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Influence of ultrasound speckle tracking strategies for motion and strain estimation

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A B S T R A C T

Speckle Tracking is one of the most prominent techniques used to estimate the regional movement of the heart based on ultrasound acquisitions. Many different approaches have been proposed, proving their suitability to obtain quantitative and qualitative information regarding myocardial deformation, motion and function assessment. New proposals to improve the basic algorithm usually focus on one of these three steps: (1) the similarity measure between images and the speckle model; (2) the transformation model, i.e. the type of motion considered between images; (3) the optimization strategies, such as the use of different optimization techniques in the transformation step or the inclusion of structural information. While many contributions have shown their good performance independently, it is not always clear how they perform when integrated in a whole pipeline. Every step will have a degree of influence over the following and hence over the final result. Thus, a Speckle Tracking pipeline must be analyzed *as a whole* when developing novel methods, since improvements in a particular step might be undermined by the choices taken in further steps. This work presents two main contributions: (1) We provide a complete analysis of the influence of the different steps in a Speckle Tracking pipeline over the motion and strain estimation accuracy. (2) The study proposes a methodology for the analysis of Speckle Tracking systems specifically designed to provide an easy and systematic way to include other strategies. We close the analysis with some conclusions and recommendations that can be used as an orientation of the degree of influence of the models for speckle, the transformation models, interpolation schemes and optimization strategies over the estimation of motion features. They can be further use to evaluate and design new strategy into a Speckle Tracking system.

1. Introduction

The analysis of the regional motion of the heart has proved to be of preeminent importance for the study of cardiac abnormal behavior. It currently plays an inarguable role in treatment and diagnosis of several pathologies, such as mitral regurgitation (Helmcke et al., 1987; Bargiggia et al., 1991), ischemia (Voigt et al., 2003), dyssynchrony (Suffoletto et al., 2006), myocardial quantification (McDicken et al., 1992; Amundsen et al., 2006; Nesser et al., 2009; Geyer et al., 2010) and diastolic dysfunction (Ommen et al., 2000). The estimation of the features that model regional motion can be done using different imaging modalities, dominant among them those based on ultrasound (US) acquisitions. Due to low cost and real time acquisition, echocardiography has become a widely used tool for motion and strain estimation, either using Doppler or non-Doppler techniques.

Despite its undeniable potential in many cardiac applications, Doppler techniques are limited by inaccuracies due to aliasing, frequency-dependent attenuation and, most importantly, the angle dependence in the assessment of tissue velocities. These limitations have prevented Doppler techniques from becoming a standard in daily praxis (Dandel et al., 2009). In contrast, non-Doppler techniques, generally known as *Speckle Tracking*, can estimate tissue velocities in the entire image while not suffering from aliasing and being angle independent (Trahey et al., 1988; 1987).

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The term *Speckle Tracking* (ST) refers to all those techniques that analyze motion by tracking the intensity or the interference patterns of the US data, known as *speckle*, along the temporal sequences. In the particular case when the motion is analyzed by tracking the speckle from the RF signal, these methods are referred to as Strain Imaging (O'Donnell et al., 1994; Konofagou and Ophir, 1998; Lopata et al., 2011). In what follows we will use the term ST in a global sense to denote all those methods that estimate the motion by tracking the speckle pattern in B-mode US acquisitions.

The phenomenon of the speckle can be explained by the physics of the problem of wave transmission in a tissue in US: it is produced by the reflection of the transmitted coherent ultrasound waves at fixed frequencies for different tissues. Since this pattern remains stable under the same acquisition conditions and exhibits an inherent relationship with the tissue structure, it can be tracked to estimate the motion of the tissue (Trahey et al., 1986; Burckhardt, 1978).

Many different approaches to ST can be found in the literature, where they have extensively proved to be powerful tools in order to obtain quantitative and qualitative information regarding myocardial deformation, motion and function assessment (Notomi et al., 2005; Crosby et al., 2005; Suffoletto et al., 2006). The clinical relevance of the motion estimation in US B-mode images has motivated the community to improve the original ST technique proposed in Robinson et al. (1982) and Trahey et al. (1988) by more complex approaches. New contributions modify the original techniques in different ways, such as the statistical modeling of speckle, using more complex registration algorithms or applying different optimization algorithms for the ST estimation. It seems clear that modifications in different steps of the process will have a different impact over the results. In addition, the influence of certain methods may obliterate the complexity of previous steps. For instance, the use of certain registration algorithms could make the process highly invariant to the similarity measure used. Thus, it becomes necessary to identify the relevant relations between the different components involved in a ST method in order to clarify which component really improves the accuracy of the estimation of motion and strain, and which ones become redundant. That is, precisely, the aim and motivation behind this work.

Some previous studies about the performance of ST methods can be found in the literature. One of the first ones was carried out by Bohs and Trahey (1991), where authors showed that a classical block matching registration together with the sum of the absolute differences –a quite simple similarity measure– could be used instead of the correlation, originally proposed by Robinson et al. (1982), achieving similar tracking results and better performance. Friemel et al. (1995) extended this study to include the non-normalized cross-correlation. Moreover, they showed that there was no statistically significant difference between the normalized cross-correlation and the sum of absolute differences at different signal to noise ratios.

In contrast to these early performance studies, in this work we propose a more global and complete approach. Instead of studying the influence of a particular improvement, we will analyze the system *as a whole*, similarly to what was done in De Craene et al. (2013) and Curiale et al. (2015) for different ST methods. However, in the proposed study, we are taking into account the relation between the steps and different choices taken to implement a ST method. The starting point is a prior identification of the basic parts of a ST method. The influence of the different techniques that can be used in each of these parts will be quantitatively analyzed. The techniques considered for the study are the following:

1. Different models for US data representation, some of them assuming an underlying statistical model for the speckle.
2. Different registration philosophies, including the classic block matching and a demons approach (Thirion, 1998).
3. Different interpolation schemes such as nearest neighbor, linear and cubic.
4. The use of structural information into the deformation model by using the normalized convolution (Knutsson and Westin, 1993) and a maximum likelihood approach such as the one proposed in Curiale et al. (2015).
5. The use of different optimization techniques, such as coarse-to-fine refinement or an efficient second-order minimization (ESM).

These techniques will not be independently analyzed since the influence of one over the other must also be taken into account and may provide useful insights for the development of novel ST methods.

This work presents two main contributions to the ST field. First, it provides a complete study to identify which are the components of a ST method with greater influence and impact over the motion and strain estimation accuracy. The second contribution is the methodology for the analysis of a ST system designed to provide an easy and systematic way to include other ST philosophies. The conclusions and recommendations obtained in this work are intended to serve as a reference about what can be expected when improving or introducing a new strategy into a ST system. We believe that new methodologies proposed for ST should not be analyzed isolatedly anymore, but in a holistic way considering the complete pipeline. Great improvements in certain steps of a ST method can be overpassed or undermined by the choices taken in further steps as we will show in the results of this work.

2. Background

Tracking the speckle patterns in US B-mode images was first reported by Robinson et al. (1982), where the authors introduced a method for determining the velocity of propagation of ultrasound in tissue by comparing individuals sectors from different transducer positions using the normalized cross-correlation. Inspired by this work, Trahey et al. (1988); 1987) proposed a novel technique of velocity imaging based upon measuring the direction and magnitude of local blood speckle pattern displacement in consecutive 2D B-mode images for blood flow detection. These displacements were estimated by using the most conceptually straightforward method, a block matching algorithm using the normalized cross-correlation as the similarity measure.

Some other metrics were proposed following the same block-matching methodology. Such is the case of Strintzis and Kokkinidis (1997), where a maximum likelihood (ML) methodology was used to provide a suitable metric for US images based on a multiplicative Rayleigh characterization. Strintzis and Kokkinidis (1997) showed that the classical ST method was improved when considering more adequate metrics. Likewise, Cohen and Dinstein (2002) extended the metric by including the relation between the multiplicative Rayleigh characterizations of consecutive frames, which resulted in a more accurate ST method. Those incremental improvements evidenced that a more detailed description of the speckle statistics provides more accurate ST methods when the block-matching methodology is adopted.

More elaborated ST approaches have been proposed to improve the ST focusing on the registration technique rather than the metric. However, it is important to remark that, though some registration or tracking techniques are used as a necessary step for ST, the speckle information present in US images should be coded into the similarity measure used for tracking. For instance, instead of the straightforward block matching, some authors proposed to introduce the speckle model into a Free-Form