Ultrasound in Med. & Biol., Vol. 37, No. 4, pp. 605–616, 2011

0301-5629/$ - see front matter

doi:10.1016/j.ultrasmedbio.2011.01.010

● *Original Contribution*

LEFT VENTRICULAR BORDER TRACKING USING CARDIAC MOTION MODELS AND OPTICAL FLOW

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(*Received* 26 *April* 2010; *revised* 14 *January* 2011; *in final form* 14 *January* 2011)

Abstract—The use of automated methods is becoming increasingly important for assessing cardiac function quantitatively and objectively. In this study, we propose a method for tracking three-dimensional (3-D) left ventricular contours. The method consists of a local optical flow tracker and a global tracker, which uses a statistical model of cardiac motion in an optical-flow formulation. We propose a combination of local and global trackers using gradient-based weights. The algorithm was tested on 35 echocardiographic sequences, with good results (surface error: 1.35 ± 0.46 mm, absolute volume error: 5.4 ± 4.8 mL). This demonstrates the method's potential in automated tracking in clinical quality echocardiograms, facilitating the quantitative and objective assessment of cardiac function. (E-mail: k.leung@erasmusmc.nl) © 2011 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Three-dimensional echocardiography, Optical flow, Principal component analysis, Tracking.**

INTRODUCTION

Echocardiography is a commonly used, safe and noninvasive technique that allows assessment of left ventricular (LV) function. Real-time three-dimensional (3-D) echocardiography, which has gained much interest in recent years, allows noninvasive imaging of the whole left ventricle in a few seconds. Compared with other modalities such as magnetic resonance imaging and computed tomography, images made with ultrasound may be more difficult to interpret. This is mainly due to the presence of speckle noise, as well as ultrasound artifacts that often lead to poorly visualized parts of the cardiac wall (see Fig. 1). Misinterpretation in these areas may lead to inaccuracies in quantification. This makes the automated analysis of such images generally more challenging.

Due to the large amount of 3-D data acquired, there is an increasing demand for automated methods to analyze LV functional parameters, such as LV volume, accurately and objectively. Therefore, segmentation and tracking in 3-D and four –dimensional (4-D) (3D+time) echocardiograms has gained considerable attention (Noble and Boukerroui 2006; Leung and Bosch 2010). Common automated methods include deformable models (Gérard et al. 2002; Montagnat et al. 2003; Walimbe et al. 2006; Nillesen et al. 2007), level sets (Corsi et al. 2002; Angelini et al. 2005), active appearance and active shape models (van Stralen et al. 2007; Hansegård et al. 2007a), state estimation (Orderud et al. 2007) and clustering/classification (Sanchez-Ortiz et al. 2002; Papademetris et al. 2001; Georgescu et al. 2005; Yang et al. 2008).

In recent years, efforts have shifted towards tracking methods for evaluating left ventricular dynamics. Tracking methods can be based on deformation of surfaces (Yan et al. 2007) or on tracking image intensities. Most commonly used intensity-based tracking techniques include nonrigid registration (Ledesma-Carbayo et al. 2005; Myronenko et al. 2007; Elen et al. 2008), Bayesian techniques (Papademetris et al. 2001), template/block matching (Yeung et al. 1998; Helle-Valle et al. 2005; Kawagishi 2008; Duan et al. 2008; Linguraru et al. 2008) and differential optical flow (Sühling et al. 2005; Veronesi et al. 2006). Many researched and commercialized methods (Leung and Bosch 2010) make use of knowledge contained in the image itself or impose general regularization constraints to provide smooth motion estimates. Compared with other modalities, tracking in ultrasound images is especially challenging, due to the presence of speckle patterns and

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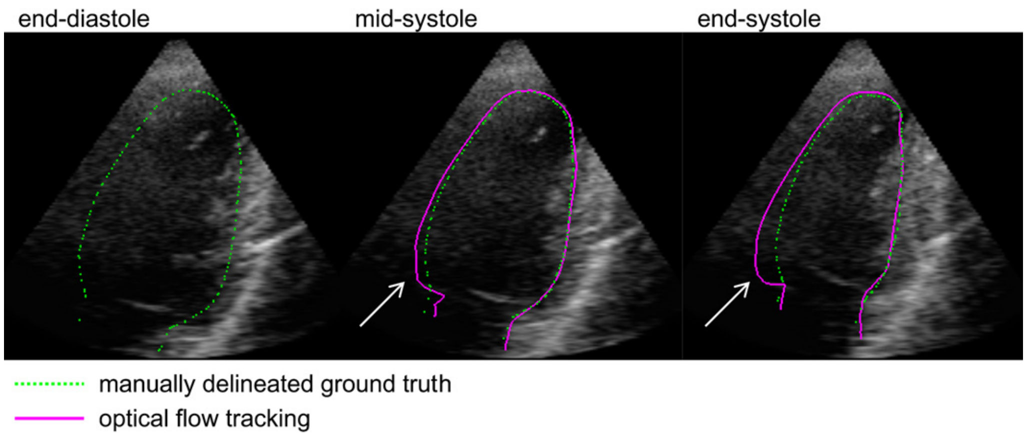

Fig. 1. Example of echocardiographic sequence (two-chamber view is shown), with poorly visualized cardiac wall in the anterior segments. Green dotted line denotes the manually delineated ground truth. Magenta solid line denotes optical flow tracking. Misinterpretation of the anterior wall (arrow) may lead to considerable inaccuracies in quantification.

ultrasound artifacts. It is our opinion that prior knowledge in the form of statistical modeling of cardiac motion will be of additional benefit for tracking left ventricular borders.

In this article, we aim at tracking the endocardial border through the cardiac cycle, given a manually delineated contour in end-diastole. Our proposed method is novel because it uses statistical modeling of cardiac motion as prior knowledge in a tracking framework. By using a statistical model, we incorporate realistic knowledge of cardiac function, derived from real patient data.

We make a distinction between spatial and temporal modeling of anatomical shape; this article addresses the latter aspect. In the medical imaging context, spatial variation is related to anatomical diversity across different patients, which can be used as priors in segmenting one 3-D image. Temporal variation captures the variability in an organ's shape due to physiologic activity. We use this knowledge to aid tracking throughout the cardiac cycle.

The proposed method consists of a *global* tracker which uses a *statistical model of cardiac motion* to ensure overall spatiotemporal consistency and a *local*, data-driven tracker for locally accurate tracking. We propose a combination, which emphasizes the advantages of each method: if the cardiac wall is obscured (see Fig. 1), we rely more on the global tracker, and if it is clearly visible, we rely more on the local tracker.

Previous work on optical flow

In this study, we choose to investigate optical flow. Optical flow based methods have previously been applied for motion analysis, modeling and tracking in ultrasound imaging. Most methods use the Horn-Schunck solution (Horn and Schunck 1981), which applies a global smoothness constraint on the motion field, or the Lucas-Kanade solution (Lucas and Kanade 1981), which assumes local motion consistency. For example, Mailloux et al. (1987) applied the Horn-Schunck solution to analyze two-dimensional (2-D) echocardiograms. Baraldi et al. (1996) compared three algorithms on synthesized ultrasound images and concluded that both Horn-Schunck and Lucas-Kanade approaches generated favorable results. LV wall motion was analyzed using the Lucas-Kanade method by Chunke et al. (1996). Mikić et al. (1998) first used optical flow for propagating contours throughout echocardiograms. Optical flow was used to initialize the contour in the subsequent frame, after which the actual contour detection was performed by active contours. More recently, Sühling et al. (2005) developed a combination of optical flow and b-splines for tracking in 2-D echocardiographic sequences. An application in 3-D echocardiography was described by Veronesi et al. (2006). In their paper, the Lucas-Kanade approach was used together with block matching to detect the long-axis of the left ventricle.

While optical flow has indeed been shown to be feasible in echocardiograms, it is important to realize that the method may fail if the structure to be tracked is poorly visible. This is often the case for clinical quality images; especially in 3-D, the large footprint of the transducer may hamper imaging between the ribs, causing considerable shadowing of the cardiac wall. In these areas, a plausible contour should be generated that is consistent with the expected cardiac motion and the remaining available image information. Statistical modeling provides an efficient way of modeling this cardiac motion.

Previous work on statistical modeling

Statistical modeling has been used in various ways for segmentation. Perhaps the most well known are those