Ultrasonics 50 (2010) 373–386

Contents lists available at ScienceDirect

Ultrasonics

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

Analysis of motion tracking in echocardiographic image sequences: Influence of system geometry and point-spread function

Basma Touil *, Adrian Basarab, Philippe Delachartre, Olivier Bernard, Denis Friboulet

CREATIS, CNRS UMR 5520, INSERM U 630, INSA-Lyon F-69621, France

ARTICLE INFO

Article history:
Received 28 April 2009
Received in revised form 6 August 2009
Accepted 7 September 2009
Available online 19 September 2009

Keywords:
Echography
Motion estimation
Decorrelation
Block matching
Bilinear deformable block matching
Cardiac motion
Echocardiography

ABSTRACT

This paper focuses on motion tracking in echocardiographic ultrasound images. The difficulty of this task is related to the fact that echographic image formation induces decorrelation between the underlying motion of tissue and the observed speckle motion. Since Meunier's seminal work, this phenomenon has been investigated in many simulation studies as part of speckle tracking or optical flow-based motion estimation techniques. Most of these studies modeled image formation using a linear convolution approach, where the system point-spread function (PSF) was spatially invariant and the probe geometry was linear. While these assumptions are valid over a small spatial area, they constitute an oversimplification when a complete image is considered. Indeed, echocardiographic acquisition geometry relies on sectorial probes and the system PSF is not perfectly invariant, even if dynamic focusing is performed.

This study investigated the influence of sectorial geometry and spatially varying PSF on speckle tracking. This was done by simulating a typical 64 elements, cardiac probe operating at 3.5 MHz frequency, using the simulation software Field II. This simulation first allowed quantification of the decorrelation induced by the system between two images when simple motion such as translation or incompressible deformation was applied. We then quantified the influence of decorrelation on speckle tracking accuracy using a conventional block matching (BM) algorithm and a bilinear deformable block matching (BDBM) algorithm. In echocardiography, motion estimation is usually performed on reconstructed images where the initial sectorial (i.e., polar) data are interpolated on a cartesian grid. We therefore studied the influence of sectorial acquisition geometry, by performing block matching on cartesian and polar data.

Simulation results show that decorrelation is spatially variant and depends on the position of the region where motion takes place relative to the probe. Previous studies did not consider translation in their experiments, since their simulation model (spatially invariant PSF and linear probe) yields by definition no decorrelation. On the opposite, our realistic simulation settings (i.e., sectorial probe and realistic beamforming) show that translation yields decorrelation, particularly when translation is large (above 6 mm) and when the moving regions is located close to the probe (distance to probe less than 50 mm).

The tracking accuracy study shows that tracking errors are larger for the usual cartesian data, whatever the estimation algorithm, indicating that speckle tracking is more reliable when based on the unconverted polar data: for axial translations in the range 0–10 mm, the maximum error associated to conventional block matching (BM) is 4.2 mm when using cartesian data and 1.8 mm for polar data. The corresponding errors are 1.8 mm (cartesian data) and 0.4 mm (polar data) for an applied deformation in the range 0–10%. We also show that accuracy is improved by using the bilinear deformable block matching (BDBM) algorithm. For translation, the maximum error associated to the bilinear deformable block matching is indeed 3.6 mm (cartesian data) and 1.2 mm (polar data). Regarding deformation, the error is 0.7 mm (cartesian data) and 0.3 mm (polar data). These figures also indicates that the larger improvement brought by the bilinear deformable block matching over standard block matching logically takes place when deformation on cartesian data is considered (the error drops from 1.8 to 0.7 mm is this case).

We give a preliminary evaluation of this framework on a cardiac sequence acquired with a Toshiba Powervision 6000 imaging system using a probe operating at 3.25 MHz. As ground truth reference motion is not available in this case, motion estimation performance was evaluated by comparing a reference image (i.e., the first image of the sequence) and the subsequent images after motion compensation has been applied. The comparison was quantified by computing the normalized correlation between the

* Corresponding author. Tel.: +33 472 43 87 81; fax: +33 472 43 85 26.
E-mail address: basma.touil@creatis.insa-lyon.fr (B. Touil).

doi:10.1016/j.ultras.2009.09.001

reference and the motion-compensated images. The obtained results are consistent with the simulation data: correlation is smaller for cartesian data, whatever the estimation algorithm. The correlation associated to the conventional block matching (BM) is in the range 0.45–0.02 when using cartesian data and in the range 0.65–0.2 for polar data. The corresponding correlation ranges for the bilinear deformable block matching are 0.98–0.2 and 0.98–0.55. In the same way these figures indicate that the bilinear deformable block matching yield a larger improvement when cartesian data are considered (correlation range increases from 0.45–0.02 to 0.98–0.2 in this case).

Contents

1. Introduction

Motion estimation of the left ventricle is a valuable tool for assessing cardiac function. Special attention has been paid to motion analysis in echocardiography, because of its high temporal resolution and its relatively low cost. However, the analysis of echocardiographic images is generally difficult because of the complexity of the echographic image formation process. Echographic images result from the elementary signals backscattered by the biological scatterers contained in the insonified tissue. Since the ultrasonic probe records the coherent sum of these signals, the image can be seen as resulting from an interference scheme, producing the speckle patterns commonly observed in ultrasound imaging. While speckle patterns are often regarded as noise (i.e., for tasks such as segmentation), they are used as information for motion estimation, since they provide natural tokens linked to the local configuration of scatterers in the tissue explored.

As a consequence, many approaches have been described that use this feature to estimate motion from echocardiographic image sequences. One of the first types of approaches described in the literature is based on the differential technique known as optical flow [1–3]. Since they rely on the local analysis of spatial and temporal gradients, these methods may fail at estimating large inter-frame cardiac motion. This implies multiscale strategies or a first stage of block-matching to provide a reliable displacement estimate [4–6]. Another approach estimates cardiac motion by performing speckle tracking, which is generally done by comparing a block in the reference image and a block in the subsequent deformed image through a similarity measure such as cross-correlation (CC) [4,5,7], the sum of absolute differences (SAD) [8] or the sum of squared differences (SSD) [9]. An interesting interpretation of these measures has been given by Strintzis [10], who formulated block matching as the maximum likelihood estimation of motion between blocks of known statistics. Maximum likelihood motion estimation is then shown to correspond to the maximization of SAD for Laplacian statistics and SSD in the case of Gaussian statistics. Using this framework, a new similarity measure was derived when the image was described through a multiplicative noise with a Rayleigh density. This line of reasoning has been pursued by Cohen [11], Boukerroui [12] and Linguraru [13], who incorporated this similarity measure for block matching.

The above-described approaches were based on conventional envelope-detected images, obtained through demodulation of the ultrasound radiofrequency (RF) signals. Some studies have proposed performing speckle tracking by using the RF signal to evaluate small displacements. Since the RF signal contains much higher frequencies, it is indeed better adapted to the estimation of small-scale motion (typically on the order of the emitted pulse wavelength). Examples of this type of study include the work by Lubinski [14] and more recently by D'hooge [15], who used speckle tracking to estimate the strain or strain rate in the myocardium. RF-based speckle tracking is, however, currently not widespread in the field of echocardiography because its high motion sensitivity implies high frame rates [15,16] and the difference in resolution in the propagation and transverse directions makes the 2D estimation of motion difficult. This extension to 2D is a challenge in terms of