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Mobility Imaging Based on Normed Space
ノルム空間に基づく動きイメージング

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1. Introduction

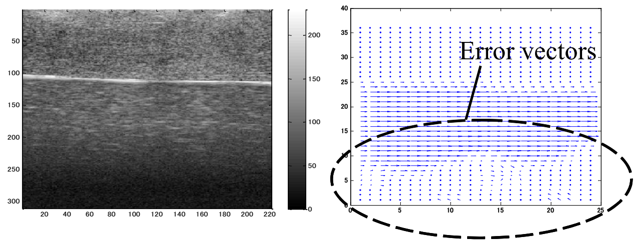
Elasticity methods [1], which are based on the hardness of tissue, are being intensively studied for their usefulness in obtaining diagnoses from tissue characterization. Meanwhile, mobility is reported to be effective for diagnosing tumors [2]. Therefore a combination of both indexes is expected to improve the accuracy of diagnosis.

We proposed new methods of ultrasonic straingraphy based on the detection of spatial discontinuity in the tissue motion vector, which is estimated by the correlation of images between sequential frames [3, 4]. However, error vectors occur in vector maps due to low intensity. An error vector causes a pseudo boundary in a scalar map. It is therefore necessary to improve the reliability of maps. Consequently, we investigated reliability estimation based on a statistical approach.

We have proposed rotation and eigenvalue decomposition techniques [5, 6] to transform a vector map to a scalar one. A motion vector is detected from normed spaces (e.g. sum of absolute differences) of two image frames based on the block matching method [7]. However, transforming a scalar map directly from a normed space is expected to improve accuracy. Imaging from the sum of squared differences was proposed by using cumulative of norms [8]. However, that thechnique does not address robust noise. We propose here a method based on statistical distribution of p-normed space as a robust-noise method. We discuss in vitro and in vivo experiments conducted using this method.

2. Reliability Evaluation

An example of error vectors in a two-layered phantom experiment is shown in **Fig. 1**. Figure 1(a) shows a B-mode image. The lower layer is shifting laterally, whereas the upper layer is relatively static. Figure 1(b) is a vector map obtained by using a block matching technique. Error vectors caused by the penetration limit are visible in the lower area.



(a) B-mode (b) Vector map

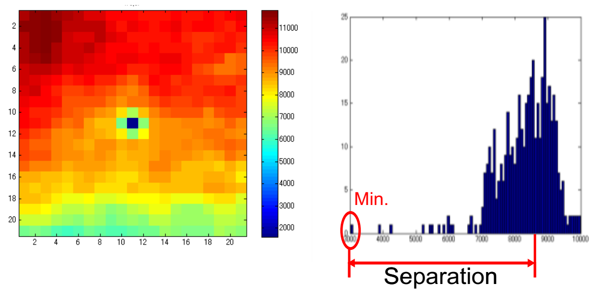
Fig. 1 Two-layered phantom experiment.

To evaluate the reliability of a vector or scholar map, the degree of separation is calculated from the p-normed space. P-norm is defined as follows:

$$p\text{-}norm = \left(\sum_{i,j} \left| p_m(i_0, j_0) - p_{m+\Delta}(i,j) \right|^p \right)^{1/p} \quad (1)$$

where $P_m(i_0,j_0)$ is the intensity distribution of the window array (region of interest: ROI) in frame m, and $P_{m+\Delta}(i,j)$ is in frame $m+\Delta$. Here, (i,j) shows the central coordinate of ROI. The window array was set in each frame to measure p-norm space. A window size of 30×30 pixels was selected for this paper. The search region was 50×50 pixels in the next frame.

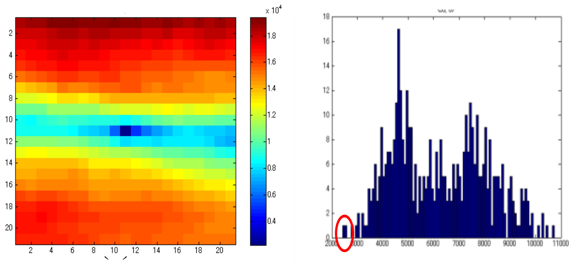
The normed space of a static region is shown in **Fig. 2**. The Position of the minimum norm stays in the center of the normed space because there was no movement. A histogram shows large separation on the distribution in Fig. 2(b).



(a) Normed space (b) Histogram

Fig. 2 Static region.

Figure 3 shows the normed space of a boundary region. A norm valley trend along the boundary is observed in Fig. 3(a). A histogram shows small separation in the distribution in Fig. 3(b).

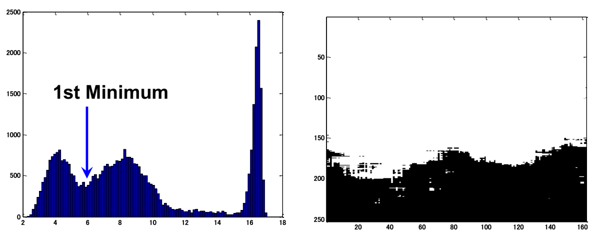


(a) Normed space (b) Histogram

Fig. 3 Boundary region.

Separation of the minimum norm in the distribution can be defined as a degree of separation. In a low reliability area of the noise region, the degrees of separation have the lowest values.

For instance, a histogram of the degrees of separation is shown in **Fig. 4**. The small distribution is in the low-value region (Fig. 4(a)). The first minimum is set as a threshold value. By using the threshold value, a binarized image is obtained (Fig. 4(b)). The colored area corresponds to error-vector one in Fig. 1(b). Accordingly, low-reliability regions can be evaluated by the degree of separation.



(a) Histogram (b) Binarized image

Fig. 4 Degree of separation.

3. Mobility Imaging

Mobility image processing can be achieved by using a slip coefficient which corresponds to the degree of separation in p-normed space. We use 2-normed space because 1-normed space is affected by sparse distribution. **Figure 5** shows a mobility image of the two-layered phantom without a low-reliability region. The boundary can be traced correctly by the slip coefficient.

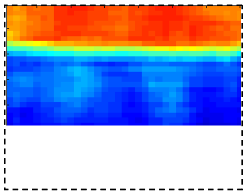
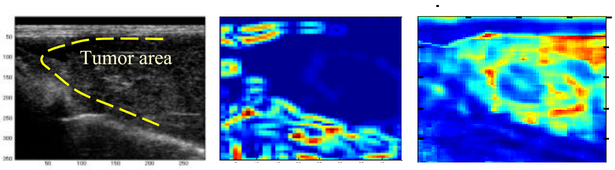


Fig. 5 Mobility imaging using slip coefficients.

Mobility images of a VXII tumor implanted in rabbit liver are shown in **Fig. 6**. Figure 6(a) is a B-mode image, and Fig. 6(b) is a strain-norm image obtained for comparison with the slip coefficients. The strain norm is a 2-norm of a 2D strain tensor [5] and is calculated from a vector map. The boundary of the tumor is indicated in this figure. Meanwhile, a slip coefficient image is shown in Fig. 6(c). Very little fluctuation occurred outside tumor. This means that the minimum position in the normed space changes, but the statistical exponent (slip coefficient) is stationary. The area inside the tumor seems to show a microstructure.



(a) B-mode (b) Strain norm (c) Slip coefficient

Fig. 6 VXII tumor implanted in rabbit liver.

4. Conclusion

We proposed reliability evaluation and mobility imaging methods based on p-normed space. The validity was confirmed by experiments conducted with a two-layered phantom and VXII tumor implanted in rabbit liver.

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