077 **TWO-STEP DETECTION OF DISPLACEMENT FOR ELASTOGRAPHY USING GRAPH CUTS.**

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Abstract: Graph cuts have attracted a great deal of attention for many vision and image processing problems, for example image recovery, segmentation and stereo reconstruction. On the other hand, elastography has been examined as an important medical diagnostic imaging. Remarkably, displacement detection required in elastography is equivalent to disparity detection in stereo reconstruction. Therefore, in this study, we propose an application of graph cuts for elastography. Especially, to construct a stable and a cost-effective algorithm, we firstly use envelopes of RF echo signals to detect large displacement sparsely, and next we use RF echo signals themselves to detect precise displacement densely. The effectiveness of the proposed algorithm is confirmed through numerical experiments using artificial images.

I. Introduction

Graph cuts can effectively perform global minimization of a certain kind of energy functions, and have attracted a lot of researchers as a useful tool for computer vision and image processing problems, for example image recovery [1], segmentation [2], image and video synthesis [3]. Especially, they can be used successfully for a stereo matching problem, and a lot of important results have been reported on this topic [1, 4 – 7]. On the other hand, elastography has been examined as an important medical diagnostic imaging [8, 9]. In elastography, the detection of displacement between echo signals measured before and after static compression of biological tissue is required, and this detection formally coincides with disparity detection in stereo matching from a viewpoint of signal processing.

From the above matters, in this study, we try to apply graph cuts to elastography in order to solve stably and efficiently the trade-off problem which consists of data consistency and penalty constraint for displacement. In consideration of high S/N imaging, our algorithm is based on an FM chirp pulse compression method instead of the usual pulse method.

Although usual displacement detection in elastography uses RF echo signals for processing, in this case an alias problem arises if the displacement is larger that the wavelength of the carrier wave. To solve this problem, we propose a two-step detection scheme as in [10], in which registration using an envelope waveforms of RF echo signals is firstly performed to detect large displacement, and subsequently registration using carrier waveforms and prior information propagated from the first registration step is done to detect precise displacement. This two-step scheme enables a stable detection. Additionally, to realize a cost-effective detection, for both registrations graph cuts can be adopted. Displacement detection needs multi-valued label assignments, and hence, multi-valued minimization of the energy function is required. However, in general, global minimization for such problems needs a large amount of computations. Therefore, for the both minimizing steps, we use the graph cuts application proposed by Kolmogorov and Zabih [6], which is used for a stereo reconstruction and outputs local minimum solution using the alpha expansion algorithm.

As a first attempt of graph cuts for elastography, in this study we examine the effectiveness of the proposed method through numerical experiments using artificially made images.

II. Methods

Graph cuts algorithm: Firstly, we briefly explain the algorithm in [6] which we call "KZ1" and the source code can be downloaded from [11]. This algorithm was constructed for multi-camera scene reconstruction using graph cuts. For consistency of multiple disparities caused by multi-camera system, the algorithm assigns depth label instead of disparity label, i.e., disparity label is assigned implicitly. Although in elastography the notion of depth is not needed, when multiple echo signals observed by continuous compression of tissue are used in future, virtual use of depth makes the algorithm simple and easy to be implemented. Therefore, in this study, we try to assign depth label virtually, but as an output it is converted to displacement label.

Energy function used in KZ1 for two-camera stereo is defined as follows:

$$E(f) = E_{data}(f) + E_{smoothness}(f) + E_{visibility}(f), \tag{1}$$

where $f(p)=l$, i.e., f is a mapping from pixel p to depth label l and $\langle p, f(p)\rangle$ indicates a 3-D position. The data term will impose photo-consistency, and it is

$$E_{data}(f) = \sum_{<p,f(p)>,<q,f(q)>\in I} D(p,q), \qquad (2)$$

where I is the set of interactions consisting of pairs of 3-D points $<p_1, l_1>$, $<p_2, l_2>$ "close" to each other in 3-D space, and p_1 is in the left image and p_2 is in the right image. $D(p,q)$ is a non-positive value depending on the intensities of the pixels p and q, and it is defined using some constant $K > 0$ as

$$D(p,q) = \min\left\{0, \left(Intensity(p) - Intensity(q)\right)^2 - K\right\}. \qquad (3)$$

The smoothness term imposes smooth label assignment for 4-neighborhood system N, and it is

$$E_{smoothness}(f) = \sum_{\{p,q\}\in N} V_{\{p,q\}}\left(f(p), f(q)\right) \qquad (4)$$

and $V_{\{p,q\}}$ is a simple Potts model with consideration of difference of the intensity between p and q.

The last term will encode visibility constraint. This means that the pixel pair p and q which can intersect in 3-D space has to have the same label corresponding to visible depth. Although the details of the definition is omitted, this term is typical for KZ1. By this constraint, we can avoid forcibly matching pixel which is not visible by occlusion.

The energy function E defined in Eq. 1 can be efficiently minimized using graph cuts. Each term in the energy is reflected in the weight of an edge included in a graph having two terminal vertices $\{s, t\}$ called the source and the sink. An example is shown in Fig. 1, for binary variable problem. The labels to be determined are assigned to the vertices except for s and t. A cut C is a partition of the vertices into two sets such that S includes s and T includes t. The cost of the cut equals the sum of the weights of the edge connecting a vertex in S and a vertex in T. The minimum cut problem coincides with finding the cut with the smallest cost, and can be solved very efficiently by computing the maximum flow between the terminals. There are a large number of fast algorithms for this problem, generally called "min-cut/max flow algorithm."

On the other hand, for the problems requiring multi-valued label assignments, global minimization of the energy needs highly complicated graph and large amount of computational cost. Hence, KZ1 uses the α-expansion operation proposed in [1] to perform local minimization with relatively small cost. We select a label value α, and we find the unique configuration within a single α-expansion move. If this move decreases the energy, then we go there; if there is no α which decreases the energy, operation is done. The min-cut/max flow algorithm applied to each single α-expansion move is that proposed in [12].

Two-step detection: To detect accurate displacement in elastography, generally RF echo signals are used for processing. However, when the displacement is larger than the wavelength of the carrier wave, alias problem may arise. Like the coarse to fine approach usually used in signal processing, we propose a two-step method using an envelope waveform as a coarse signal and an RF waveform as a fine approach. Processing steps are defined as follows:

(i) Envelope signals of both RF echo signals measured before and after compression of biological tissue are computed.

(ii) Large displacement is roughly detected by applying KZ1 using the envelope signals with down-sampling in consideration of the cost-effective detection.

(iii) The RF echo signal measured before compression is deformed in accordance with the large displacement detected in step (ii).

(iv) The perturbation around the large displacement detected by step (ii) is computed by KZ1 using the RF echo signals obtained by step (iii) and that measured after compression.

(v) The sum of the large displacement by step (ii) and the offset one by step (iv) is computed as an output.

The reason why the deformation of the RF signal is performed in step (iii) is that in the usual α-expansion operation, which is used in KZ1, the variable range of labels are common to all sampling points, and we can not vary each label value separately around the value detected by step (ii) for each sampling point. We will develop the function which enables to use the individual label range for each sampling point in future.

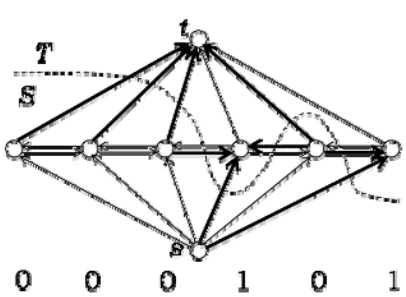

Fig.1: Example of Graph for binary problem. The below numbers indicate the assigned labels for the corresponding vertices. The bold lines indicate the cut edges.

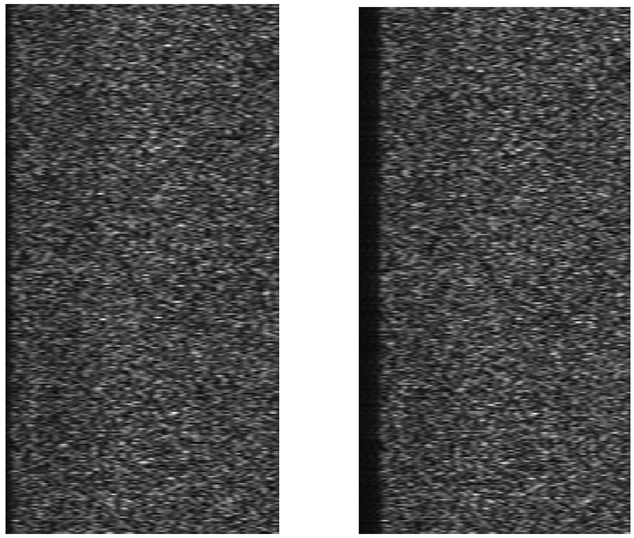

Fig. 2: Artificial B-mode images. (a) before compression and (b) after compression.

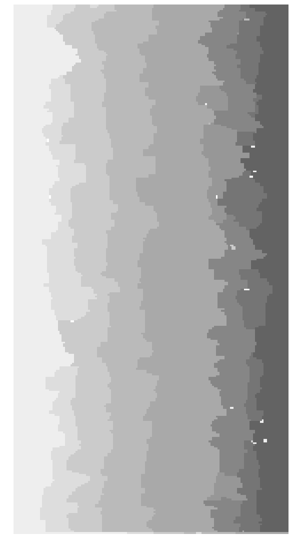

Fig. 3: Image representation of detected large displacement using envelope signals.

III. Results

In order to confirm the performance of our method, we carried out numerical experiments using artificial images, which were made in the following way. Firstly, we assume that there are three layers having different elasticity and in each layer some point-scatterers having random reflection rate are randomly distributed. We suppose an FM chirp pulse compression method, and for simplicity, transmitted beam width and reflected beam spread for the azimuth direction are constant along the range direction. Transmitted FM chirp signals have 10 MHz of central frequency, 8 MHz of frequency bandwidth and 20 μm of pulse width. Sampling rate of RF echo signals is 100 MHz. Figure 2(a) indicates an example of B-mode image before compression, which is a set of envelope signals generated from echo signals by pulse compression and by quadrature detection. In this figure, a transducer is assumed to be at the left end side. The main-lobe width of the compressed pulse here is approximately five sample points. After slight static compression from left to right, we again produce RF echo signals and envelope signals shown in Fig. 2(b).

Figure 3 shows the result of the large displacement computed using the envelope waveforms, which is the output of step (ii) described in the previous section. The down-sampling rate is one fourth. The parameters values are adjusted automatically in KZ1. In the experiments, to evaluate the applicability of our method, the large displacement is given to the echo signals after compression. Hence, the displacement range, i.e. variable range of the label, is set as (0 – 10) sample points after down-sampling, which correspond to (0 – 40) points with the original sampling rate. Figure 3 is an image representation of the displacement with a grayscale range of (0 – 10). The CPU time of this result is 4.34 sec with Intel Core2Quad 2.66 GHz.

The output of step (iv) is shown in Fig. 4 as an image, for which the parameters are also determined automatically, and the displacement range is set as (-5 – 5) sampling points. In step (iv), the number of sampling points is large, but we can reduce the variable range of the label as compared with the method in which graph cuts are directly applied to the RF echo signal, since the offset displacement is computed in this step. The CPU time for the result shown in Fig. 4 is 63.64 sec. Subsequently, the output of step (v) is shown as an image in Fig. 5, and the total CPU time is 67.98 sec. The certain line information in Figs. 3, 4, and 5 is quantitatively shown in Fig. 6. In this figure, the vertical axis indicates a displacement as a sampling point with the original sampling rate. Additionally, "envelope" indicates the result by step (ii) converted into the original sampling rate, "carrier" indicates that by step (iv), and "total" indicates that by step (v). The grand truth is also shown as "true." From these results, we can conclude that our method can compute accurate displacement stably. To compare the effectiveness, in Fig. 7, we show the result by directly applying KZ1 to the RF echo signals as "carrier only." The displacement range is set as (0 – 40). This result indicates that graph cuts are comparatively robust for alias problem, but the severe errors are caused for very large displacement. Furthermore, the CPU time is 142.92 sec, hence we can confirm that the proposed two-step method is highly efficient.

IV. Conclusions

We construct a two-step method for detecting the displacement in elastography using graph cuts, especially Kolmogorov and Zabih algorithm. This can perform stable and cost-effective detection avoiding an alias

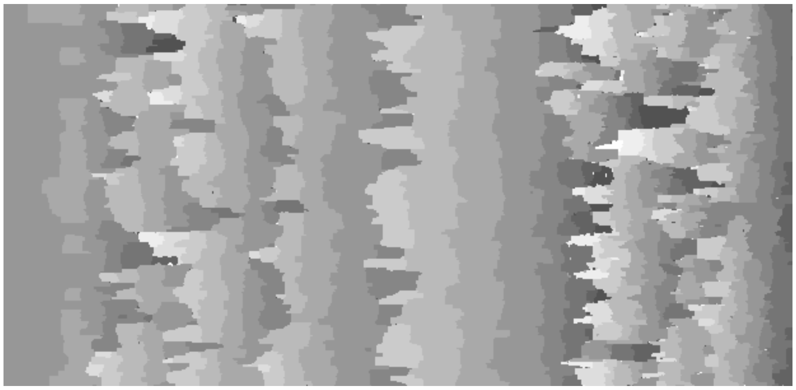

Fig. 4: Image representation of detected offset displacement using RF signals.

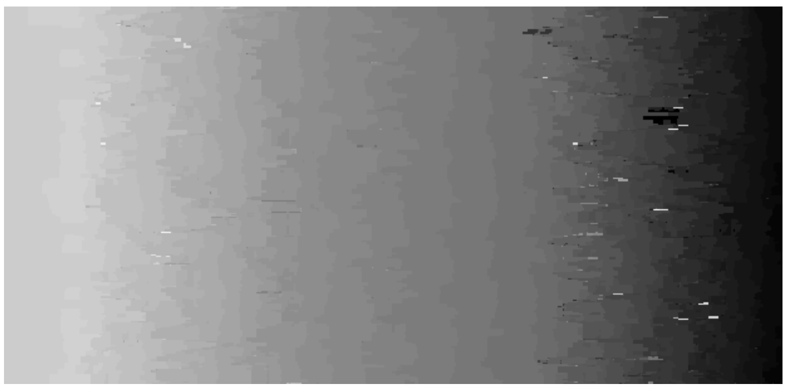

Fig. 5: Image representation of detected total displacement by proposed method.

problem. The effectiveness of our method was confirmed by numerical experiments. For the next step, we have to show the performance of our method for real ultrasound images. Additionally, using harmonic echo signals, we are going to improve this method in order to detect higher accurate displacement in the future.

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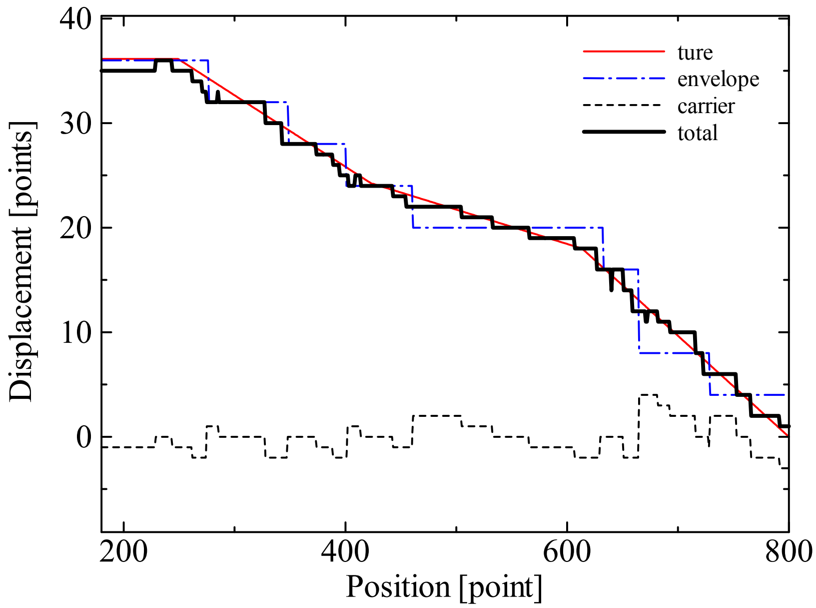

Fig. 6: Quantitative representation of detected displacement by the proposed method.

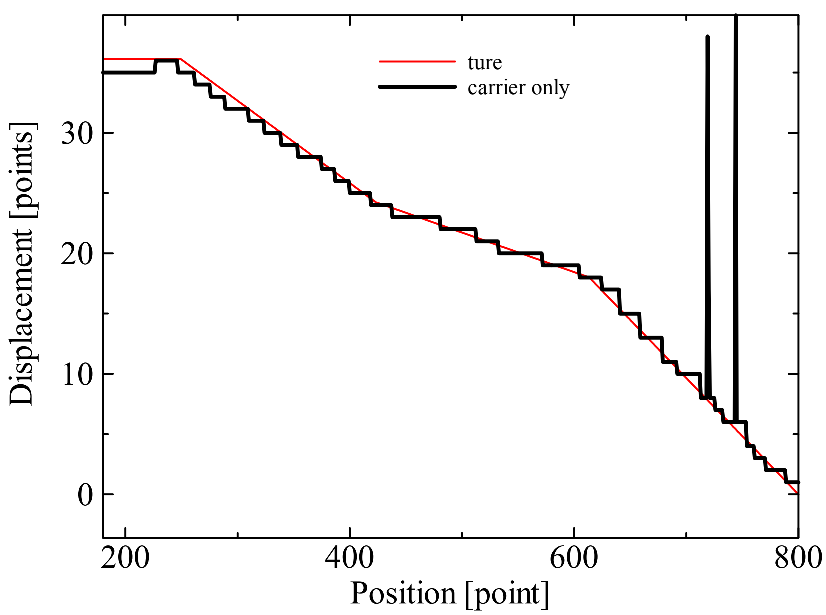

Fig. 7: Quantitative representation of detected displacement by applying graph cuts directly to the RF echo signals.