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● *Original Contribution*

COMPUTER-AIDED SEGMENTATION OF THE MID-BRAIN IN TRANS-CRANIAL ULTRASOUND IMAGES

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Abstract—This paper presents a novel and rapid method developed for semi-automated segmentation of the mid-brain region in B-mode trans-cranial ultrasound (TCS) images. TCS is a relatively new neuroimaging tool having promising application in early diagnosis of Parkinson's disease. The quality of TCS images is much lower compared with the ultrasound images obtained during scanning of the soft tissues; the structures of interest in TCS are difficult to extract and to evaluate. The combination of an experience-based statistical shape model and intensity-amplitude invariant edge detector was proposed for the extraction of fuzzy boundaries of the mid-brain in TCS images. A statistical shape model was constructed using 90 manual delineations of the mid-brain region made by professional neurosonographer. Local phase–based edge detection strategy was applied for determination of plausible mid-brain boundary points used for statistical shape fitting. The proposed method was tested on other 40 clinical TCS images evaluated by two experts. The obtained averaged results of segmentation revealed that the differences between manual and automated measurements are statistically insignificant ($p > 0.05$). (E-mail: andrius.sakalauskas@ktu.lt) © 2015 World Federation for Ultrasound in Medicine & Biology.

Key Words: **B-mode ultrasound, Edge detection, Local phase, Midbrain, Statistical shapes.**

INTRODUCTION

The problem of limited resolution is quite common in ultrasonic medical examination, as ultrasonographic image quality is key for reliability in diagnostics (Sakalauskas et al. 2013). Segmentation of the regions of interest is strongly under the influence by the quality of data in ultrasonic imaging (Noble and Boukerroui 2006). Limited, variable spatial resolution and contrast and speckle noise are the barriers constraining possibilities to accurately detect boundaries of the regions of interest in images, which makes the segmentation of ultrasound images a challenging and non-trivial task. Trans-cranial sonography (TCS) is a B-mode-based method of trans-skull brain sonography, which was recently applied as a supporting diagnostic tool for the clinical diagnosis of idiopathic Parkinson's disease (PD; Berg et al. 2008; Laučkaitė et al. 2012). The TCS was introduced by G. Becker et al. (1994, 1995) and later widely investigated by Daniela Berg and her scientific group (Berg et al. 2008). The internal structures of the mid-brain (the substantia nigra and raphe nuclei) served as biomarkers of PD and depression. PD diagnostics and screening are the main recommended application of TCS today (Berardelli et al. 2013).

In the retrospective study performed in Kaunas (Laučkaitė et al. 2012), the sensitivity (94.3%) and specificity (63.3%) values of TCS in differentiating PD from the rest of the cohort were determined. These results indicate that the examination is a valuable tool for screening of elderly people for PD, but relatively low specificity limits the ability to apply TCS as a primary test for differential diagnosis of neurodegenerative movement disorders. Bouwmans et al. (2013) recently published results of prospective study where 196 patients with various neurologic disorders were examined by both TCS and single photon emission computed tomography. A clinical diagnosis established after 2-y follow-up served as a reference diagnostic standard in the study. Only 40% sensitivity and 61% specificity of TCS for PD were reported; for single photon emission computed tomography, the values were 66% and 88%, respectively. These findings are controversial given previously determined

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diagnostic accuracy values. However, in an earlier study performed by Mehnert et al. (2010), TCS was applied for PD patients and healthy controls. In total, 400 patients were examined by TCS (199 had clinical PD, 201 were healthy controls) and impressive values of 95% sensitivity and 96% specificity were established.

Trans-cranial scanning is performed through the pre-auricular temporal bone, and so the spatial resolution is much lower because of specific distortions. (Berg and Walter 2010) compared with the ultrasound images obtained during scanning of the soft tissue. Ultrasound waves are affected by attenuation and refraction in non-homogeneous layers of the skull bone, thus causing a de-focusing effect (Vignon et al. 2005). In addition, scanning is performed at a relatively low frequency range of ultrasound waves (1–4 MHz) because high frequency (>4 MHz) ultrasound cannot penetrate through the bone to the deep layers of the brain; spatial resolution is directly related to scanning frequency, which is inversely related to the penetration depth. Unfortunately, the perceptible improvement of spatial resolution is impossible because of the fundamental limits of TCS. The structures of interest (mesencephalic substantia nigra, red nucleus, nuclei raphe) usually are hardly recognizable in the obtained B-mode images because of missing or strongly diffused boundaries.

The limited quality of the images makes the diagnosis of neurologic disorders highly dependent upon the experience of the examiner. The inter- and intra-observer variability is noticeably poor in case of TCS (Sakalauskas et al. 2013; Školoudik et al. 2007). Školoudik et al. (2007) investigated the reproducibility of neurosonographic measurements, and it was found that only experienced sonographers are capable of reproducing the measurements, whereas the correlations between less-experienced operators were found to be unreliable. The authors concluded that automated programs for extraction and measurement of the structures of interest are desirable for TCS. Computer-assisted segmentation of the images could reduce raters' and ratings' variability, but currently there is no validated, efficient technique for the segmentation of brain structures in TCS B-mode images.

A comprehensive review of the algorithms proposed for segmentation of ultrasound images was presented by Noble and Boukerroui (2006). The authors reviewed segmentation techniques developed for the processing of echocardiographic, breast, prostate and intra-vascular B-mode ultrasound images and determined that the principle of deformable contour (active contours [Belaid et al. 2011a; Petroudi et al. 2012], statistical shape models [He and Zheng 2001; Yan et al. 2011] and level sets [Belaid et al. 2011b; Lin et al. 2003]) is the most frequently applicable for the fuzzy boundary detection in ultrasound because of its robustness and adaptability. Our group, in previous research (Sakalauskas et al. 2013), had developed an automated method for segmentation of structures of interest based on an active contour. Unfortunately, only moderate results were obtained because the applied intensity-based contour attracting external force was too weak for acoustic boundary shaping and detection in TCS images.

This paper presents an improved algorithm for the segmentation of the mid-brain region. In the present study, we propose to employ an anatomic prior and to use local phase congruency–based boundary detector with superior edge localization properties. The key advantage of a phase-based method is the invariance to amplitude, so the boundary can be detected even if contrast at the boundary is very low and spatially variable because of depth-dependent signal level degradation. Kovesi (1996) and Mulet-Parada and Noble (2000) were the first to pioneer successful approaches for image edge detection exploiting local phase congruency at different scales of imaging.

There are very few computer-assisted approaches for the segmentation of the brain structures in ultrasound images (Ahmadi et al. 2011; Engel and Toennies 2009a,b; Kier et al. 2007). Engel and Toennies (2009b) proposed a computationally complex two-component deformable model for the mid-brain and substantia nigra segmentation. Pilot approaches for the brain structures' segmentation in 3-D sonographic data (Plate et al. 2012) were recently published by Ahmadi et al. (2011), Pauly et al. (2012) and collaborators. Unfortunately, the availability of 3-D ultrasonic imaging is still limited in clinical practice due to costs and complexity in interpreting 3-D data. Chen et al. (2010, 2011, 2012) analyzed the texture of manually extracted mid-brain regions and found that the local features could be used for the automated evaluation of echogenicity in the midbrain region.

The aim of this paper is to present a new, fast method for computer-aided segmentation of the mid-brain area. The area of interest in trans-cranial ultrasound images has a characteristic shape; the term "butterfly-shaped midbrain" (see Fig. 1a) frequently is used. Taking into account this feature and the experience of professional neurosonographer, the statistical shape model (SSM) of mid-brain contour was constructed and fitted by the use of an amplitude-invariant local phase–based step edge detector.

METHODS AND MATERIALS

The aim of the developed method is to exploit the ultrasonic image properties and to employ the experience and anatomic knowledge of the neurosonographer to achieve a stable and precisely outlined boundary of the