On the use of block matching for the estimation of arterial wall motion

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Abstract— **Motion of the carotid artery wall is important for the quantification of arterial elasticity and contractility and can be estimated from sequences of B-mode ultrasound images. In the relatively few studies on the subject, block matching has been used to estimate displacements of selected areas of the arterial wall and of the atheromatous plaque. In this paper, we attempted a small study on the use and performance of three variations of block matching, namely forward-, backward- and combination-block-matching, in terms of estimating arterial wall motion. Simulated ultrasound image sequences, generated using (a) FIELD-II, an ultrasound simulation package and (b) a mathematical model of arterial wall displacement, were used. The warping index, defined as the mean geometric error in pixels between the true and recovered deformation, was used to evaluate the performance of the block matching techniques. Reasonably high values were obtained for all three cases; specifically, the warping index was 1.879 for forward-, 0.984 for backward- and 1.122 for combined block matching. In conclusion, block matching techniques are appropriate for estimating arterial wall motion from sequences of ultrasound images; backward tracking may be the preferred technique in such applications.**

I. Introduction

The estimation of motion of the carotid artery wall is important for the quantification of arterial elasticity and contractility. Throughout the arterial tree, wall motion is caused by blood pressure, blood flow and tethering to surrounding tissue. Motion of the atheromatous plaque, in particular, may be responsible for tissue rupture and cerebrovascular symptoms [1]. The movement of the carotid artery wall can be quantitatively estimated from sequences of B-mode ultrasound images. Ultrasound imaging of the carotid artery is widely used in the diagnosis of atherosclerosis because it allows noninvasive assessment of the degree of stenosis as well as of tissue morphology. Tracking carotid artery wall motion in real-time from a series of ultrasound images is challenging due to the fact that the images are noisy, images are acquired rapidly (≈40ms), motion is nonrigid, and the image contrast/intensity may change over time due to flowing blood and/or contrast agent.

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In the relatively few studies on the subject, block matching has been extensively used to estimate displacements of selected areas of the arterial wall as well as of the atheromatous plaque from B-mode [2], [3], [4] and radiofrequency [5], [6] ultrasound images. Golemati et al. [2] demonstrated that two-dimensional (2D) motion of the normal and diseased (atherosclerotic) arterial wall as well as of the surrounding tissue can be quantified accurately through cross-correlation. Cinthio et al. [3] designed and evaluated an echo-tracking system based on block matching for measurement of radial and longitudinal motion of small regions of the intima-media complex of the arterial wall. They subsequently used this system to estimate longitudinal movements and resulting shear strain of the arterial wall [4]. Bang et al. [5] quantified plaque motion dynamics and produced a displacement vector map by 2D correlation of local areas in consecutive RF images. Using the same technique, Dahl et al. [6] quantified plaque motion through 29 parameters representing amplitude, stretch/compression and shear motion, and evaluated reproducibility of the technique.

Block matching is based on tracking speckle patterns in image sequences assuming that movement of speckle patterns corresponds to movement of image patterns. Block matching using forward tracking is the most common variation of block matching used in similar studies. Backward tracking, or the combination of forward and backward tracking, may also be considered.

Validation of the block-matching-based motion analysis in the previous studies was mostly performed using specially devised phantoms [3], [5], which simulate the acoustic properties of biological tissue. The use of tissue-mimicking phantoms is useful for validation experiments, but requires specialized equipment which may not be easily available. Software programs capable of simulating ultrasound images have been developed, which allow the evaluation not only of transducers and focusing schemes but also of image processing methods. FIELD II is an ultrasound simulation package, which provides a useful framework to simulate ultrasound fields by incorporating realistic transducer features [7].

In this paper, we attempted a small study on the use and performance of three variations of block matching, namely forward-, backward- and combination-block-matching, in terms of estimating arterial wall motion. The evaluation of the three techniques was based on simulated images generated using FIELD-II and a mathematical model of arterial wall deformation. Indicative results of the application of the investigated techniques on real image data are also produced.

II. Methodology

A. Simulated Dynamic Ultrasound Data

Using FIELD II, B-mode ultrasound images were generated from a sequence of scattering strength maps, according to the procedures described in [8]. Briefly, the first frame of the scattering map sequence was designed using a real end-diastole B-mode ultrasound image as a template. The scattering map models the different densities and speeds of sound in the different arterial tissues. A total of 128 scanning lines were used and the resultant image size was 300×250 pixels. Figure 1 shows an example of a simulated ultrasound image using the above procedures.

To create a sequence of anatomic phantoms, the previously described scattering map, corresponding to the first frame of the sequence, was deformed according to an appropriately constructed mathematical model of arterial wall motion, also described in [8]. The mathematical model, defined as a separable model in space and time, expresses the radial and axial components of tissue displacement.

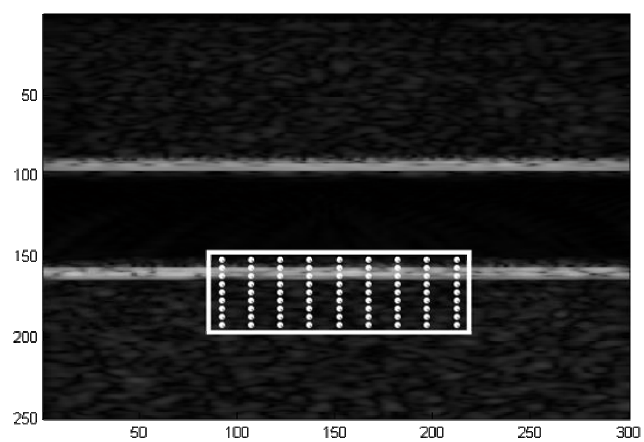


Figure 1. Example of simulated ultrasound image of the carotid artery wall using FIELD II. The white box delineates the area for which the warping index was calculated. The white dots correspond to the centers of the interrogated ROIs.

B. Using Block Matching to Estimate Motion

Block matching can be used to track speckle patterns in ultrasound images, under the assumption that movement of speckle patterns corresponds to movement of image patterns. Given a block of pixels, or reference block, in the first of two images, matching consists in finding the block in the second image that best matches the block in the first image, termed reference image [9] (Fig. 2). This definition relies on the assumption that the reference block remains constant over time and motion which is valid if the frame rate is sufficiently high. The method requires a good measure of match. The value of such a measure should be large when the selected block and the interrogated image region coincide in intensity levels and small otherwise. The normalized correlation coefficient [2] corrected for the average values was used here as the preferred matching criterion. The search for the best-matched block is typically constrained to a search window, the size of which has to be appropriately chosen. A large search window allows accurate tracking of rapid movements that could be lost if the search widow was smaller, but increases the possibility for mismatch and the computational complexity of the algorithm.

Forward tracking, in which the first image of the sequence is used as reference, is the most commonly used procedure for block matching. An alternative, namely backward tracking, consists in using the last image of the sequence as reference. In this study, in addition to forward and backward tracking, we used their combination, calculated as the average of the positions obtained using only forward and only backward tracking.

Rectangular blocks, or regions of interest (ROIs), of size 2.5x1.7 mm2 were tracked. The result of the motion analysis consists in waveforms showing radial and axial displacements of the selected ROIs.

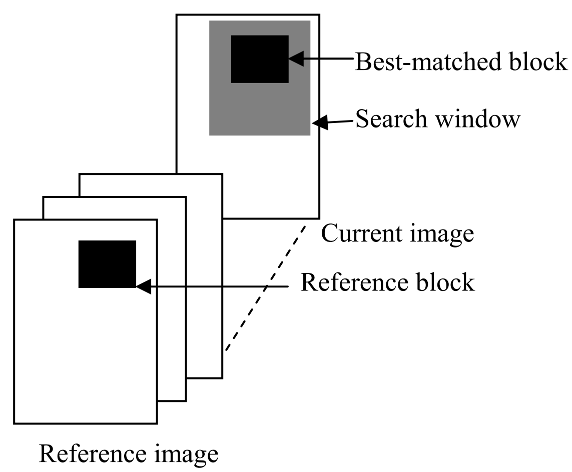


Figure 2. Illustration of the block matching algorithm for motion analysis from sequences of images. Motion of a block of pixels is estimated by searching for the most similar block of pixels in a search window at subsequent frames. In forward tracking, the reference image corresponds to the first image of the sequence, whereas in backward tracking, the reference image corresponds to the last image of the sequence.

C. Estimating the Performance of Block Matching Techniques

The accuracy of motion estimation was evaluated using a warping index [10], defined as the mean geometric error in pixels between the true and recovered deformation:

$$\varpi = \sqrt{\frac{1}{N_R T}\sum_{k\in T}\sum_{\boldsymbol{i}\in R}\left\|\boldsymbol{g}(k,\boldsymbol{i})-\boldsymbol{g}_0(k,\boldsymbol{i})\right\|^2}$$

where R is the region of interest (Fig. 1), N_R is the number of pixels in this region, T is the total number of images in the sequence, and $\boldsymbol{g}$ and $\boldsymbol{g_0}$ correspond to the estimated and true deformation fields, respectively. This index represents an overall measure of the local error.

The warping index was calculated for an area (R) around the posterior arterial wall, as shown in Fig. 1 (white box). A total of 81 points were included in this area separated by 15 pixels in the axial (horizontal) and by 5 pixels in the radial (vertical) direction. Pixel density was lower in the axial direction because less relative motion is expected compared to the radial direction.

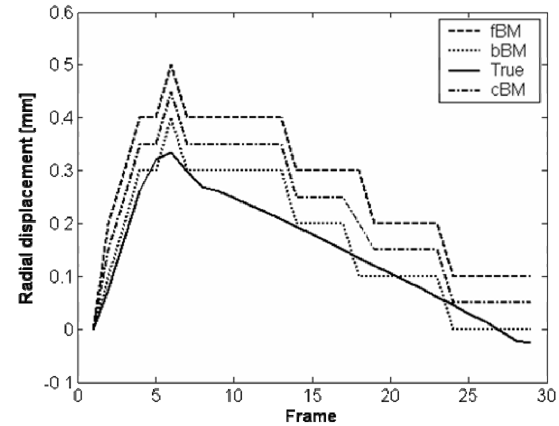
D. Estimating Arterial Wall Motion in Real Ultrasound Images

Block matching, in all three variations, was applied to a sequence of B-mode ultrasound images of the common carotid artery of a young adult with normal (non-stenotic) carotid arteries. The sequence was obtained with an ATL (Advanced Technology Laboratory) Ultramark 4 Duplex scanner (Philips Medical Systems, Bothell, WA, USA) and a high-resolution 7.5MHz linear array scan head. Scanner settings included dynamic range, 60dB; 2D gray map, linear; persistence, low; frame rate, high. The image sequence, corresponding to a longitudinal arterial section, was recorded at a rate of 25 frames/sec for approximately 3 seconds (2-3 cardiac cycles) during breath holding. The images were transferred to a magnet optical disc and then copied to a compact disc. Then they were copied to a personal computer (PC) where the analysis was performed. A rectangular ROIs of size 3.2x2.5 mm2 was investigated using block matching.

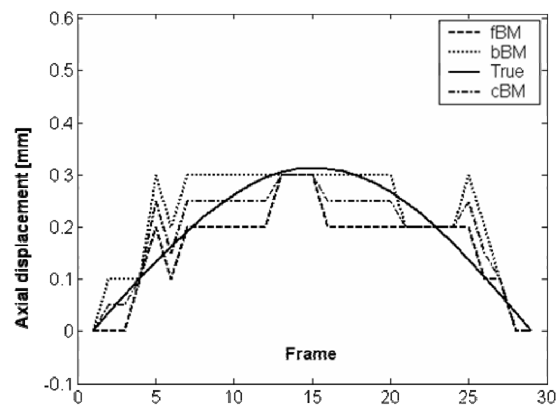
III. RESULTS

Fig. 3 shows radial and axial displacements obtained using forward, backward and combined block matching. The waveforms of actual displacements are also shown in Fig. 3. These tracings correspond to a ROI on the posterior wall (Fig. 1); specifically, the one with center corresponding to the first row and the fifth column of the illustrated grid of points. As we can see, the shapes of the estimated waveforms are similar for forward and backward tracking; this is more pronounced in the radial case but appears to be also valid in the axial case. In the radial direction, individual values of the waveform estimated using backward tracking was closest to the true displacement values, whereas for forward tracking, an overestimation of the displacements was observed.

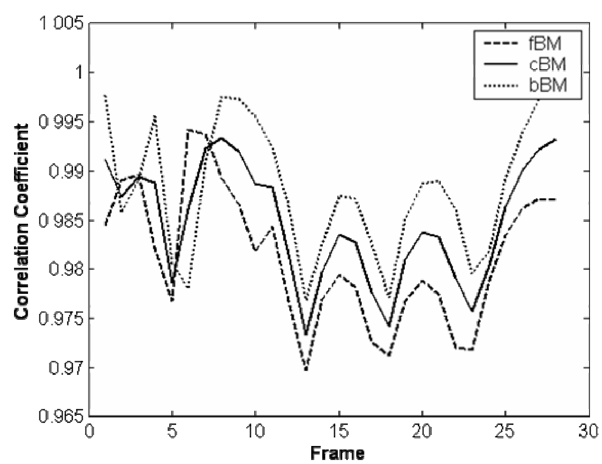
Table 1 shows the values of the warping index for the three different scenarios investigated. The lowest warping index values were found for backward block matching.



(a)



(b)



(c)

Figure 3. Radial (a), axial (b) displacement and correlation coefficient (c) waveforms for a ROI on the posterior wall of the simulated ultrasound image.

In Fig. 4 the results of the application of the investigated block matching techniques on real ultrasound data are depicted. Fig. 4(b) and Fig. 4(c) show radial and axial displacement waveforms, respectively, for a ROI on the posterior arterial wall (Fig. 4a). As in the simulated data, waveforms for real data have similar shapes; they all follow the progressive "drift" towards lower values.

TABLE I.
WARPING INDEX, IN PIXELS, FOR THE THREE BLOCK MATCHING TECHNIQUES. RD: RADIAL DISPLACEMENT, AD: AXIAL DISPLACEMENT, FBM: FORWARD BLOCK MATCHING, BBM: BACKWARD BLOCK MATCHING, CBM: COMBINED BLOCK MATCHING.

	fBM	bBM	cBM
RD	0.873	0.459	0.524
AD	1.664	0.871	0.992
Total	1.879	0.984	1.122

IV. DISCUSSION

Block matching, a well-known motion analysis algorithm, has been extensively used to estimate the movement of the carotid artery wall and plaque from sequences of ultrasound images. In this study, we investigated three different scenarios for region tracking using block matching. The results were interesting and may be considered in applications of block matching for arterial wall motion estimation.

Tracking of a small, user selected ROI throughout a sequence of images was performed using block matching in the forward and backward directions; their combination was also considered. Block matching in the backward direction, i.e. using the last frame as reference, produced the lowest error in an experiment with synthetic data. This was a particularly interesting finding and may be due to the order in which the sequence of events during the cardiac cycle are encountered during the tracking. Specifically, in forward tracking, systole, a relatively fast event, becomes evident as a steep transition from low to high values. Diastole, a relatively slower event, becomes evident as a smooth transition from high to low values. In backward tracking, on the other hand, the previous transitions, corresponding to physiological events, occur in opposite directions. Related to this phenomenon, may be the fact that radial displacements are overestimated in forward tracking.

The preliminary findings of this study indicate that further investigation is required to elucidate the use of block matching, in applications concerning the estimation of arterial wall motion from ultrasound images.

V. CONCLUSION

Block matching techniques are appropriate for estimating arterial wall motion from sequences of ultrasound images. The backward approach for the region tracking appeared to perform best in this type of application; suggesting that further investigation is required to elucidate the procedures involved.

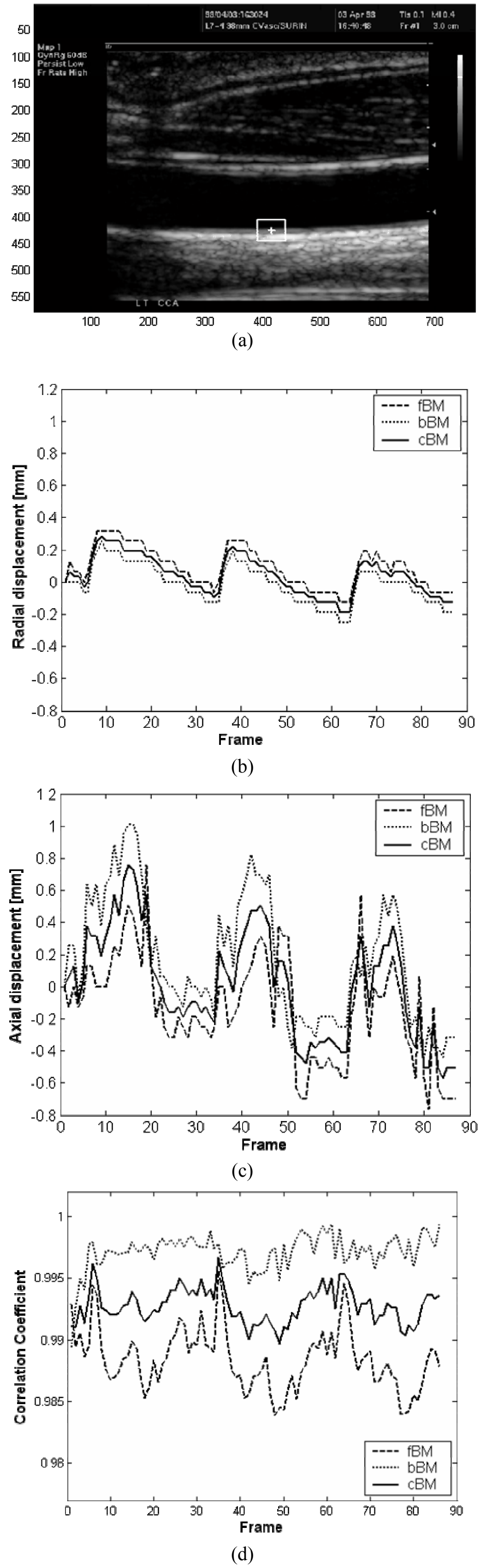


Figure 4. Real ultrasound image with a selected ROI on the posterior arterial wall (a) and radial (b) and (c) axial displacement and (d) correlation coefficient waveforms for this ROI estimated using the investigated block matching techniques.

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