

MOTION DECORRELATION IN ECHOCARDIOGRAPHY: ANALYSIS FROM A REALISTIC SIMULATION

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ABSTRACT

Echocardiography has been widely used to perform motion estimation in real time for heart function analysis. However, this imaging modality may induce a decorrelation between the real tissue motion and its ultrasonic speckle in the corresponding echocardiographic images. Most of the studies that investigate this problem are based on the assumption of a spatially invariant point spread function (PSF) which represents an oversimplification of the echographic acquisition process. Moreover, these studies use linear scanning which is not realistic in the context of echocardiography where the acquisitions are performed using sectorial probes. In this paper, we thus study the influence of echocardiographic equipment and acquisition geometry on the apparent motion through a realistic simulations using Field II. Contrary to the results obtained from an invariant PSF assumption, we show that decorrelation appears even in the case of a simple axial translation. Axial deformation is also studied and we show that the amount of decorrelation depends on the geometry of the probe.

Index Terms— Echocardiography, motion estimation, decorrelation, simulation

1. INTRODUCTION

Quantitative analysis of left ventricular deformation is a valuable tool for assessing cardiac function. The analysis of echocardiographic images is generally difficult due to the complexity of echographic imaging process and the high level of noise. In this context, different methods of motion estimation have been proposed. Such techniques are generally based on optical flow [1-3] block matching [4-6] or RF signal phase analysis [7]. In each approach, the support signal used to perform motion estimation corresponds to either the radio-frequency (RF) or the B-mode (BM) signal. The choice between these two signals clearly depends on the displacement magnitude to be recovered. Since the RF signal provides finer structures than the BM signal, some approaches [6,9] have suggested to use it in echocardiography for the analysis of small displacement (lower than the wavelength).

Unfortunately, these techniques suffer from the problem of motion-feature decorrelation, *i.e.* the difference between the

apparent motion present in the image and the real movement. This phenomenon has been recognized for a long time in related works [8,9]. In this context, simulations have been proposed in order to quantify such decorrelation as a function of the displacement type. Most of these simulations are based on the assumption that the image formation model is linear and invariant in space, which means that the underlying system PSF is spatially invariant. These studies generally introduce a further simplification by considering a linear probe. Unfortunately, such simulations appear to be far from realistic since the underlying PSF is known to be spatially variable and that sectorial probes are generally used in echocardiography, in order to have an acoustic access to the heart between the ribs. We thus propose in this paper a new simulation study using both linear and sectorial probe with dynamic focusing, making the corresponding PSF spatially variant.

The paper is structured as follow. In Section 2, we present the simulation model we used, along with the relative parameters. From this simulation, we study in Section 3 the decorrelation process for two particular displacements (a translation and an axial deformation) and for both linear and sectorial probes. The main conclusions of this work are given in Section 4.

2. SIMULATION

2.1. Simulation model

Most of the previous studies using simulations to assess motion in echocardiography [1,8,9,11] have used the linear system-based model initially proposed by Meunier [8] to generate US images. However, this model is valid only locally and cannot properly model the acquisition performed with a real echographic device, which implies beam forming (allowing dynamic focusing), apodization and sectorial geometry.

This lead us to perform the simulation of US images based on FIELD II [10], which provides an efficient tool to simulate ultrasound fields by incorporating realistic transducer features. The simulation of the ultrasound field is based on the computation of the spatial impulse response, including the excitation scheme (dynamic focusing and apodization). As a consequence, the simulated acquisition set-up may be seen as a system with a spatially variant PSF. The simulation requires choosing the parameters defining

the probe. We used a typical cardiac probe of which parameters are given in table 1. The output of a simulation consists in the RF image of the explored tissue. The BM images are obtained as the logarithm of the Hilbert transform of the resulting RF signal.

In each experiment, we use a rectangular tissue region having a size of 2.4×1.4 mm. These dimensions are of the order of the resolution cell. The region includes 50 scatterers, of which the spatial distribution is uniform and echogenicity follows a normal distribution. The resulting RF signal thus follows a Normal distribution and the corresponding BM image a Rayleigh distribution.

These parameters are used to simulate acquisitions with a linear probe and sectorial probe in order to compare the influence of the probe geometry on the echo images.

Parameters	Value
Transducer frequency	3 Mhz
Sound speed in tissue	1540 m/s
wavelength	0.256 mm
Sampling frequency	33 Mhz
Dynamic focalization	[15mm, 25mm, 35mm...100mm]
angle of increment (for sectorial)	0.7°
Number of active elements	64 (for sectorial) 64 (for linear)
Number of lines	64
Element height	14mm
Pitch (distance between two consecutive elements center)	0.3mm
Kerf (space between two consecutive elements)	0.05mm
Elevation focus	67mm

Table 1: The simulation parameters

2.1. Correlation measurement

Using the initial position of the scatterers (i.e. "before" motion), an initial image, I_0 , is simulated. A motion transformation T is then applied to I_0 , yielding the image I_1 .

I_1 will be used as a reference image, since it corresponds to the image that we would get if no decorrelation occurred. We then apply the same motion transformation T directly to the scatterers from which we generate a second image I_2 , which thus corresponds to the "real" echographic image after motion. The comparison of I_1 and I_2 thus allows us to measure the decorrelation introduced by motion.

We use the normalized correlation to compute this comparison measure. In the case of linear probe, the data are in Cartesian coordinates (x, y) . So we compute the correlation as:

$$corr = \frac{\sum \sum (I_1(x, y) - \bar{I}_1) \times (I_2(x, y) - \bar{I}_2)}{\sqrt{\sum (I_1(x, y) - \bar{I}_1)^2} \times \sqrt{\sum (I_2(x, y) - \bar{I}_2)^2}}$$

In the case of sectorial probe, the data are in polar coordinates (r, θ) and we compute the correlation as:

$$corr = \frac{\sum \sum (rI_1(r, \theta) - r\bar{I}_1) \times (rI_2(r, \theta) - r\bar{I}_2)}{\sqrt{\sum (rI_1(r, \theta) - r\bar{I}_1)^2} \times \sqrt{\sum (rI_2(r, \theta) - r\bar{I}_2)^2}}$$

\bar{I}_1 and \bar{I}_2 are the grayscale means of I_1 and I_2

3. EXPERIMENTS

3.1. Translation

The first experiment is based on an axial translation (i.e. along the central axis of the probe). This simple motion transformation represents a useful reference for our work. Most of the previous studies [8,9] indeed use a spatially invariant PSF to simulate echocardiographic image formation: by definition, translation yields no decorrelation with such PSF. As a consequence these studies do not consider translation.

3.1.1. Linear probe

We simulate images at first with a linear acquisition. In order to assess the influence of the spatial variations of the PSF, the experiments are performed for different depths D of the region relative to the probe. In Fig.1, we plot the resulting normalized correlation for RF (a) and BM (c) with respect to translation.

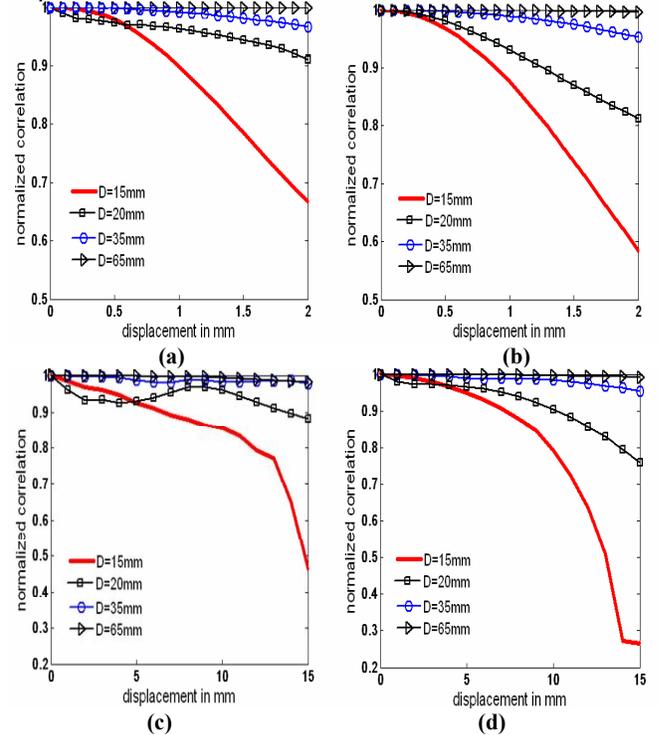


Fig.1. Normalized correlation in the case of translation **Column 1:** Result for a linear probe on the RF image (a) and on the BM image (c). **Column 2:** Result for a sectorial probe on the RF image (b) and on the BM image (d).

Note that the maximum translation magnitude is 2 mm for the RF data: the RF correlation indeed decreases rapidly, since it is linked to the wavelength of the imaging pulse. On the other hand, because the BM image corresponds to a demodulation of the RF signals, it allows for larger scale motion [9] and the maximum applied translation is 15 mm in this case.

Fig. 1 (a) shows that the correlation coefficient computed on the RF data using a linear probe decreases when the translation parameter increases. This behavior is more significant when the tissue is located in near field. Indeed the correlation reaches 0.67 at a depth of 15mm for a displacement of 2mm. We can clearly observe that we obtain best results in the focus region ($D=65\text{mm}$). Thus, even for a linear probe, the image formation introduces a decorrelation which depends on the position from the probe.

This phenomenon may be explained by computing the correlation between the PSF at the focus position ($D = 67\text{mm}$) and the PSF at other depths, as shown in **Fig.2 (a)**. The correlation value is 1 at the focus distance and decreases on both sides, especially in near field (closer to the probe). This reflects the spatially variant nature of the PSF. A tissue experiencing translation in the near field will be thus "seen" with two different PSFs, inducing the decorrelation observed in **Fig.1 (a)**.

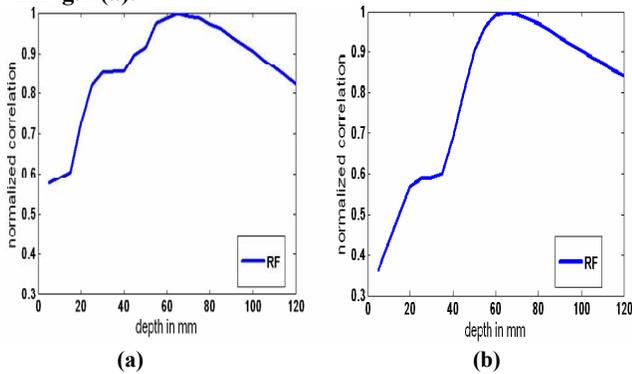


Fig.2: Correlation of PSF for a linear probe (a) and for a sectorial probe (b).

We give in **Fig.1 (c)** the normalized correlation computed on the BM data using the linear probe. We clearly observe that BM data yields the same tendency than the RF.

Obtained results confirm that, even if we use a linear probe, echographic image formation introduces a decorrelation for a simple translation. This is in contrast with previous studies which assumed that no decorrelation occurs in the case of translation [8,9].

3.1.2. Sectorial probe

Fig. 1 gives the correlation coefficient computed on the RF data (b) and the BM data (d) using a sectorial probe. The results show the same behavior as the one observed for the linear probe, with slightly more decorrelation.

For $D = 15\text{mm}$, the correlation for the RF data decreases to 0.57 at 2mm for the sectorial probe against 0.67 for the linear probe; the correlation for the BM data decreases to 0.29 at 15mm against 0.42 for linear probe. Thus the sectorial geometry of the acquisition introduces more decorrelation. This is confirmed by **Fig.2 (b)**, which shows that the variation of the PSF are more pronounced than in the case of the linear acquisition.

The translation used in the above discussed results is applied along the central axis of the probe (see **Fig.3 (a)**). The effect of the sectorial geometry is even clearer if we apply the translation out of the central axis, as shown on **Fig.3 (b)**. The obtained results given in **Fig.3 (c), (d)** indeed show that the correlation is still smaller in this case both for the RF and the BM data.

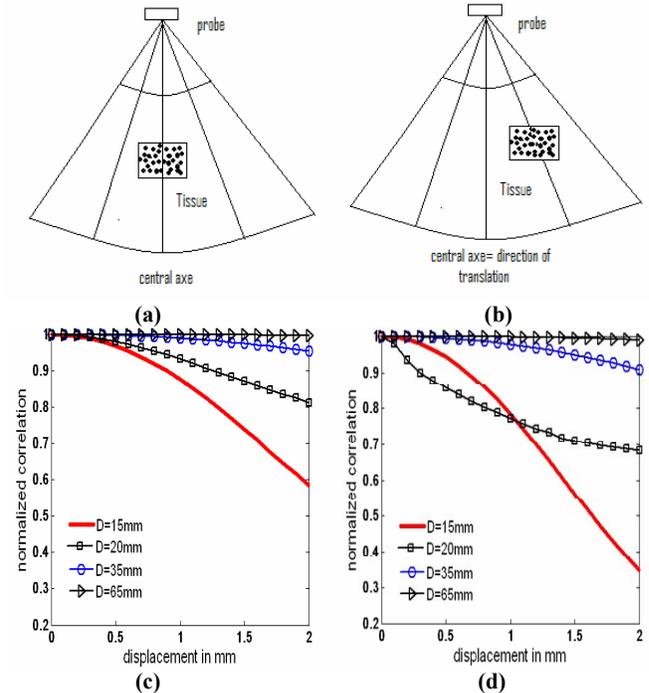


Fig.3: Normalized correlation in the case of translation for the RF data. **Column 1** Position of the tissue on the central axis (a) and the corresponding correlation (c). **Column 2** Position of the tissue off of the central axis (b) and the corresponding correlation (d).

3.2. Deformation

In this section we apply an axial deformation centered on the tissue region.

3.2.1. Linear probe

In the **Fig.4** we plot the normalized correlation for the RF (a) and BM data (c) with respect to the axial deformation parameter and for different depths. Note that the maximum deformation magnitude is 4% for the RF data and 50% for the BM data.

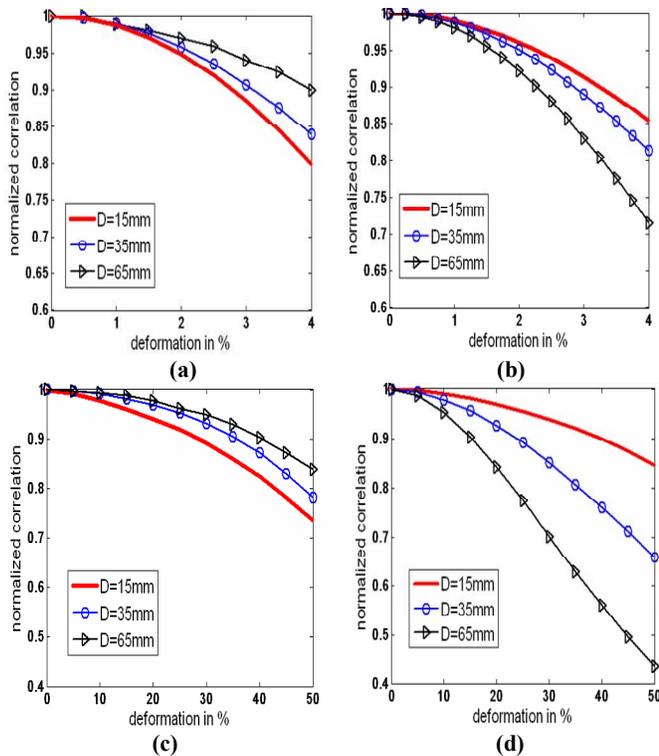


Fig.4: Normalized correlation in the case of an axial deformation **Column 1:** Result for a linear probe on the RF image (a) and BM image (c). **Column 2:** Result for a sectorial probe on the RF image (b) and BM image (d).

The obtained results are similar to the ones obtained for the translation. The correlation coefficient for both the RF and the BM data decreases when the deformation parameter increases. This phenomenon is amplified as the region gets closer to the probe.

3.2.2. Sectorial probe

Fig.4. gives the correlation coefficient computed on the RF data (b) and the BM data (d) in the case of an axial deformation using a sectorial probe. As for the linear acquisition, the correlation coefficient for both RF and BM data decreases when the deformation parameter increases. However, in contrast with the linear probe, it is interesting to note that the correlation is larger in the near field than in the focal region (D=65mm). This change of behavior may be explained as follows. As opposed to translation, the axial deformation modifies the spatial distribution of the scatterers, and thus the structure of the resulting speckle, resulting in a significant decrease of the correlation coefficient. This phenomenon is still increased in the focal region due to the fact that the sectorial acquisition geometry yields a sparser lateral sampling far from the probe.

4. CONCLUSION

In this paper, we have studied the influence of the acquisition set-up on the motion decorrelation in echocardiography.

Obtained results reveal that even in the case of simple translation decorrelation appears because of a realistic modeling of the echographic acquisition yields a spatially variant PSF. This is in contrast to the results given in previous studies [8,9] which assume that translation does not induce decorrelation. The results also show the influence of the acquisition geometry. In particular, they indicate that a sectorial geometry yields a stronger decorrelation.

From these results, our future work involves evaluating the influence of the above discussed behavior on the accuracy of motion estimation techniques.

5. REFERENCES

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