Algorithm for the Detection of Mid-Brain in B Mode Ultrasound Images

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Introduction. Transcranial sonography (TCS) is a relatively novel imaging method, which is frequently used in neurology. This procedure visualizes brain structures non-invasively by using ultrasound waves. A possibility of diagnosing a Parkinson’s disease by using TCS is mentioned in many publications [1, 2]. B mode TCS allows the user to visualize brainstem and surrounding structures. Visualized mid-brain has a shape of a butterfly. Mid-brain visualization by TCS allows doctors to evaluate *substantia nigra* structure changes, which are common for Parkinson’s disease. During the degeneration process, that is related with Parkinson’s disease, oxygen is overproduced and minerals (mainly iron) are stored in dopaminergic neurons. Due to these degenerative processes, the dopamine neurons are becoming extinct in *substantia nigra*. Ultrasound reflections can be used for visualization of these changes [3]. However spatial resolution of TCS images is limited, since the temporal bone, through which scanning is performed, distorts ultrasonic beam. Currently, during the clinical examination, mid-brain area is marked manually by expert-neurosonographer. The marked contour is not always precise and that depends on expert’s experience. Time can be saved by making this step automatic as well as the inexperienced experts can be trained to outline the mid-brain area in ultrasound images. The automated algorithm for midbrain segmentation was developed recently [4], but it requires manual intervention of operator for the placement of seed shape. The mid-brain area detection could allow whole process of segmentation and evaluation to be automatic. This paper presents an algorithm for the detection of midbrain area in B mode ultrasound images.

Materials and Methods. For the development and testing of the algorithm 43 ultrasound images that were obtained during clinical study in Lithuanian University of Health Sciences clinics of Neurology (expert neurosonographer dr. Kristina Laučkaitė) were used.

All obtained TCS images are 800 × 600 pixel resolution (isotropic pixel size 0.0421 mm). Mid-brain area contours manually marked by experienced expert neurosonographer were used to verify the created algorithm. Typical B mode ultrasound image with marked mid-brain region is shown in Fig. 1.

The proposed algorithm is based on the assumption that the shape of the midbrain is close to constant, but it differs in width, length and orientation. The template matching was chosen as a method for the detection of mid-brain region. The template was adjusted in terms of scale and orientation during the matching procedure. The scheme of the proposed algorithm is presented in Fig 2.

Fig. 1. Ultrasound image with outlined mid-brain region

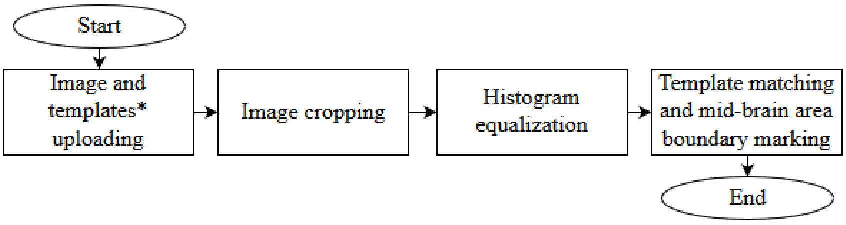

Fig. 2. Scheme of the main algorithm applied for the detection of mid-brain region

The initial template was made by obtaining average, the most probable, shape by using Procrustes method [5]. Manual delineations made by experienced expert served for the purpose. The shape was obtained taking the average of collected shapes.

To increase algorithms adaptability to the slight anatomical variations of the size and orientation of midbrain, family of the templates was created by varying templates scale s and rotation α through an affine transform. The transform for single pixel spatial coordinates could be defined as follows:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = s \cdot \begin{bmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{bmatrix} \cdot \begin{bmatrix} x \\ y \end{bmatrix}, \tag{1}$$

where x' – transformed x coordinate, y'– transformed y coordinate, x – original coordinate of template, y – original coordinate of template. The algorithm of the template family creation is shown in Fig. 3.

The most probable rotation angle range -9° to 18° with a step of 1° and range of scale 70% – 140% with a step of 10% were determined. The statistical ranges of typical orientation and size of the midbrain contours was obtained analysing set of shapes outlined by physician. The statistics of typical size range and extension of midbrain was employed for the reduction of field of search and speeding up computations. The crop area, where the mid-brain usually appears, was determined (see Fig. 4).

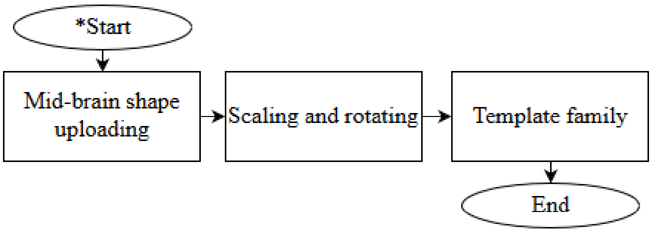

Fig. 3. Scheme of the template family creation algorithm

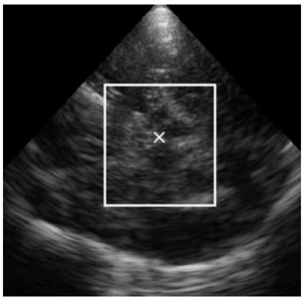

Fig. 4. B mode image of mid-brain together with crop region and statistical center point

The region of midbrain in the images is of relatively lower echogenicity to compare with the surroundings, so the inner area of the contour is relatively dark and the outer – brighter. Taking into account these considerations three different templates were made and tested developing the algorithm (see Fig. 5.): outer and inner region template (a), inner area template (b), gradient of mid-brain contour template (c).

Template a) uses two regions around mid-brain contour: outer that is brighter and inner that is darker. Both regions are 1-2 pixels width. Template b) uses only inner area of mid-brain contour. Template c) uses contour gradient components *dX* and *dY* information of mid-brain. This requires double computational time as template calculates match of *dX* and *dY* gradient directional components and takes average.

The dynamic range of TCS images intensity depends on the properties of the temporal bone and in some cases (for the subjects having poor acoustic window) the range is used inefficiently and the images look dark. Therefore cropped image histogram was modified. Two methods were tested for the purpose: equalization using cumulative distribution function (CDF):

$$h_{x,y} = \frac{\sum_{i=0}^{2^{bpp}} p_i}{TP} \times 2^{bpp}, \tag{2}$$

where $h_{x,y}$ – equalized histogram pixel value at x, y coordinates, TP - total number of pixels in the image, $\sum_{i=0}^{2^{bpp}} p_i$ – cumulative distribution function which is adjusted by stretching histogram values through whole range 1–255.

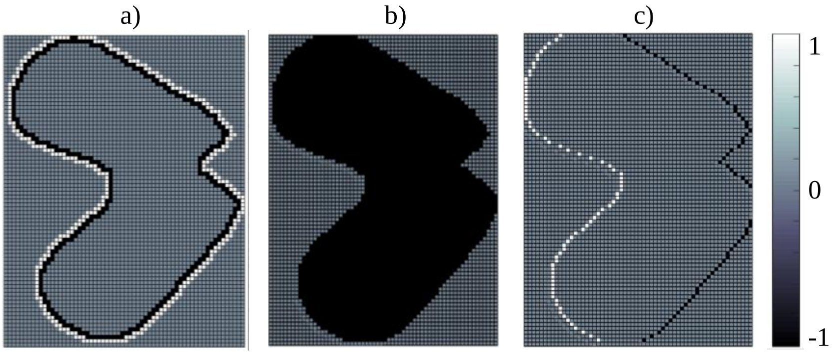

Fig. 5. The templates tested developing the algorithm: outer and inner region template (a); inner area template (b); gradient (example presents the *dX* component) of mid-brain contour template(c)

Second method only adjusts histogram values through whole range without equalising pixel values evenly:

$$h_{x,y} = \frac{h1_{x,y} - h1_{\min}}{h1_{\max} - h1_{\min}} \times 2^{bpp}, \tag{3}$$

where $h1_{x,y}$ – histogram pixel value at x, y coordinates, $h1_{\min}$ – minimum pixel value, $h1_{max}$ – maximum pixel value, 2^{bpp} – histogram range (bits per pixel), $h_{x,y}$ – adjusted histogram pixel value.

Template matching method shifts a template and matches it in every possible spatial position. The match for each position had been estimated by normalized cross-correlation coefficient:

$$r = \frac{\sum_i [(x(i) - mx) \times (y(i-d) - my)]}{\sqrt{\sum_i (x(i) - mx)^2} \sqrt{\sum_i (y(i) - yx)^2}}, \tag{4}$$

where mx – average pixel value of template, my – average pixel value of matching region , d – template shift.

Algorithms accuracy was measured by calculating overlapping area between region detected by algorithm and the area defined by the expert via DICE coefficient:

$$DICE = \frac{2 \cdot |g \cap k|}{|g| + |k|}, \qquad (5)$$

where k is manually extracted area and g is automatically determined area.

Results. Original image cropping reduced the image size 90.9 times from 800 x 600 to 80 x 66 pixels.

Histogram equalization increased mid-brain area recognition by 5.12%.

The two regions around contour template showed the best fit (Fig. 5. a) template). This template was used in final version of the algorithm.

The results of correspondence of area detected by algorithm and delineations made by expert are presented in Table 1. Algorithm recognition was assumed as failed if overlap between algorithms recognized area and the area defined by the expert is less than 30%.

Table 1. Results obtained testing the algorithm

	Without rotation and without scaling	**With rotation**	**With rotation and scaling**
Algorithm's accuracy	67.86 % (± 16.15 %)	69.47 % (± 15.62 %)	72.29% (±12.89 %)
Accuracy and fail count	95 %, 2	95 %, 2	100 %, 0

Mid-brain segmentation algorithm was 88.47% ± 3.65 accurate when seed shape of mid-brain contour was placed manually [4] and 72.29% ± 12.89 when combined with created algorithm. Fig. 6. shows the comparison of algorithm output and expert's marking.

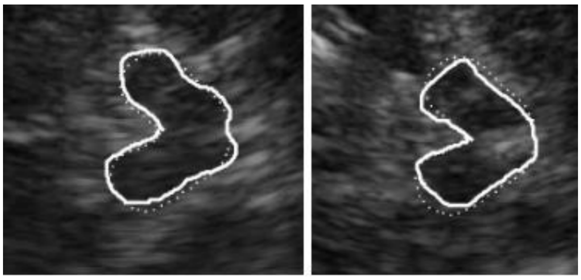

Fig. 6. Examples of algorithm results: solid line – expert's marking, dashed line – contour placed by algorithm

Conclusions and Future work. After implementing histogram equalization and creation of template family which accounts for different scale and rotation of mid-brain area, algorithm showed quite good results. Algorithm can automate the process of evaluation of the mid-brain area by substituting the manual mid-brain shape seeding. This algorithm can be used to train inexperienced experts to find mid-brain area as well. The algorithm marks the mid-brain borders inaccurately when mid-brain shape differs from average shape, this can be fixed by making template family more representative.

The algorithm is not fully optimized. Future work would require to use bigger training set. By acquiring time and accuracy graph, exact values can be determined how many templates should be used. Calculation of the optimal angle step and optimal scale step between templates would increase algorithms efficiency. Implementation of a warning that should appear when algorithm might not correctly detected min-brain area would be useful. This could be done by setting appropriate threshold value of the cross-correlation coefficient when the match is not that high.

References

1. Mehnert, S., Reuter, I., Schep K., Maaser, P., Kaps, M. "Transcranial sonography for diagnosis of Parkinson's disease." *BMC neurology* 10.1 (2010): 1.
2. Kim, JS., Oh, YS., Kim, YI., Koo, JS., Yang, DW., Lee, KS. "Transcranial sonography (TCS) in Parkinson's disease (PD) and essential tremor (ET) in relation with putative premotor symptoms of PD." *Archives of gerontology and geriatrics* 54.3 (2012): e436-e439.
3. Kolevski, G., Petrov, I., Petrova, V. Transcranial Sonography in the Evaluation of Parkinson Disease. Journal of Ultrasound in Medicine : Official Journal of the American Institute of Ultrasound in Medicine, Apr, 2007, vol. 26, no. 4, pp. 509-512. ISSN 0278-4297; 0278-4297.
4. Sakalauskas, A., Laučkaitė, K., Lukoševičius, A., Rastenytė, D. Computer-aided segmentation of the mid-brain in trans-cranial ultrasound images. Ultrasound in medicine & biology, 2016, 42.1: 322-332.
5. Ross, A. "Procrustes analysis." Course report, Department of Computer Science and Engineering, University of South Carolina (2004).

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This paper presented an algorithm for the detection of the mid-brain in B mode ultrasound images. Template matching is used to detect and mark the mid-brain area. Templates are created by changing scale and orientation of average mid-brain region outline, which is made by using Procrustes analysis and statistical methods on 43 mid-brain contours markings made by an expert. The algorithm process the original image by cropping it and equalizing histogram. The normalized cross-correlation is used to match the mid-brain contour. The results of the algorithm showed that it can be used to automate the process of evaluation of the mid-brain area. The results showed that created algorithm detects mid-brain area in most of the cases.