A COMPARISON OF THE MOTION TRACKING OF 2-D ULTRASONIC B-MODE TISSUE IMAGES WITH A CALIBRATED PHANTOM

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Abstract

In evaluating tissue motion, it is necessary to know the precision and relative error associated with correlation tracking as a function of distance. Quantitative estimates of tissue compressibility, elasticity, lesion mobility and other mechanical properties of tissue are largely based on tissue displacements and in the accuracy and precision of its estimation. To quantify the uncertainty of speckle tracking, the motion of a tissue phantom was tracked and compared with known displacements. For planar translations, a relative tracking error ranging from 14% to 18% was found for tissue displacements ranging from 2.0 mm and 14.1 mm. Simulated tracking was performed for six translational and rotational motions. These results suggest that computational estimates of tissue velocity, compressibility, elasticity and mobility should be based on an overall uncertainty of ±18% relative to known tissue displacements between 2.0 mm and 14.1 mm.

Introduction

In previous studies, it was shown that correlation techniques could be used to detect motion [1,2]. Typically, a region of interest (ROI) is selected from a B-mode image and its motion is tracked through a sequence of images. If the ROI remains time invariant and there is no noise in the system then the planar translational motion of the ROI can be tracked exactly. A sequence of tissue scans will become decorrelated from the original tissue scan due to noise. For the worst case an ROI may actually change with time and become lost in the background during tracking. To quantify the error in tracking B-mode speckle images, known linear transformations were applied to a tissue phantom and the correlation tracked motion of the phantom was compared with the known transformations.

Correlation Tracking

A two-dimensional image can be represented by a two-dimensional array. In this case, each location in the array contains the color of a pixel in the image. An image can also be viewed as a one-dimensional array if the rows of the two dimensional array are concatenated to form a line. Suppose we have a pair of images represented by arrays A and B. An ROI X, is selected from the first image. The ROI can be considered a subarray of A. A template Y, with the same dimensions as the ROI is moved over all possible locations in the second image. At each position the correlation coefficient between the ROI and the image under the template is computed. The correlation coefficient for discrete time functions is given by:

$$\rho_{xy} = \frac{\sum_{i=0}^{M}\sum_{j=0}^{N}(x_{i,j}-\bar{x})(y_{i+k,j+l}-\bar{y})}{\sqrt{\sum_{i=0}^{M}(x_{i,j}-\bar{x})^2\sum_{j=0}^{N}(y_{i+k,j+l}-\bar{y})^2}} \qquad (1)$$

where k and l specify the position of the template in the second image, $\bar{x}$ and $\bar{y}$ denote the average pixel values in the ROI and in the template, and the covariance and variance of the sub-images X,Y are evaluated from the probability density functions by the summations. The new position of the ROI is assumed to be the position that gives the peak correlation coefficient.

The correlation coefficient provides a measure of how linearly related the functions (or images) are. The normalization factor in the denominator of equation (1) forces the correlation coefficient to take on values between -1.0 and 1.0. If two images X and Y are linearly related by Y=cX where c is a constant then the correlation coefficient for these images is ±1.0. One problem with two-dimensional correlation-based algorithms is that they perform poorly when tracking rotational motion and motion in three dimensions. Another problem that has remained unresolved is the determination of an optimum window size (dimensions) for an ROI.

Methods

A small section of wood sponge implanted in a standard porous sponge was used as the tissue phantom. The sponge was immersed in a water tank and lowered to a fixed depth just below the surface of the water. Continuous B-mode images were obtained using a 5 MHz ATL transducer and an ATL MK 500 Ultrasonic Imager (Figs 1. & 2.). Linear transformations were simulated using a Daedal motorized positioning system which has a precision of ± 1.0 μm for translational motion and ± 0.01 degrees for rotational motion. For planar transformations the transducer must be aligned so that the scanning plane is parallel to one of the coordinate axes of the Daedal system. In addition, the transducer axis must also be aligned perpendicular to the coordinate axes of the Daedal system. A small portion of the overall tracking error was assumed to be due to misalignment.

Computer tracking

For each transformation a corresponding sequence of images was recorded using a Targa 16 frame grabbing system and a Compaq 386 computer. The linear transformations included four planar translations (vertical, horizontal, diagonal and closed octagonal path) and two rotational translations (planar and non-planar rotation). An ROI was selected from the first frame of each sequence and tracked in a progressive manner using a correlational-based search. The ROI was tracked from a position (x_1,y_1) in frame 1 to a position (x_2,y_2) in frame 2 using a correlation-based search. The ROI was then tracked from position (x_2,y_2) in frame 2 to (x_3,y_3) in frame 3 and so on. This procedure was continued until the ROI was tracked to it's final position (x_N,y_N) in frame N. The correlation tracking was implemented by programs generated in 'C' and run on a Sun Sparc 330 workstation. As a preliminary step each sequence of images was first converted from standard RGB (Red-Green-Blue) color format to a 32 level grey scale format with a desired weighting function. The converted images were then correlated in the progressive manner described above and the intermediate and final correlation coefficients and positions were saved. As expected the correlation coefficients for rotations were about 0.15 lower than the correlation coefficients for translational motion. Non-planar motion of 10.0 mm of ROIs was tracked as planar motion of 1.3 mm.

To validate the correlation tracking done by the computer an arbitrary speckle image was acquired and saved. An ROI was selected and the image was correlated with itself. The ROI was tracked from position (x_1,y_1) in frame 1 to position (x_1,y_1) in frame 2 with a correlation coefficient of 1.0. This was exactly what was expected since frame 2 was a copy of frame 1 and the ROI did not move. In earlier tests the correlation algorithms also tracked the motion of a sequence of computer generated images exactly $(x_n=x_{n-1},y_n=y_{n-1})$ and with correlation coefficients of 1.0. To validate the progressive tracking, a ROI was tracked through a sequence of images in both the forward and reverse directions. (In the reverse direction the ROI was tracked from the end of the sequence back to the original frame). For each of the motion patterns tested an ROI $X(x_1,y_1)$ was tracked to $Y(x_N,y_N)$ and then $Y(x_N,y_N)$ was tracked back to $X(x_1,y_1)$ as expected.

To obtain a measure of the ambient noise in the system the motion of a stationary ROI was tracked through a sequence of B-mode images. In the absence of noise the peak displacement of the ROI should be zero. The actual peak displacement or tracking error due to noise was found to be 0.43 mm.

The image resolution defines the smallest unit of motion. The resolution for tracking is 1 pixel length in the vertical and horizontal directions. From 1 cm display markers and images of a straight edge of known length it was found that 1 vertical pixel corresponded to 0.1938 mm and that 1 horizontal pixel corresponded to 0.2143 mm. This means that motion is tracked in steps of .2143 mm in the horizontal direction and .1938 mm in the vertical direction. Since images have a finite resolution there is an associated error for objects whose edges fall between pixels. The uncertainty due to vertical resolution is equal to one half of one vertical pixel or 0.0964 mm. Similarly the uncertainty due to horizontal resolution is 0.1072 mm. The total tracking error in the system is

$$e_t = e_{noise} + e_{mot} + e_{align} + e_{res} \tag{2}$$

where e_t represents the total error in the system, e_{mot} represents error due to changes in the ROI from non-planar motion, e_{noise} represents the tracking error due to ambient noise, e_{align} represents the alignment error, and e_{res} represents the error due to finite resolution of the image.

Results

Correlation tracked displacements were compared with known displacements by computing the uncertainty associated with tissue tracking. The displacement of an ROI was measured by,

$$d_{measured} = \sqrt{|x_1 - x_N|^2 + |y_1 - y_N|^2} \tag{3}$$

By computing the absolute tracking error for known displacements,

$$e_{abs} = \sqrt{|x_N - \hat{x}|^2 + |y_N - \hat{y}|^2} = uncertainty \tag{4}$$

the uncertainty in tissue tracking for each of the linear transformations was found. Basically this range indicated the maximum allowable error in tracking (Figs. 3. & 4.). The percent relative error was computed for known displacements by,

$$= 100 \left| \frac{e_{abs}}{|x_1 - \hat{x}|^2 + |y_1 - \hat{y}|^2} \right| \tag{5}$$

In the above equations (x_1,y_1) represents the initial position of the ROI (actual), (x_N,y_N) represents the final position of the ROI (actual), and $(\hat{x},\hat{y})$ represents the final position of ROI (tracked) The absolute tracking error is equal to the geometric distance between the actual final position of the ROI and the tracked final position of the ROI. This is a measure of the total error in tracking due to noise, non-planar motion, and resolution $(e_t=e_{abs})$. The relative error is equal to the absolute error divided by the actual displacement of the ROI. For the linear transformations that were applied, it was observed that the absolute tracking error increased with displacement while the relative tracking error remained fairly constant. Variation of the absolute tracking error and relative tracking error versus displacement are shown in Figs. 5. & 6 for the case of diagonal translation. The precision of tissue tracking was computed by,

$$p_t = \frac{\sigma_x}{\mu_x} \qquad (6)$$

where μ_x and σ_x represent the mean and standard deviation of the tracked values. Samples of correlations, error and precision associated with tissue tracking for known linear transformations are shown in table 1.

Conclusion

Quantitative estimates of the uncertainty and relative error associated with correlation-based tracking of tissue images were obtained. The motion of a calibrated phantom was tracked for six translational motions and the results were compared with known displacements. This kind of uncertainty measurement is a necessary step in obtaining quantitative estimates of tissue velocity, mobility, and shear elastic modulus. While the actual error values and uncertainties presented may not match the nominal uncertainties of individual systems, they more importantly demonstrate the concept. To obtain more reliable estimates future studies will entail a larger number of trials with more precise alignment techniques. In addition implementation of tracking algorithms for rotational motion will be useful for the case of planar rotation.

References

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Fig. 1. Experimental Setup

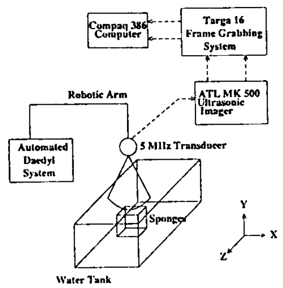

Fig. 2. Scanning Plane

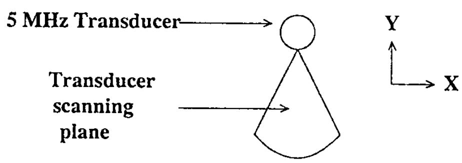

FIG. 3. TRACKING ERROR FOR A KNOWN DISPLACEMENT

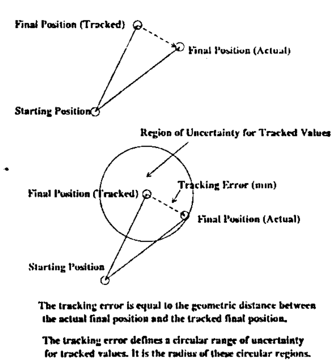

FIG. 4. RANGE OF UNCERTAINTY VS DISPLACEMENT

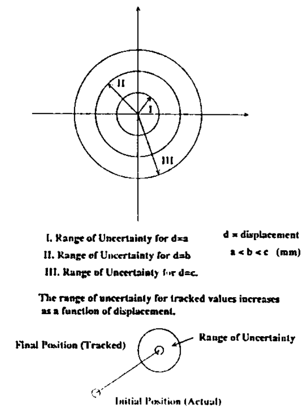

Fig. 5. ABSOLUTE ERROR VS DISPLACEMENT

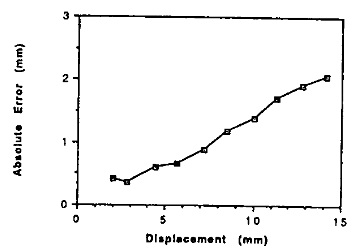

Fig. 6. PERCENT RELATIVE ERROR VS DISPLACEMENT

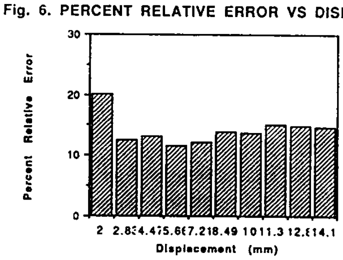

Table 1. ERROR AND PRECISION FOR LINEAR TRANSFORMATIONS

Pattern	Displacement	Correlation	Absolute Error	Relative Error	Precision
Vertical	9.0 mm	0.9417	1.50 mm	15.0 %	0.077
Horizontal	9.0 mm	0.9197	1.55 mm	15.5 %	0.040
Diagonal	14.1 mm	0.9411	2.03 mm	14.3 %	0.085
Octagon	0.0 mm	0.9152	0.21 mm	-	0.037
Swing (In plane)	42.6 mm	0.7649	10.09 mm	23.6 %	0.011
In/Out plane	10.0 mm	0.8779	1.28 mm	-	0.812