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doi:10.15199/48.2017.05.20

Using a priori data for segmentation anatomical structures of the brain

***Abstract**. The paper presents a method for providing a segmentation of the anatomical structures of the brain at the image. The proposed method of segmentation makes the analysis of tomographic slices based on the stage of the provisional classification. Furthermore, for the segmentation of brain CT slices, it is proposed to use as the information about the position and the shape of structures and the X-ray density.*

***Streszczenie.** Artykuł prezentuje metodę segmentacji struktur anatomicznych mózgu. Przedstawiona metoda segmentacji wykorzystuje etap wstępnej anlizy przekrojów tomograficznych. Dodatkowo informacji uzyskana na etapie segmentacji obrazów CT mózgu, może być wykorzystana do określania kształtu o położenia struktur mózgowych, jak również określenia wiązki promieniowania X podczas zabiegu operacyjnego (**Wykorzystanie danych a priori do segmentacji anatomicznych struktur mózgu**).*

Keywords: brain, computed tomography, image segmentation, a priori information.
Słowa kluczowe: mózg, tomografia komputerowa, segmentacja obrazu, informacja a priori

Introduction

Currently, stereotactic brain surgery relies heavily on computer planning of surgical accesses. These systems, using introscopic research data (such as CT, MRI, etc.) allow us to identify the most optimal (in terms of the least trauma) path of a surgical intervention. Development of computer planning systems is a challenge that includes both hardware and software levels.

One of the fundamental parts of a planning system is space of operation on which the calculation is made. This space is the volume of brain, elementary item which contains the value of invasiveness index corresponding to a specific anatomical structure. Building of such a volume according the introscopic data manually is a tedious task.

It is therefore necessary to carry out the automatic segmentation of brain CT slices based on a priori information about the disposition of anatomical structures. The solution to this problem is to allow reaching a higher level in the computer planning stereotactic neurosurgery.

The current state of art

Segmentation of digital images is a classic problem of discipline of image analysis. Above the automated segmentation process operates a huge number of researchers at different application areas [1-5]. One of the most socially-oriented and important areas is the segmentation of medical images of different nature. Examples of such image are slices, obtained by introscopic methods. These studies are among the most widely used. They clearly show the anatomical features of the structure of the internal organs (computed tomography, magnetic resonance imaging), and functional processes within the body (positron emission tomography, functional magnetic resonance imaging).

The problem of segmentation of tomographic slices is described in a large number of works [6-16]. So in [6] an approach is presented using a genetic algorithm for the segmentation of the prostate gland on CT slice. Genetic algorithm works with the segmented contour. The algorithm selects the best path based on the training set. The sample consists of sections, segmented manually. The paper [7] proposes an approach to liver segmentation. This process is based on segmentation of tomographic images using the threshold, and a priori knowledge about the shapes and the locations of organ. A similar approach, but for a wider range of structures are used in the [8]. In addition, the segmentation results are presented not only for individual tomographic slices, but also for the whole volume.

Of particular interest are the works related to the segmentation of brain structures [9-17]. This is due, primarily, with the fact that during brain surgery is largely used stereotaxis [18]. Because for stereotactic interventions at the deep structures of the brain need information about personalized anatomical structure.

For example, in [9] an approach is illustrated for the segmentation of multimodal MRI brain sections based on (T1 and T2) to the elements of white and grey matter.

At the same time, the work [10] is aimed at segmentation of cancer on MRI image using fuzzy classification. A completely different approach is used by researchers and presented in paper [11]. The segmentation process is done by deforming the known volume to the test volume.

The paper [12] analyzes the MRI image segmentation methods applied to multiple sclerosis. A huge number of papers are devoted to the development and use of segmentation techniques using anatomical atlases [13-17], it can be explained primarily by quality of segmented data. To test the developed segmentation methods, in [18] developed and proposed to use the Web resource that is based on the 40 segmented datasets.

The purpose and objectives of the study

Automated segmentation of the anatomical structures of the brain is an important component in the construction of software and hardware for medical purposes, including computer systems for surgical procedures planning. The main objective of this work is to improve the quality of the preparation and conduct of neurosurgical intervention, using the computer-aided analysis of medical images, namely the segmentation process.

It will be appreciated that the tomographic image segmentation process is a complex process, so it was decided to use the additional step of classification to facilitate the work [19].

Thus, the main objective was the segmentation of anatomical structures at the tomographic slices of CT studies.

Development of the method of segmentation

As the initial data CT-slices of the human brain were used. These tomographic slices were obtained with the Toshiba Aquilion 16 machine with the following parameters: X-ray tube voltage KVP = 120 kV, tube current AI = 300 mA. All data presented in DICOM format, with the HFS position (that corresponds to the position on the back with the head forward – Head First Supine). CT slice example is shown in Fig.1.

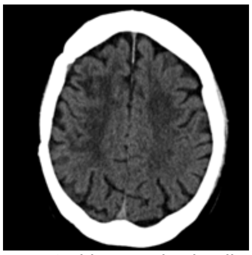

Fig.1. Example of segmented human brain slice

The whole segmentation process comprises sequential steps, which constitute a chain of CT-slice analysis (Fig. 2). The initial image processing steps correspond to the main stages in the [19] up to the classification of CT slices.

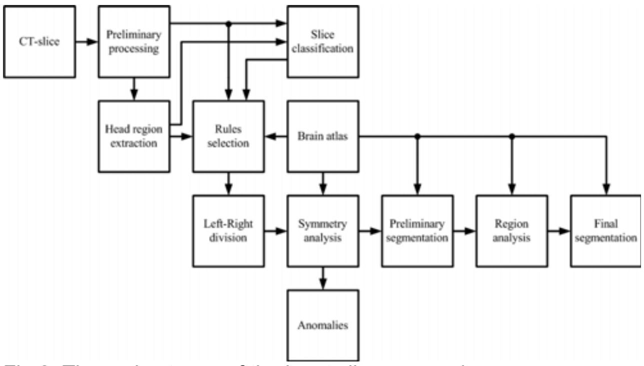

Fig.2. The main stages of the input slice processing

Thus, the data from the classification unit, along with the information about region and the relevant atlas is supplied to the block of rule selection. This block, based on the segmented level (class), selects and applies rules from the brain atlas, in relation to the investigated region. In the next stage, the division of an image into two parts – left and right hemisphere of the brain. These data are subject to further analysis on the symmetry; if there are significant deviations we get an abnormal result. Otherwise, a preliminary segmentation is performed, after which the obtained area will be analyzed. The last stage is the stage of the final segmentation.

Let us consider each of these steps in more detail. Rule selection unit is one of the fundamental. For a particular class of tomographic slices, proceeding from anatomical atlas as shown in Figure 3, the component composition of segmented structures in the image was defined.

Fig.3. An example brain slice in anatomical atlas [20]

The rules, in turn, relate to the anatomical atlas and define the binding of structures to the each other.

Isolation of the left and right side of the analyzed areas is necessary for the subsequent segmentation separately the right hemisphere from the left, and to anomalies determination in the tomographic images. In turn, this step can be divided into two parts (Fig. 4.).

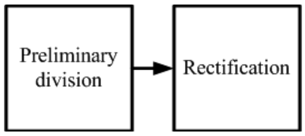

Fig.4. Stages of searching of line of symmetry

Pre-split is based on a segmented area of the bounding box (Fig. 5.):

(1) $$D_x = \frac{\max_x + \min_x}{2},$$

where D_x – coordinate of line of pre-splitting; $\max_x$, $\min_x$ – the position of the left and right side of the bounding box.

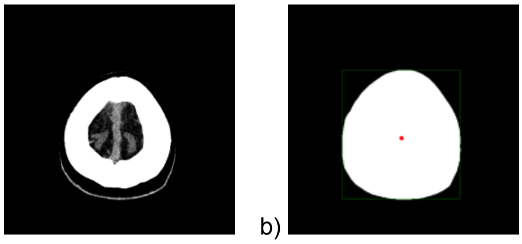

Fig.5. Tomographic slice – a) and the corresponding segmented region – b).

Refinement of the partition line is performed by calculating the luminance profile (Fig.6.) on the image (along the abscissa). The maximum value of the intensity corresponds to the line of the partition (within 1–2 cm from the original position).

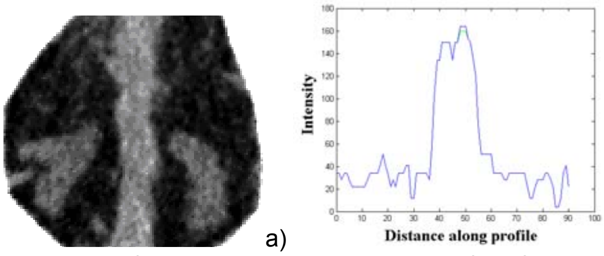

Fig.6. Part of tomographic slice and their profile of brightness, which crosses the partition line.

The symmetry analysis consists in comparing (Fig. 7) of histogram (2) of the left (H_l) and right (H_r) images using the following expression (3):

(2) $$H_l(I(x,y)) = \frac{\sum_y \sum_x 1 \,|\, I(x,y) \in L}{count(L)};$$
$$H_r(I(x,y)) = \frac{\sum_y \sum_x 1 \,|\, I(x,y) \in R}{count(R)},$$

(3) $$D = \sum_i (H_l - H_r),$$

where D – integrated indicator of the consistency of the left and right side of the image.

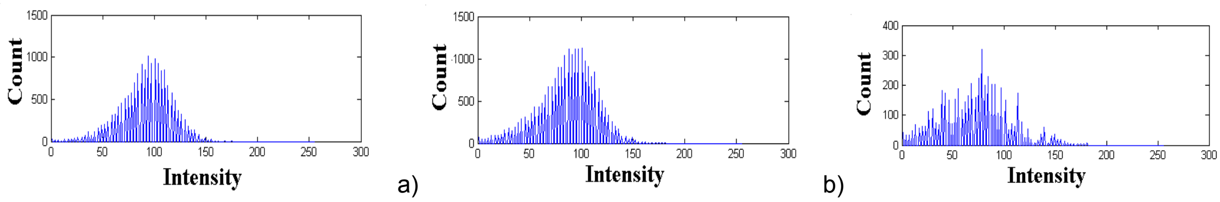

Fig.7. Samples of histograms of left (a) and right (b) sides of the image, as well as the module of their difference (c)

In the case of asymmetry of histogram of parts of the image (4) we carry out the calculation of anomalies.

(3) $$D > T_S,$$

where Ts – integral threshold of symmetry (calculated based on the stage of training).

Analysis for the presence of abnormal areas is carried out by comparing the histograms areas (Fig. 8) of analyzed tomographic slice with the "normal" tomographic slice. Here we use analogous expressions (2–4), as with the analysis of symmetry. The number of areas of the partition corresponds to a specialized tomographic level.

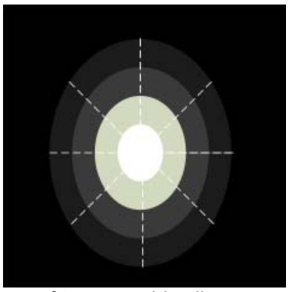
Fig.8. Analyzed areas of tomographic slices

The model uses a set of concentric ellipses [19] (5):

(5) $$\frac{(x-x_c)^2}{a^2}+\frac{(y-y_c)^2}{b^2}=1$$

where a, b – axis of the ellipse, x_c, y_c – center of ellipse.

Semiaxes of the outer ellipse, and the center coordinates of the ellipse are calculated based on the bounding box (the coordinates of the upper left and lower right corners equal $\min_x$, $\min_y$, $\max_x$, $\max_y$).

(6) $$a=\frac{(\max_x-\min_x)}{2}$$

(7) $$b=\frac{(\max_y-\min_y)}{2}$$

(8) $$x_c=\min_x+a$$

(9) $$y_c=\min_y+b$$

If there is symmetry, then the next phase we perform a preliminary segmentation. This step consists in partition of the space in accordance with the anatomical atlas. Moreover, splitting elements are regions with the considerable size namely lobes of the brain, falx cerebri, cerebral ventricles, midbrain, cerebellum etc.

Each area is divided into a specified group, which correspond to the anatomical structures. The initial data for the partition are densitogram and histogram indicators of researched areas.

Results and discussion

Data for the study was CT slices of 5 people. Fig. 9a shows the original slice. Also on the image shows the expected line of symmetry, which is used for the pre-separation. Fig. 9b shows only region of the brain (after the isolation of bone structures and their cut-off) with refined line of symmetry.

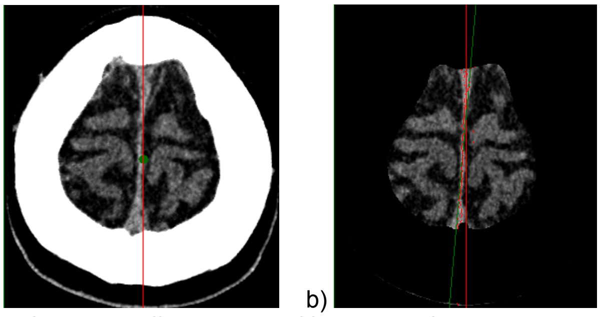

Fig.9. CT slice at different stages of finding line of symmetry

Symmetry line was built according to the maximums of brightness profiles (Fig. 10). For this purpose, we used a linear regression algorithm:

(10) $$\begin{bmatrix} a \\ b \end{bmatrix}=\frac{1}{n\sum_{i=1}^{n}x_i^2-\left(\sum_{i=1}^{n}x_i\right)^2}\begin{bmatrix}\sum_{i=1}^{n}y_i\sum_{i=1}^{n}x_i^2-\sum_{i=1}^{n}x_i\sum_{i=1}^{n}x_iy_i \\ n\sum_{i=1}^{n}x_iy_i-\sum_{i=1}^{n}x_i\sum_{i=1}^{n}y_i\end{bmatrix},$$

where x_i, y_i – coordinates; a, b – coeficients of line $y = a + bx$.

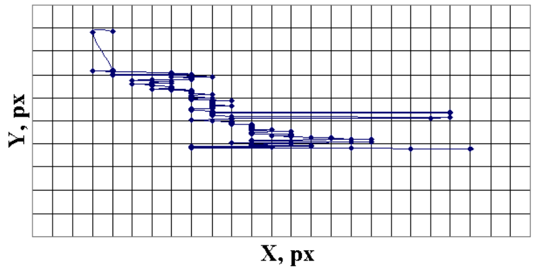

Fig.10. Illustration of high intensity search on the CT-slice

Based on the line, we have implemented partitioning of the study area on the area of the right and the left hemisphere (Fig. 11a). Also we received region of the falx cerebri by clarifying (Fig. 11b).

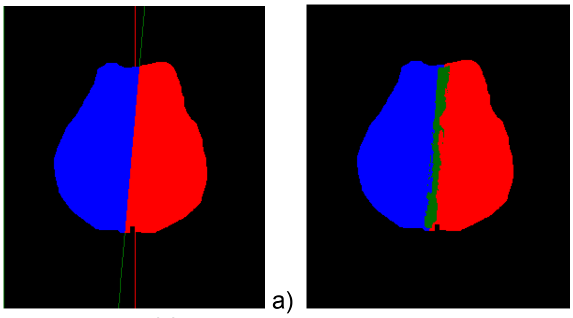

Fig.11. Example of CT slice segmentation

Based on data from the tomographic atlas we perform pre-partition to the region of the frontal and parietal lobes of the brain (Fig. 12a).

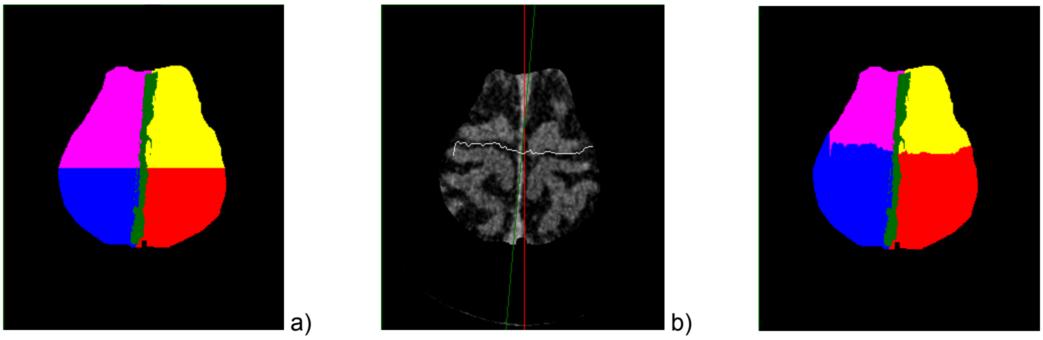

Fig.12. An example of the wide figure inserted into the text

With the use of modified algorithm of active contour, we perform search the optimal partition in the frontal and parietal lobe (Fig.12b). Based on the line of the partition we have refined the field of anatomical structures (Fig. 12c).

Partitioning corresponds to the manually segmented slices on 90%. But at the same time, it should be taken into account, at the levels of midbrain the quality of the segmentation is about 60%, which is not sufficient.

Conclusions

In the course of the study examined current issues and approaches to segmentation of tomographic slices, in general, and in especially the brain. It is also we propose approach to segmentation of anatomical structures of the human brain, which is based on the use of a priori information about the tomographic slice. The basis for this a priori information is the method of classification of CT slices depending on the level of its location. Partially we resolved the issue of automatic segmentation of anatomical structures on CT slices of the human brain. These results indicate the need for further development and testing of developed methods.

Also, the main promising direction is the inclusion of emerging approaches to the planning computer system of the interventions on the brain.

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