Ultrasound in Med. & Biol., Vol. ■■, No. ■■, pp. ■■–■■, 2017

0301-5629/$ - see front matter

https://doi.org/10.1016/j.ultrasmedbio.2017.09.001

● *Original Contribution*

SPATIAL COMPOUNDING OF 3-D FETAL BRAIN ULTRASOUND USING PROBABILISTIC MAPS

Jorge Perez-Gonzalez,* Fernando Arámbula-Cosío, † Mario Guzmán,‡ Lisbeth Camargo,‡ Benjamin Gutierrez,§,¶ Diana Mateus,¶ Nassir Navab,¶ and Verónica Medina-Bañuelos*

* Neuroimaging Laboratory, Electrical Engineering Department, Universidad Autónoma Metropolitana, Iztapalapa, Mexico; † Biomedical Imaging Laboratory, Centro de Ciencias Aplicadas y Desarrollo Tecnológico, Universidad Nacional Autónoma de México, Mexico City, Mexico; ‡ Department of Fetal Medicine, Instituto Nacional de Perinatología, Mexico City, Mexico; § Department of Child and Adolescent Psychiatry, Psychosomatic and Psychotherapy, Ludwig–Maximilians–Universität, Munich, Germany; and ¶ Chair for Computer Aided Medical Procedures, Technische Universität München, Munich, Germany

(*Received* 11 *May* 2017; *revised* 12 *August* 2017; *in final form* 1 *September* 2017)

Abstract—A new method to address the problem of shadowing in fetal brain ultrasound volumes is presented. The proposed approach is based on the spatial composition of multiple 3-D fetal head projections using the weighted Euclidean norm as an operator. A support vector machine, which is trained with optimal textural features, was used to assign weighting according to the posterior probabilities of brain tissue and shadows. Both phantom and real fetal head ultrasound volumes were compounded using previously reported operators and compared with the proposed composition method to validate it. The quantitative evaluations revealed increases in signal-to-noise ratio ≤35% and in contrast-to-noise ratio 135% using real data. Qualitative comparisons made by obstetricians indicated that this novel method adequately recovers brain tissue and improves the visibility of the main cerebral structures. This may prove useful both for fetal monitoring and in the diagnosis of brain defects. Overall this new approach outperforms spatial composition methods previously reported. (E-mail: vera@xanum.uam.mx)   © 2017 World Federation for Ultrasound in Medicine & Biology. All rights reserved.

Key Words: **Ultrasound shadows, Support vector machine, Image fusion, Speckle reduction, Fetal brain, Spatial composition.**

INTRODUCTION

Ultrasound imaging has been widely applied to monitoring and diagnosis of several diseases, pre-operative modeling and computer-assisted surgery. In many cases, ultrasound (US) is preferred to other imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI), because it gives real-time feedback; is non–invasive, compact and portable; and is low in cost (Contreras Ortiz et al. 2012). This work focuses on the application of ultrasound in obstetrics, where it is used for estimating gestational age, fetal monitoring and diagnosis of a number of conditions, for example, placental insufficiency and congenital brain defects.

In this context, the fetal central nervous system (CNS) is one of the structures that undergoes the most important developmental changes during the second and third trimesters of gestation; these changes include brain size, union of the cerebellar hemispheres, development of the corpus callosum and increasing complexity of the cerebral cortex (Monteagudo and Timor-Tritsch 2009). Currently, a combination of examinations by specialists and US fetal head biometry is recommended in antenatal care to determine the health of the CNS. However, accurate biometric measurements are difficult to obtain, given that US images present several limitations, such as badly defined edges, multiplicative speckle noise, intensity variations and acoustic shadows.

One of the significant problems in the acquisition of fetal head US images is acoustic occlusion of the ultrasound waves (Timor-Trisch et al. 2004). A suitable extraction of the fetal brain volumes depends on acoustic beam penetration and tissue impedance. Most of the brain tissue has similar acoustic properties and impedance, but the fetal skull has higher impedance compared with soft tissue (Culjat et al. 2010). This phenomenon

Address correspondence to: Verónica Medina-Bañuelos, Neuroimaging Laboratory, Electrical Engineering Department, Universidad Autónoma Metropolitana, Iztapalapa, Ciudad de Mexico C.P. 09340, Mexico. E-mail: vera@xanum.uam.mx

causes the images to contain shadows and artifacts, especially in the second and third trimesters, as the cranial bones thicken and calcify during the gestation process. These changes, in turn, affect the appropriate identification of several fetal structures and the correct measurement of development indicators such as biparietal diameter, head circumference and cerebellar volume (Jardim and Figueiredo 2005).

To attenuate the ultrasound shadows and artifacts, this study focuses on the improvement of fetal head US images during the second and third trimesters of gestation. At this age, cranial calcification leads to partial acoustic occlusions, which make difficult the precise extraction of brain indicators and, consequently, may result in an inaccurate assessment of fetal health. A new spatial composition method is proposed that extracts information from several US fetal brain volumes. It allows characterization of the acoustic parameters of brain tissue in areas where cranial occlusion is present. This information may then be used to mitigate the effect of occlusion on image quality. This approach is based on the automatic classification and probabilistic estimation of brain tissue and shadow areas from multiple US projections.

Related work

Numerous physical or computational approaches have been proposed to improve the quality of US acquisitions. The focus of this study is on image compounding methods, which combine information of different acquisitions to improve image quality and reduce noise.

There are two types of compounding methods: frequency and spatially based. Frequency compounding combines multiple images of the same object acquired at different frequencies, which has been reported to improve the signal-to-noise ratio (SNR), but affects axial resolution (Erez et al. 2008; Perperidis et al. 2015). In contrast, spatial compounding fuses several US images of the same region taken from different angles or transducer positions with the purpose of building a new image with enhanced contours, better SNR and attenuated artifacts, without negative effects on resolution. According to Contreras Ortiz et al. (2012), if N uncorrelated or partially correlated volumes are used in the composition, the reduction in speckle is of the order of $\sqrt{N}$ using coherent averaging.

Also, several authors have carried out spatial compounding using the mean operator and have reported SNR and contrast-to-noise ratio (CNR) improvements in US volumes of the female breast (Krücker et al. 2000), gall bladder of a healthy human (Rohling et al. 1997), atherosclerotic plaques (Jespersen et al. 2000; Kofoed et al. 2001) and bovine muscle and epidural space with warping (Groves and Rohling 2004; Tran et al. 2007). In another approach reported by Vogt and Ermert (2008), a combination of high-frequency ultrasound with a mechanical scan and multi-angle compounding for skin image acquisition is used.

Wilhjelm et al. (2004) performed an extensive visual and qualitative evaluation of composition operators based on mean, geometric and logarithmic mean, median, maximum values and root mean square; they reported that the mean is the operator that provided better results regarding SNR and CNR improvement when the number of projections used in the composition increases. Adam et al. (2006) found that the application of non-linear filters, such as adaptive anisotropic diffusion or Gaussian kernels, after the composition process by coherent averaging, significantly reduces the speckle noise; however, this can also attenuate edges.

Grau and Noble (2005) proposed a spatial composition method using multiscale information and phase-based image analysis for US heart compounding, achieving speckle noise reduction without a decrease in contrast on the main heart features. Rajpoot et al. (2011) presented a cardiac volume compounding strategy based on a wavelet-fusion approach that improves SNR and CNR. Gooding et al. (2010) investigated the benefits of fusing several 4-D heart US acquisitions, using different operators such as the mean, median, maximum values, wavelet transform and mean shift algorithms. They obtained noise reductions and contrast increases up to 50% compared with a single scan. Perperidis et al. (2016) employed an anthropomorphic left ventricle phantom to examine the interslice angular displacement and 3-D sector angular range on the elevational spatial compounding using the mean operator in cardiac ultrasound data.

Another compounding operator used is the weighted mean. zu Berge et al. (2014) published results of an orientation-aware compounding using confidence maps (Karamalis et al. 2012), which can compensate uncertainty in attenuated regions by estimating a per-voxel confidence in the information depicted by US volumes following a random walk framework. These maps can be used as weights to compound several US images. Preliminary results have been reported on the weighted mean composition of multiple 2-D simulated brain images contaminated by artificial multiplicative noise (Perez-Gonzalez et al. 2015).

These previous works focus mainly on enhancing image quality from multiple projections; however, the specific goal of recovering or estimating missing information in occluded areas is only partially solved. This work represents a new approach that has as its main aim dealing with the problem of acoustic occlusions in US volumes. The proposed method is based on the spatial composition of multiple projections accompanied by a suitable estimation of the posterior probability of tissue and shadows or artifacts. This method can be useful in building a new