Ultrasonics 53 (2013) 111–121

Contents lists available at SciVerse ScienceDirect

Ultrasonics

journal homepage: www.elsevier.com/locate/ultras

Automated segmentation of transcranial sonographic images in the diagnostics of Parkinson's disease

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ARTICLE INFO

Article history:
Received 9 August 2011
Received in revised form 29 March 2012
Accepted 15 April 2012
Available online 24 April 2012

Keywords:
Transcranial sonography
Image segmentation
Speckle noise
Averaging frames
Active contours

ABSTRACT

Images captured during routine clinical transcranial sonography (TCS) examination are of a low resolution, so can be confusing for diagnostic evaluations. Manual segmentation of brain structures (areas of the midbrain and substantia nigra (SN)) that are of special interest cause inter-observer and intra-observer variability, thus restricting the reliability of Parkinson disease (PD) diagnostics. This paper presents a new technique for automated segmentation applicable to low resolution sonographic images, and particularly to brain structures related to PD. The segmentation was performed by a modified shape-based active contour (AC) segmentation algorithm. In order to suppress the speckle noise and to improve the AC segmentation, a pre-processing technique based on the averaging of adjusted spatially varying TCS images is proposed. The latter technique was tested on clinical TCS images. The results of the automated segmentation were compared with the manual markings. Two experts on the 40 TCS images performed these markings. The comparison showed that an automated method is effective when segmentation of the midbrain is performed (averaged overlap between regions obtained automatically and outlined manually was 73.10 ± 7.45%). The results of the segmentation of the SN area showed that a sufficiently correct contour of this area could also be obtained, but the accuracy of the segmentation is related to the image quality. It should be emphasised that the main difficulty in evaluating the accuracy of automated segmentation of the SN was the indefinite "gold standard" (variation between the measurements of two experts with different experience was found). And, therefore, the diagnostic reliability of the proposed technique was inconclusive.

1. Introduction

The problem of limited resolution is quite common in ultrasonic medical sonography since ultrasonic image quality is decisive for reliability in diagnostics. In particular cases, limited resolution is an especially hard issue to solve, one of which is transcranial B – mode sonography (TCS). TCS is a diagnostic technique for supporting the clinical diagnosis of Parkinson's disease (PD) as was proposed in 1995, by Berg [1]. Initial results revealed that TCS has the potential to become a powerful tool in diagnostics of various neurological movement disorders. It is assumed that the early stages of PD can be diagnosed by using TCS [2]. But scanning of the deep brain structures through the skull bone inevitably causes specific problems with image quality, particularly when scanning a butterfly-shaped midbrain and the small areas of the midbrain called the mesencephalic substantia nigra (SN) where neurotransmitter dopamine is produced – the region of interest (ROI) during TCS examination. Hyperechogenicity of the SN in the cross-sections of the midbrain is thought to be a characteristic feature for PD patients in the B – mode TCS images. Several researches [1–3] had shown that the size of the echogenic SN area of PD affected patients was larger than in healthy people. It was shown also that hyperechogenicity of the SN area is found in up to 90% of patients with PD [1]. The majority of authors recommend diagnosing neurological disorder when the SN area exceeds 0.20 cm^2 (S_{SN} > 0.20 cm^2) [3].

Ultrasonic examination is quick, relatively cheap and harmless to the patient. However, one of the main drawbacks of TCS examination is a spatial resolution of TCS images that is much lower compared with the ultrasound images obtained during scanning of the soft tissue: an axial resolution obtained in TCS images is 0.7–1.0 mm and the lateral resolution is approximately 3.0 mm [4] at a 6–9 cm depth where the ROI structures are located, meanwhile, the resolution measured using soft tissue mimicking phantom is approximately 0.5–1.0 mm, 1.0–1.5 mm respectively

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http://dx.doi.org/10.1016/j.ultras.2012.04.005

(at the same depth and scanning frequency). The limited spatial resolution of images makes the diagnostics of neurological disorders dependent upon the experience of the examiner. The structures of interest are hardly recognizable in the obtained TCS images and only an experienced physician is capable of identifying and correctly interpreting the corresponding brain structures. Here automated image processing and segmentation tools are necessary for the assistance.

Three main factors affect TCS image quality. Firstly, the examination is performed through the preauricular temporal bone therefore, propagation of the ultrasound waves are affected by attenuation and refraction of non-homogeneous layers of skull bone, thus causing a defocusing effect [5]. Secondly, due to frequency-dependent skull bone attenuation and internal reflection, 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. Low frequencies used also limit spatial resolution of the TCS images. Last, but not least, the image quality affecting factor is noise. There are two sources of noise: acoustic and electronic [6]. Acoustic noise is the result of interference by ultrasound waves reflected from distributed scatterers in a non-homogeneous media. It is frequently called a speckle noise [7] and depends on interference conditions – mainly on the position of a transducer and scanning frequency. Electronic noise is random and appears in ultrasonic images, because the amplitude of noise, which is produced by the electronic circuits of the scanning system and amplitudes of echo-signals acquired from the deep layers of the brain is comparable, and noise level is increased during amplification of the echo-signals [6]. Speckle is the dominant noise compared with electronic noise. A suppression of the speckle noise is a priority task concerning denoising of the ultrasonic images. Due to the above-mentioned specifics, images acquired during routine clinical TCS examinations are quite confusing for the diagnostic evaluation of the ROI. Manual segmentation of the ROI structures causes inter-observer and intra-observer variability, thus restricting reliability of PD diagnostics. Automated segmentation of TCS images could reduce inter-observer and intra-observer variability, but there is no validated efficient technique for the segmentation of the brain structures in TCS images, which are of special interest in the clinical diagnostics of PD. Only a few computer-based attempts to perform the segmentation of midbrain structures could be found [8,9]. The segmentation of brain regions in TCS images is more complicated that of the segmentation of images obtained while performing ultrasonic examination of the abdomen or the heart, because the factors mentioned before cause missing or diffused boundaries [10]. Therefore, robust, adaptive and approximating methods should be used for the segmentation of TCS images. During the last decade several advanced methods were applied for segmentation of sonographic data. The active contour (AC) method is the most applicable for the segmentation of ultrasound images [10]. AC is a continuous spline defined within an image domain that is controlled under the influence of internal forces coming from within the spline itself and external forces computed from the image data [11]. Commonly, the AC uses primary edge (image gradient) information to derive external image forces that attract a shape-based contour to boundaries of a region to segment [12]. The contour is adapted to the boundaries despite holes or diffusions at the boundary. But a common drawback of the AC method is its dependence on the image gradient information that makes AC sensitive to the speckle noise, the cause of comparatively strong gradients in the ROI [11]. This shortcoming can be overcome by performing a pre-processing of the TCS images for suppression of the speckle noise and initializing a contour close to the boundary of the ROI to avoid getting stuck in local minima during convergence of the contour.

One quite effective technique proposed for suppression of speckle noise was spatial frame averaging [13]. It was noticed [13,14] that if an object is scanned from different spatial positions preserving the same scanning plane, and if the probe is translated at about a half of its width – acoustic noise in different frames could be concerned as random. In that case speckle noise in images is uncorrelated and could be suppressed by frame averaging. This method is similar to the time synchronous averaging technique known in the signal processing. Authors frequently indicate [13] that a multiplicative model of noise free image and locally correlated speckle noise in ultrasound images is more adequate, but because of the application of logarithmical transformation during processing of radio frequency signals it could be interpreted as additive [15] and, therefore, frame averaging could be applied. It should be pointed out that frame averaging also reduces electronic noise, which is random in all frames. Wavelet based digital filters [16,17], and anisotropic diffusion filters [18,19], were also proposed for reduction of the speckle noise influence in ultrasound images, but application of image filtering for noise suppression frequently causes the loss of important image details such as texture patterns, or blurring edges of an image [15].

The aim of this paper is to present new methods, developed for the pre-processing and segmentation of the TCS images that address the problems listed above, and to evaluate the accuracy on clinical PD diagnostic images.

This paper is organized as follows. Subjects and TCS scanning protocol are presented giving the raw material for image processing. Then a proposed pre-processing method based on optimized averaging of displacement-corrected spatially varying frames for suppression of the speckle noise in TCS images is described. At the next two sections the segmentation of the ROI structures – midbrain and SN area is presented applying modified AC algorithm on preprocessed images: there a method for midbrain detection is developed in order to initialize the proper contour for the AC segmentation automatically. The results and accuracy of the method evaluated by comparison between the contours obtained by the proposed method and manual markings performed by two experts for 40 TCS images are shown in Section 3. Finally, Section 4 presents discussion and concluding remarks.

2. Materials and methods

2.1. Subjects and scanning protocol

TCS of PD patients is the field of ultrasonic echography where the problem of segmentation accuracy and precision is especially actual and decisive for PD diagnostic possibilities. This implies the choice of subjects and images for the present development of pre-processing and segmentation methods. Altogether, forty subjects were examined during our research: twenty had clinically diagnosed PD. The mean age (±standard deviation) was 54.8 ± 14.77 years, range 20–80 years, 12 (60%) were male and 8 (40%) female, while 20 other healthy control subjects were matched-to-the PD group by age and gender. The cases were randomly selected from 131 eligible for TCS examination subjects: 20 cases from 71 with PD and 20 from 60 non-PD subjects. Approval from the Regional Ethical Committee of Biomedical Studies (Kaunas, Lithuania) was obtained to ensure the study was in accordance within the guidelines of the Helsinki declaration. Every adult subject provided a written agreement to participate in the study and, also, written permission to use the obtained images confidentially. This study was carried out in Department of Neurology, at the Hospital of Lithuanian University of Health Sciences (Kaunas, Lithuania).