Computers in Biology and Medicine 63 (2015) 99–107

Contents lists available at ScienceDirect

Computers in Biology and Medicine

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

Adaptive image inversion of contrast 3D echocardiography for enabling automated analysis

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ARTICLE INFO

Article history:
Received 21 January 2015
Accepted 12 May 2015

Keywords:
Contrast 3D echocardiography
3D echocardiography
Image inversion
LV segmentation
Histogram analysis

ABSTRACT

Introduction: Contrast 3D echocardiography (C3DE) is commonly used to enhance the visual quality of ultrasound images in comparison with non-contrast 3D echocardiography (3DE). Although the image quality in C3DE is perceived to be improved for visual analysis, however it actually deteriorates for the purpose of automatic or semi-automatic analysis due to higher speckle noise and intensity inhomogeneity. Therefore, the LV endocardial feature extraction and segmentation from the C3DE images remains a challenging problem.
Methods: To address this challenge, this work proposes an adaptive pre-processing method to invert the appearance of C3DE image. The image inversion is based on an image intensity threshold value which is automatically estimated through image histogram analysis.
Results: In the inverted appearance, the LV cavity appears dark while the myocardium appears bright thus making it similar in appearance to a 3DE image. Moreover, the resulting inverted image has high contrast and low noise appearance, yielding strong LV endocardium boundary and facilitating feature extraction for segmentation.
Conclusions: Our results demonstrate that the inverse appearance of contrast image enables the subsequent LV segmentation.

1. Introduction

Cardiovascular disease (CVD) is the leading cause of deaths worldwide [1]. To reduce the number of CVD mortality rate, it is necessary to have an efficient diagnostic method for timely detection and monitoring of disease status. For this purpose, cardiac imaging is frequently used by the cardiologist for the diagnosis of CVD and the study of cardiac structure as well as its function by automatic or semi-automatic analysis. Moreover, the segmentation of left ventricle (LV) endocardium or epicardium boundaries is an active area of research.

Among the cardiac imaging modalities, the echocardiography is generally accepted as a quick, non-invasive, cost effective and practical method for examining and exploring the cardiac structure as well as its function at rest and during stress. Real-time three-dimensional echocardiography (3DE) is a relatively recent addition to the echocardiography imaging scene [2] with success in providing more accurate and useful results. Despite the fact of being widely used in a large proportion of patients, the 3DE occasionally fails to produce diagnostically useful images [3]. The image quality is known to be affected by ultrasound physics and influenced by factors such as fat, rib spacing, ultrasound reflection angle, and lung breathing [3,4]. Therefore, the echocardiography suffers from intensity dropout, missing features and speckle noise. These artefacts may further lead to inaccurate assessment and anomalous interpretation of the cardiac structure. Fig. 1 presents some examples of 2D cross-sections from 3DE images with intensity dropout, where the arrows point to the missing anatomical structures.

To tackle these limitations, contrast enhanced 3d echocardiography (C3DE) scans are acquired as an alternative choice with relatively improved image quality for patients with poor acoustic window. In contrast echocardiography, the contrast agent drugs containing hyper-echoic micro-bubbles are injected intravenously. The ultrasound characteristics of these contrast agents are distinctly different from the blood and the cardiac tissue. The contrast agents intravenously mixed in the blood produce strong backscatter to the ultrasound waves, thus causing an increase in the echocardiographic signal and resulting in better image quality [6].

The concentration of micro-bubbles in the LV blood pool is much higher than in vessels of the cardiac muscles, thus resulting in inverted image appearance (see Fig. 2) compared with routine 3DE image and often provides a clear LV endocardium boundary

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http://dx.doi.org/10.1016/j.compbiomed.2015.05.009
0010-4825/

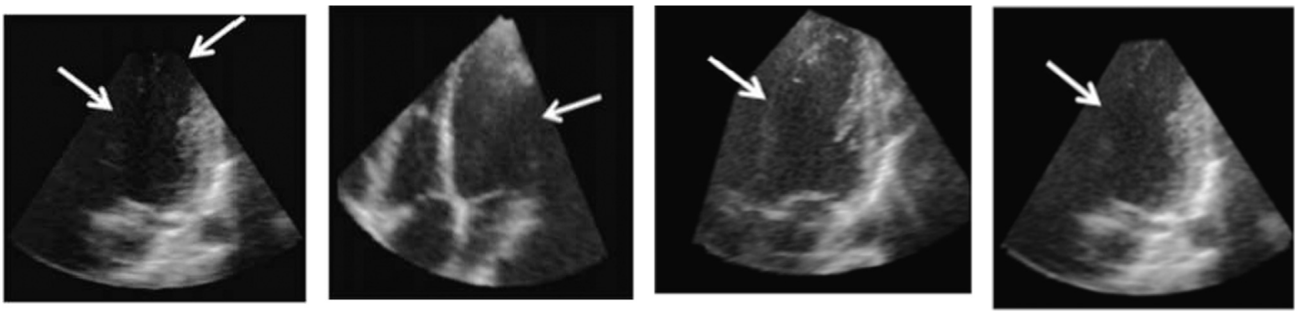

Fig. 1. The 2D cross-sections from 3DE images show example echocardiographs of heart taken from different transducer positions, where the arrows indicate intensity dropout and missing anatomical structures [5].

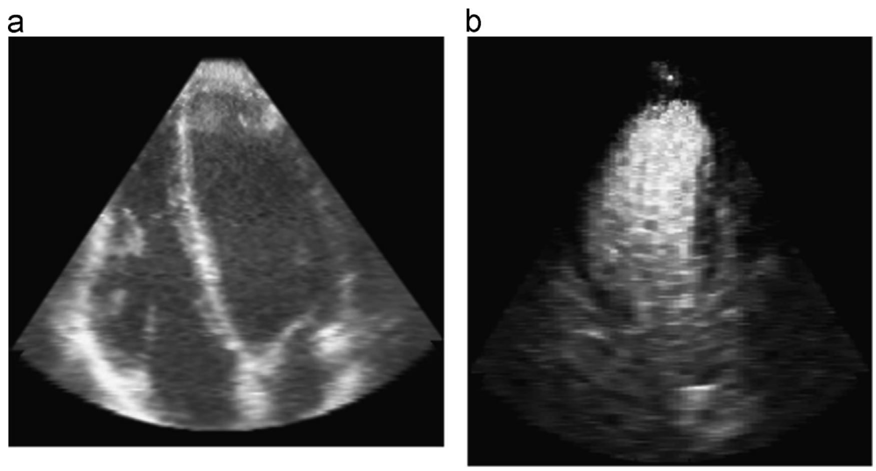

Fig. 2. Comparison of image appearance between (a) routine echocardiography and (b) contrast echocardiography. Note the inverted appearance.

[7]. The visual appearance of endocardial delineation is often improved in contrast echocardiography, thus enhancing the cardiologist's diagnostic ability. Cardiologists often choose the contrast images over non-contrast images, when corresponding non-contrast image quality is poor due to poor acoustic window.

Although the image quality in C3DE is perceived to be improved for visual analysis, it seems to deteriorate for the purpose of automatic or semi-automatic analysis due to high speckle noise and intensity inhomogeneity within the LV cavity. In the C3DE images, due to this inverted appearance compared to the 3DE, the LV segmentation methods proposed for 3DE images fail on the C3DE images. Moreover, the commercial software (QLAB [8] and TomTec [9]) do not presently support automatic or semi-automatic C3DE segmentation. Therefore, the LV endocardial feature extraction and segmentation from C3DE images remain challenging problems. In the previous literature, no considerable work has been done to address these issues. Hence, there is a genuine need for the exploration of C3DE pre-processing technique to enable automated image analysis.

The C3DE image analysis appears to face the following difficulties, due to image quality, which hinder the subsequent automatic or semi-automatic image analysis:

a) Contrast intensity inhomogeneity within the LV cavity, as a result of reflection and scattering of the ultrasound beam by many uncorrelated free moving contrast microbubbles (see Fig. 3(a)).
b) There is a relatively low contrast or slow intensity change between brighter LV cavity and the myocardium border (see Fig. 3(b)). This low contrast between myocardium border and the LV cavity can obstruct the traditional LV edge driven feature extraction.

This work proposes an adaptive automatic pre-processing technique for image inversion in which the new inverted representation of a C3DE image is constructed to overcome the above-mentioned difficulties. This inverted representation facilitates the further automatic or semi-automatic analysis.

This paper is organized as follows: Section 2 describes the relevant research work. Section 3 briefly elaborates the proposed work. Further, Sections 4 and 5 present and discuss the results, respectively. Towards the end, the paper ends with concluding remarks in Section 6.

2. Related work

To the best of our knowledge, there has been no previous work in the literature on C3DE pre-processing to assist in subsequent image analysis. However, considerable work has been done in ultrasound and echocardiography image enhancement. Zwirn and Akselrod [10] proposed a histogram based technique for the noise reduction in the echocardiographic images. They used an adaptive method of brightness transfer function to increase the spread of the grey level histogram in order to improve image quality. The obtained results were found to be better in contrast with richer grey-levels within the cardiac muscle. Tay et al. [11] presented a technique of speckle reduction and homogenisation in cardiac ultrasound images. In their method, image homogenisation is achieved by decreasing the pixel variation in the inhomogeneous region by an iterative method that smoothes at each iteration only outlying pixel values by local mean. Chang et al. [12] presented an image contrast enhancement technique which is based on a histogram transformation of local standard deviation. Their adaptive contrast enhancement algorithm has a