Tumor detection in Ultrasound B-mode images through motion estimation using a texture detection algorithm.

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Abstract

A method is described for the determination of an immobile region of an ultrasound image of the heart. Following a noise reduction operation using an optimal signal-adaptive algorithm, a luminance-based block matching technique is used to determine the motion field. Subsequently, the motion field map is processed and the immobile region is extracted by using a 2-D texture separating algorithm.

1 Introduction

One of the significant advantages of the medical ultrasound imaging modality is its ability to sense tissue motion at low instrument cost and in a noninvasive fashion. This may be used to determine a pathological state of tissue by analyzing its motion. This powerful real-time capability has been used primarily for rapid anatomical location and in cardiological diagnosis [2].

The present paper develops a new technique for the identification and isolation of immobile regions in ultrasound B-mode images and applies it for the identification of mediastinal lymphomas. Following noise removal by use of the theoretically optimum signal-adaptive method, the technique relies on block-matching to determine the motion vector field for each ultrasound frame. An image is then formed with intensity proportional to the magnitude of the motion vector associated with each pixel. Finally, this image is segmented by using a novel texture separation process, aiming to produce a reliable estimate of the immobile area.

The technique was applied to the identification of a typical mediastinal lymphoma, and gave encouraging preliminary results.

2 Tumor detection method

The method used to detect the mediastinal lymphoma is described in the following sections.

2.1 Noise reduction

The optimal signal-adaptive maximum likelihood method in [2] was used for the reduction of the speckle noise. If $x(k,l)$ is the noisy image intensity at pixel (k,l), the signal-adaptive estimate of the original signal $s(k,l)$ at the same picture location is chosen to be [2]:

$$\hat{s}(k,l) = \hat{s}_{ML}(k,l) + \beta(k,l)[x(k,l) - \hat{s}_{ML}(k,l)] \tag{1}$$

where $\hat{s}_{ML}(k,l)$ is the maximum likelihood estimate of $s(k,l)$ based on the observations $x(k-i,l-j)$ in a window W about (k,l), and

$\beta(k,l)$ is a weighting factor. If $\beta(k,l)$ approaches 1, the actual observation is preserved by the suppression of the low-pass component $\hat{s}_{ML}$. When $\beta(k,l)$ is close to 0, maximum noise reduction is performed, since the high frequency component is suppressed.

The factor $\beta(k,l)$ is chosen so as to minimize the local variance:

$$e(k,l) = E_W[(s(k,l) - \hat{s}(k,l))^2] \qquad (2)$$

where E_W denotes the local averaging operator over a window W. The resulting value of β is [2]:

$$\beta = \frac{E_W[(s - \hat{s}_{ML})(x - \hat{s}_{ML})]}{E_W[(x - \hat{s}_{ML})^2]} \qquad (3)$$

If the speckle noise is assumed to be a multiplicative Rayleigh-distributed noise, the maximum likelihood estimate $\hat{s}_{ML}$ in (1) and (3) may be shown to equal [2]:

$$\hat{s}_{ML}(k,l) = \frac{\sqrt{\pi}}{2}\sqrt{E_W[x^2]} = \frac{\sqrt{\pi}}{2}\sqrt{\frac{1}{N}\sum_{i=1}^{N} X_i^2} \qquad (4)$$

where $X_1, \ldots, X_N$ are the observations $x(k-i, l-j)$ for (i,j) in the window W. The resulting value of β in (3) is:

$$\beta = 1 - \left(\frac{4-\pi}{4}\right)\frac{E_W[x^2]}{E_W[(x - \hat{s}_{ML})^2]} \qquad (5)$$

2.2 Motion estimation

The block matching technique is used for the motion estimation. According to this technique [4], each frame is divided into small orthogonal blocks which are labeled by the coordinates of their upper-left corner. For each of the reference blocks, a search is performed to find the best matching block of the next frame.

Considering the reference block with its upper-left corner at the position (x,y), the search is done in a restricted area around the pixel (x,y) of the next frame, as we assume that the block translations are small from frame to frame.

The matching criterion is that of the minimum absolute difference between the luminance values of the two blocks:

$$\forall (dx, dy) \in W, \quad \text{find the vector } [dx, dy]^T$$
$$\text{that minimizes the sum:}$$
$$\sum_{(x,y)\in w} |ref(x,y) - next(x+dx, y+dy)|$$

where *ref* stands for the reference frame, *next* is the next frame, w is the block area, W is the search area, and dx, dy are the horizontal and vertical displacements of the reference block.

If the best-matching predicted block has its upper-left corner at the position (x', y') on the next frame, the *motion vector* $[dx, dy]^T = [x - x', y - y']^T$ represents the estimated displacement of the reference block (x,y). The magnitude of all motion vectors, after being scaled to a 0–255 integer range, is used to form the motion-magnitude map. In this image, small intensity values —dark blocks— represent parts of the picture that have small or no motion.

In this work, the size of the block used is 8×8 pixels, and the searching area is a square of 15×15 pixels centered at the reference block's coordinates (x,y).

2.3 Texture separation procedure

A novel texture separation method was developed, aiming to segment the resulting motion-magnitude map so as to clearly and reliably isolate the immobile area. The method uses two concentric moving windows with dimensions $m = 7$ and $n = 3$, shown in Figure 1. If $f(i,j)$ is the motion magnitude at pixel (i,j), the mean values of f at the inner and outer window are respectively calculated by:

$$M_{inner} = \frac{1}{n^2}\sum_{i=-n/2}^{n/2}\sum_{j=-n/2}^{n/2} f(k-i, l-j) \qquad (6)$$

$$M_{outer} = \frac{1}{m^2 - n^2}\left[\sum_{i=-m/2}^{-n/2}\sum_{j=-m/2}^{-n/2} f(k-i, l-j) + \sum_{i=n/2}^{m/2}\sum_{j=n/2}^{m/2} f(k-i, l-j)\right] \qquad (7)$$

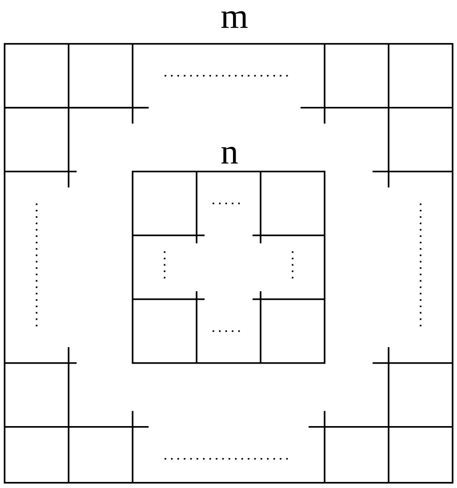

Figure 1: The two concentric moving windows.

These are then compared to thresholds T_{low} and T_{high} found empirically. Then if

$$M_{outer} < T_{low} \ and \ M_{inner} > T_{high},$$

the output image pixel grey level is set to its minimum value (zero), while if

$$M_{outer} > T_{high} \ and \ M_{inner} < T_{low},$$

the output image pixel grey level is set to its maximum value (255). If none of the above conditions holds, the output image grey level remains equal to the magnitude of the motion vector.

2.4 Results

The above method was applied to an ultrasound B-mode image of a mediastinal lymphoma. One of the original frames is shown in Figure 2a. Figure 2b is the same frame following signal-adaptive processing for the reduction of speckle noise. The map of the magnitude of the motion vectors is shown in Figure 2c. Finally, upon segmenting the motion magnitude map, the final image in Figure 2d specifies the immobile region.

3 Conclusions

The method presented above gives encouraging results, as it identifies with satisfactory detail the tumor region. The use of the motion features of the picture's regions seems to provide a reliable estimate of the tumor area, which is clarified after the texture separation procedure. Further improvement could be based on a fusion of the motion information with the intensity image.

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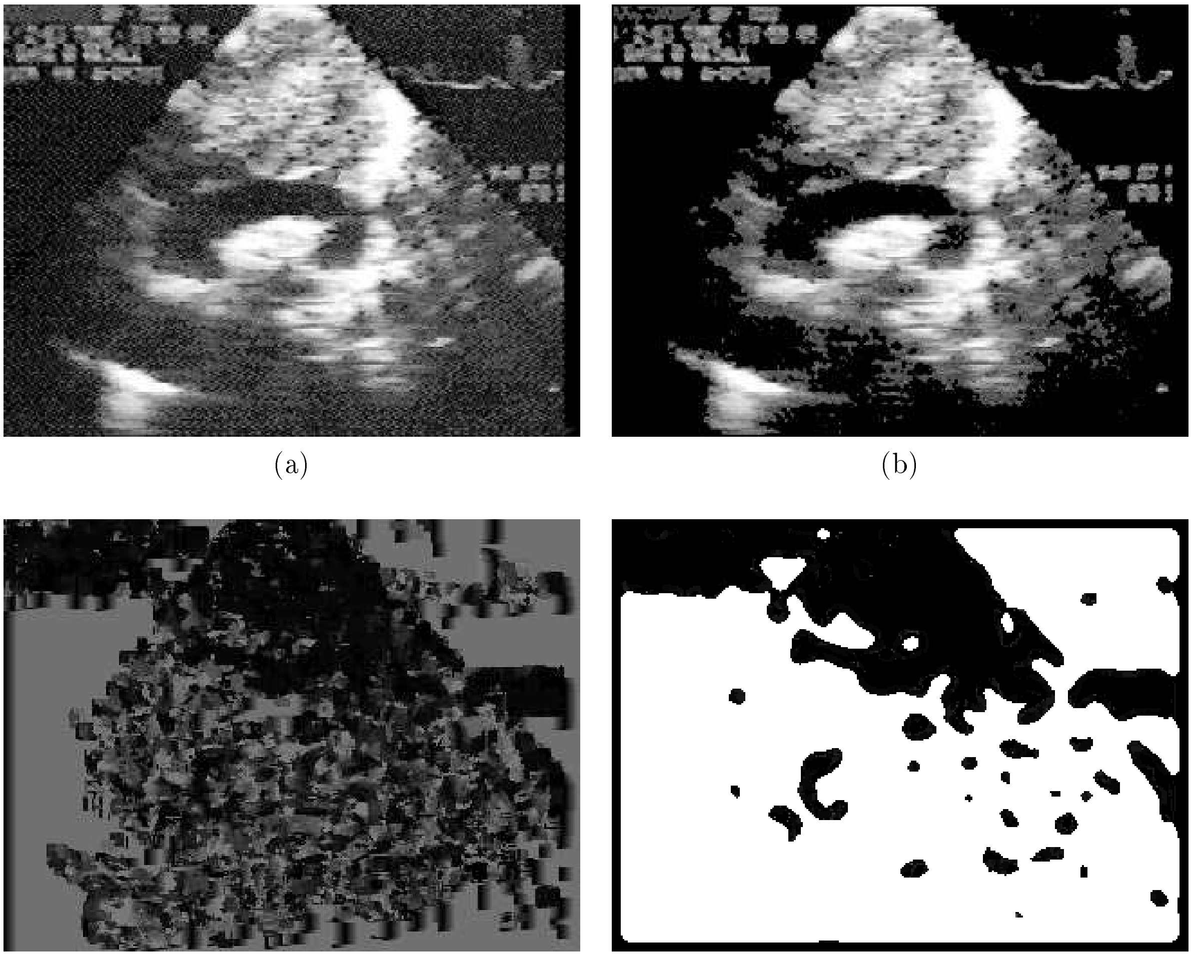

(a) (b)

(c) (d)

Figure 2: The stages of the method. (a) An original frame, (b) The same frame after the noise reduction filtering, (c) The motion magnitude map, (d) The output of the texture separation process.