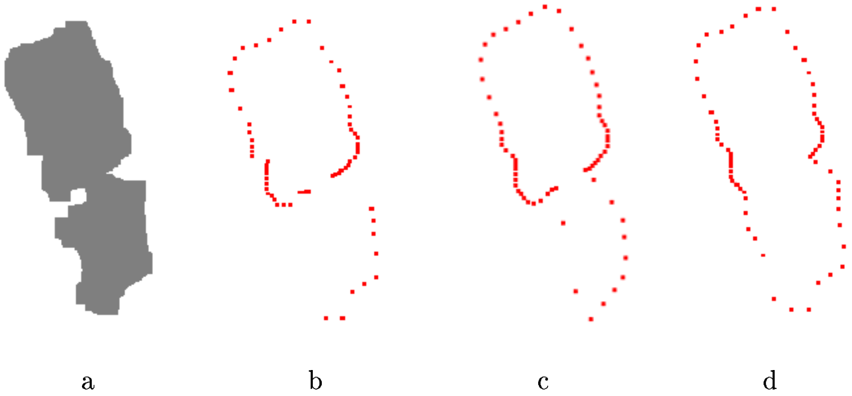

Figure 6. Consequent stages of boundary processing (inner rays, $R = 64$, 7th slice).

Thus we have obtained an optimization problem for determination of the coefficient k, which can be solved by the least square procedure:

$$\sum_{r=1}^{R}(kx_r - \xi_r)^2 \to \min_k, \tag{2.6}$$

$$k = \frac{\sum\limits_{r=1}^{R} x_r\xi_r}{\sum\limits_{r=1}^{R} x_r^2}, \tag{2.7}$$

where k is extension (contraction) coefficient, ξ is the length of unprocessed ray.

2.6. Filling of Inner and Outer Stroke Space

Inner and outer spaces were filled to determine true stroke and true non-stroke segmented regions (Fig. 7). Outer space (in gray colour) is bigger than inner space (in black colour). Gray colour represents the non-stroke segmented area, and black colour – stroke segmented area. Intermediate region (in white colour) between inner and outer spaces represents undefined texture.

2.7. Computing Stroke Volume via All Slices

Let S_k be a square of stroke area in k-th slice, approximately calculated as sum of triangles:

$$S_k = \sum_t S_{kt}, \tag{2.8}$$

Figure 7. Filled inner (black) and outer (gray) spaces. White space represents undefined regions.

where k is the number of the slice; t is the number of triangle of stroke region.

The two sides of such triangle are the rays which connect center of area with boundary points, while the third side connects two neighbour points of the contour. Then stroke volume was calculated by involving segmented stroke region in all slices by trapezoidal formulae:

$$V = h\left(\frac{1}{2}(S_1 + S_K) + \sum_{k=2}^{K-1} S_k\right), \tag{2.9}$$

where h is a distance between adjacent slices.

3. CONCLUSIONS

The filtering algorithm of segmented stroke region was presented. All accidental points were filtered successfully.

The contour of segmented stroke area was located by using inner and outer rays technique, true stroke, true non-stroke, unknown, and predicted stroke regions were defined there. This information can be useful for future CT examination as radiologist's adviser.

The stroke volume was computed by using the simple numerical integration formulae. The presented technique helps to determine stroke region location, shape and volume.

The quality of initial information (results of stroke area segmentation) plays the crucial role for later image processing.

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Žmogaus galvos smegenų ischeminio insulto segmentuoto tomografinio atvaizdo kontūrų automatinis nustatymas

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Straipsnyje aprašytas algoritmas, skirtas žmogaus galvos smegenų tomografinių atvaizdų apdorojimui. Ischeminio smegenų insulto atveju reikalinga tiksli informacija apie insulto srities lokalizaciją, pavidalą ir tūrį. Siūlomą algoritmą sudaro kelios nuosekliai atliekamos procedūros: vaizdo filtravimas, insulto srities centro kiekviename sluoksnyje nustatymas, kontūro taškų išskyrimas, kontūro glodinimas ir ištempimas, insulto ir ne insulto sričių vizualizacija bei tūrio apskaičiavimas. Tai įmanoma atlikti personaliniu kompiuteriu. Pateiktas kompiuterinės tomogramos apdorojimo, naudojant minėtą algoritmą, pavyzdys.