Ultrasound Image Enhancement using Markov Random Field Model

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Abstract. In this paper, we propose a methodology to improve a parametric image which is a visualization of the transit time in contrast-enhanced ultrasound(CEUS) image. Distortions in the form of lesion in the image for diagnosing liver ailment are resulted due to the respiratory motion and noise. In this study, an optimization technique using MRF(Markov Random Field) model is suggested as the way to improve the problem. An energy function for the Gibbs sampler is defined and the image enhancement algorithm based on it is implemented. The effectiveness of the suggested theory is evaluated by the experiments using the practical medical diagnostic system.

Keywords: Ultrasound image, image enhancement, Markov Random Field

1 Introduction

Evaluation of regional hepatic perfusion by contrast-enhanced ultrasound is helpful to the differential diagnosis of focal liver lesions. However, the contrast agent in the typical ultrasound image progresses in very rapid speed that distinguishing them with naked eye is not easy. Moreover, it is very difficult to extract clear image due to the respiratory motions and the noise of micro bubbles.

In this paper, as a image modeling technique that reflects dependency between pixels in image, MRF (Markov Random Field) model [1] is applied to the image enhancement. First, we have proposed a respiratory motion compensation technique using dynamic weights and a momentum term. Then we have developed an image restoration method based on the Gibbs sampler to enhance the parametric images which are generated by the analysis of the contrast agent transit times.

2 MRF-Based Image Enhancement

We have developed a TIC(time intensity curve) analysis software for the contrast-enhanced ultrasound(CEUS) video data. In recent researches, it has been reported that the arrival time information is helpful to measure the severity of liver disease[2-3]. Therefore, out system provides the TIC analysis results and an arrival time image as
shown in Fig. 1. However, the image includes the noise which is due to the respiratory motions in the diagnosis process.

![Fig. 1. TIC analysis results and an arrival time image for a CEUS video data.](image)

In this study, we have proposed a MRF-based technique to improve the image. The MRF is defined as follows:

$$P(X_s = x_s | X_r = x_r, r \neq s) = P(X_s = x_s | X_r = x_r, r \in \eta_s) ,$$

where $\eta_s$ is the neighborhood system of the pixel $S$. The Gibbs distribution can be shown as the following equation.

$$\pi(\omega) = \frac{1}{Z} \times \exp \left( - \sum c V_c(\omega) / T \right) ,$$

where, the $C$ and $Z$ are the clique and a constant for normalization, respectively. We have defined the potential function $V_c$ as follows:

$$V_c = \begin{cases} + \zeta & i (x_s \neq x_r) and L(x_s, x_r) < \lambda \\ - \zeta & i (x_s = x_r) and L(x_s, x_r) < \lambda \\ + \delta & otherwise \end{cases}$$

where, $L(x_s, x_r)$ is the line element between two pixels on the dual matrix structure of the image.

We have combined the image enhancement technique and a respiratory motion correction technique. The weight adaptation method of our technique can be defined as follows:

$$W'_i = W'^{i-1} + \Delta W'_i,$$

$$\Delta W'_i = \begin{cases} P(v) \cdot (D_{\text{max}} - d(v', k)) & if d(v', k) < D_{\text{max}}, \\ 1.0 - W'^{i-1} & otherwise \end{cases}$$
Ultrasound Image Enhancement using Markov Random Field Model

\[
\rho(t) = \eta \cdot \sin \left( \frac{t - T_0}{\tau} \right) \pi,
\]

where \( \mathcal{W} \) and \( \rho(t) \) are the dynamic weights and the momentum factor, respectively. They reflect the change of the respiratory motions and the image distortions.

In the equations, \( \rho(t) \) is the momentum factor of the respiratory motion and the \( D_{\text{max}} \) and \( D_{\text{th}} \) are the constants to determine the distance between two images. The weight change \( \Delta \mathcal{W} \) is in inverse proportion to the difference between the current decision and the previous location and in proportion to the sine function with the respiration cycle. \( d(v',k) \) is Euclid distance between two location points. The \( T_s \), the start point of a respiration period, is updated from the EOI and SOD periodically.

Since the noise ratio varies with the stages, the value of constant \( \eta \) is selected as a different value for each stage as follows:

\[
\eta \in \{\eta_A, \eta_B, \eta_C, \eta_D\}
\]

3 Experimental Results

A set of CEUS data has been used for the experiments. Fig. 2 shows the experimental results for the image enhancement technique. In the figure, (a) is an original parametric image and (b) is the result of the respiratory motion compensation, and (c) is the result of the image enhancement technique. As shown in the figure, the noise and distortion can be effectively reduced through the proposed method.

![Fig. 2. Experimental results: (a) the original parametric image, (b) the motion correction result, (c) the result of the image enhancement technique.](image-url)
4 Conclusions

In our tracking algorithm, the dynamic weights reflect the momentum factor for the variance of the ROI location and the noise ratio. The MRF-based optimization process has been implemented to enhance the parametric images for ultrasonography. The edge element terms are included in the potential function to prevent the loss of boundary information of the images. A pixel classification technique has been used for the parametric imaging in which four-color images are generated. The experimental results show that the proposed method can reduce noise of the parametric images and can effectively detect the object regions in ultrasound images.

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References