Ultrasound Extended-Field-of-View Imaging Based on Motion Estimation Using Quaternion Wavelet

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Abstract—**In this paper, we propose a novel extended-field-of-view (EFOV) imaging algorithm based on the property of motion estimation in quaternion wavelet domain (QWD) for ultrasound images. Firstly, transform the ultrasound video frames into QWD from spatial domain, and the result consists of one magnitude and three phases. Secondly, use two phases to estimate the motion of image sequence derived from the shift theorem. We can obtain the motion vectors through motion estimation, and the registered images through the affine transform of the motion vectors. Thirdly, use the third phase with the magnitude to fuse the registered images. Finally, the ultrasound panoramic image is achieved by means of fusing the registered images. Finally, experiments are conducted to verify the performances of the proposed algorithm.**

Keywords-ultrasond extended-field-of-view; motion estimation; quaternion wavelet; affine transform; image fusion

I. INTRODUCTION

Ultrasound imaging is an essential part of medical imaging technology. Due to its portability and the safe, real-time, non-invasive characteristics, ultrasound imaging has been more and more popular with a wide range of applications for medical diagnosis purposes.

The drawback of traditional ultrasound image is that the view field of examiner for local tissue is limited and narrow by the width of the transducer which is typically 4 to 6 cm such that the global view of the whole lesion area cannot been observed [1] The examiner has to analyze multiple images separately when larger or longer structures, like the arm muscle tissue and the carotid artery, are imaged. This is increasingly prominent with the rapid development of ultrasound and computer technology [2]. Ultrasound EFOV technique provides high-quality panoramic images in real time by experts' free-hand scanning with standard probes, first introduced in 1997 [3]. EFOV imaging is a sort of medical application of image mosaics, which is also called panoramic imaging. EFOV obtains a series of two-dimensional ultrasound images by transducers moving along the patient's anatomy in almost the same plane surface. The series of multiple images is spliced into a consecutive and long panoramic image with an extremely wide field of view using image processing techniques.

The important steps in EFOV technique are image registration and fusion. The image registration is the core of ultrasound EFOV imaging which finds the relative translation and rotation between adjacent images and determines the accuracy of EFOV, meanwhile the effect of image fusing is closely relevant with visual quality. Weng first measured the probe motion by means of using an image registration technique in the literature [3]. The current frame (termed as moving image) is divided into non-overlapping blocks. Each image block is matched to the corresponding positions in the previous frame (termed as fixed image) and the result is to obtain a group of local motion vectors. Then a least-square optimization technique is used to derive the global motion from the local motion vectors. Some literatures [4, 5] made a certain improvement on the basis of the literature [3].

Quaternion wavelet was first introduced by T. Bulow in his Ph.D dissertation [6] and provides a powerful and efficient tool for multiscale analysis of images, which has been paid increasing attentions. In the literature [7], W. Chan makes use of the dual-tree filter bank with linear computational complexity to compute QWT and estimates the disparity between a pair of images.

In this paper, we present a novel ultrasound EFOV framework in the light of the QWT's latest development. Ultrasonic image sequence can be regarded as video owing to high frame rate of ultrasound imaging which make the displacement between two successive frames is small. The initial idea of the paper is to achieve EFOV from a motion estimation point of view rather than image registration taking advantage of the development in video or optical flow motion estimation. Thus the algorithm avoids the procedure of searching for matched blocks on the basis of sifting feature points and/or blocks. Our algorithm uses two phases in the result of QWT for the input images to estimate the motion of video frames by shift theorem and the third phase with magnitude to fuse the registered images.

The rest of this paper is organized as follows. Section II presents a brief introduction to existing general algorithm of EFOV. The basic knowledge on QWT and motion estimation framework based on QWT are explained in Section III. Besides, the proposed algorithm is also described in detail in this section. In Section IV, the experimental results and corresponding analyses are given. Finally, we draw the conclusions with future work in Section V.

II. OVERVIEW OF EFOV

As a form of image mosaics, although there are different techniques for each step, EFOV has four essential steps [8], shown in figure 1. We describe them in a general way as follows.

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1) Acquire the images: Different image acquisition will cause different input images , and affect splicing result. According to the application background, we choose specific image acquisition means.

2) Match the images: Find the corresponding postions of templates or points of interest in the image to be spliced (denoted as image S) from reference image (image R).

3) Align the images: Calculate geometric transformation parameters from the image S to the image R. And then uniform two image coordinates and determine the overlapping regions to obtain the aligned image, denoted as Image A.

4) Fuse the images: Adopt a certain fusion stategy for image A to eliminate the gaps and discontinuous regions owing to the fact that there are seams in the sliced regions and blurring or distoration in the overlapping regions.

Typically, step 2) and 3) are carried out together, known as image registration.

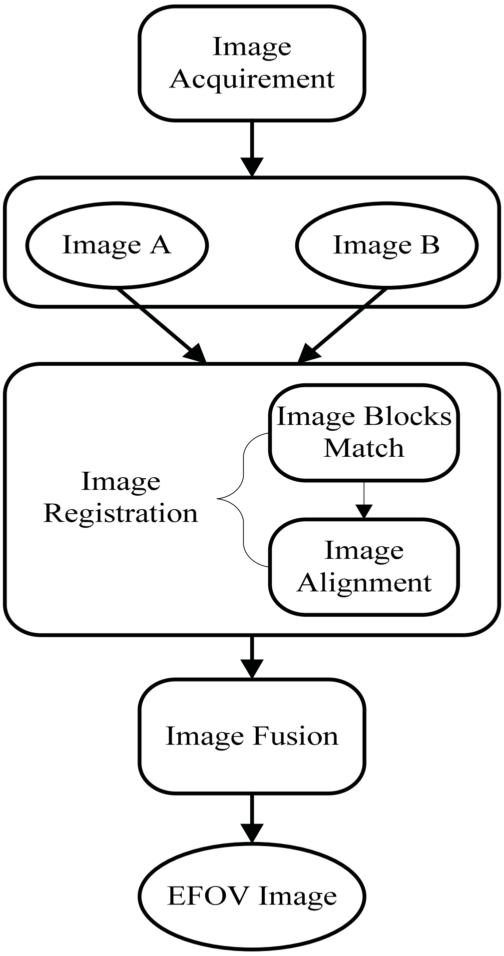

Fig. 1. The flow chart of EFOV

III. Description of QWT Based EFOV Algorithm

A. Basics

For convenience of further discussions, we briefly review some basic ideas on quaternion and construction of QWT.

The quaternion algebra H was invented by Hamilton in 1843 which is a generalization of the complex algebra.

$$\mathrm{H} = \{ q = a + bi + cj + dk \mid a,b,c,d \in \mathrm{R} \} \tag{1}$$

where the orthogonal imaginary numbers i , j and k satisfy the following rules

$$i^2 = j^2 = k^2 = -1,\ ij = k,\ jk = i,\ ki = j \tag{2}$$

An alternative representation for a quaternion is

$$q = |q| e^{i\phi} e^{k\psi} e^{j\theta} \tag{3}$$

where $(\phi,\theta,\psi) \in [-\pi,\pi[\times [-\pi/2,\pi/2[\times [-\pi/4,\pi/4]$ .It is defined by one modulus and three angles that we call phase. The computational formulae refer to [9].

The quaternionic analytic signal is defined by its partial (H_1, H_2) and total (H_T) Hilbert transforms (HT).

$$f_A(x,y) = f(x,y) + iH_1(f(x,y)) + jH_2(f(x,y)) + kH_T(f(x,y)) \tag{4}$$

If the mother wavelet is separable,

$$\text{i.e. } \psi(x,y) = \psi_h(x)\psi_h(y) \tag{5}$$

the 2D HT's is equivalent to 1D HT's along rows and/or columns. Considering the 1D Hilbert pair of wavelets $(\psi_h, \psi_g = H\psi_h)$ and scaling function $(\varphi_h, \varphi_g = H\varphi_h)$, the analytic 2D wavelets are written in terms of separable products.

$$\psi^D = \psi_h(x)\psi_h(y) + i\psi_g(x)\psi_h(y) + j\psi_h(x)\psi_g(y) + k\psi_g(x)\psi_g(y) \tag{6}$$

$$\psi^V = \varphi_h(x)\psi_h(y) + i\varphi_g(x)\psi_h(y) + j\varphi_h(x)\psi_g(y) + k\varphi_g(x)\psi_g(y) \tag{7}$$

$$\psi^H = \psi_h(x)\varphi_h(y) + i\psi_g(x)\varphi_h(y) + j\psi_h(x)\varphi_g(y) + k\psi_g(x)\varphi_g(y) \tag{8}$$

$$\varphi = \varphi_h(x)\varphi_h(y) + i\varphi_g(x)\varphi_h(y) + j\varphi_h(x)\varphi_g(y) + k\varphi_g(x)\varphi_g(y) \tag{9}$$

Each sub-band of the QWT can be seen as the analytic signal associated with a narrowband part of the image. The QWT magnitude |q|, with the property of shift-invariance, represents features at any spatial position in each frequency sub-band, and the three phases (ϕ,ψ,θ) describe the 'structure' of those features. More details about implementation and phases of quaternion wavelet are referenced to [7] and [9], respectively.

B. Proposed algorithm

In this part, we describe the proposed algorithm used for the ultrasonic EFOV outlined in figure 2 and detailed in algorithm 1 as follows.

1) Motion estimation based on QWT

First, we transform the fixed image and moving image into QWD. Each QWT coefficient can be expressed in terms of formula (3). The literature [8] verifies that the QWT holds shift theorem approximately. When we shift an image from $f(x)$ to $f(x-r)$, the QWT three phases undergo the following change:

$$\left(\phi(u),\theta(u),\psi(u)\right)\rightarrow\left(\phi(u)-2\pi ur_1,\theta(u)-2\pi vr_2,\psi(u)\right) \quad (10)$$

where u is a frequency parameter in QWD and $r=(r_1,r_2)$ denotes the shift in the horizontal /vertical spatial coordinate system with (u,v) is defined as effective center frequency for the corresponding wavelet coefficient.

To estimate the image shift, we should first calculate the effective center frequency (u,v), and then we can achieve the estimation for image shift from the phase change $\Delta\phi,\Delta\theta)$ through (11). Conversely, we can measure the phase change through a given image shift. We set the image shift to a given value, and then measure the phase shift $(\Delta\phi,\Delta\theta)$, so we obtain the (u,v) using (12).

$$(r_1,r_2)=\left(\frac{\Delta\phi}{2\pi u},\frac{\Delta\theta}{2\pi v}\right) \quad (11)$$

$$(u,v)=\left(\frac{\Delta\phi}{2\pi r_1},\frac{\Delta\theta}{2\pi r_2}\right) \quad (12)$$

2) Affine transform

When we get the image shifts for blocks with an assigned size, we have to collect all of them to form a projection for the whole image because we aim to produce a panoramic image rather than bitty fragments caused by blocks shift.

For points set $\{\mathbf{x}_i\}$, we have obtained the destination $\{\mathbf{y}_i\}$ through (11), and we can find the motion vector naturally. Using the method in [10], we collect all the vectors to form affine transformation matrix:

$$\mathbf{M}=\begin{bmatrix} c\cos(\theta) & -c\sin(\theta) & tx \\ c\sin(\theta) & c\cos(\theta) & ty \\ 0 & 0 & 1 \end{bmatrix} \quad (13)$$

where c, θ and (tx,ty) mean zoom, rotation and translation respectively.

3) Image fusion

The literature [11] proposed the potential use of QWT in image fusion. As mentioned above, there is one magnitude with three phases in QWT decomposition coefficients. It is obvious that they have their own characteristics. We design initial strategies for projection of two images after affine transform here. A simple energy-based fusion method is adopted that the larger coefficients are preferred for generating the fusion result across scales except that at the coarsest scale the coefficients are averaged for both magnitude and three phases.

Algorithm 1 Motion estimation based ultrasound EFOV imaging in QWD

-**Input**: Fixed image I_1, moving image I_2 with desired quaternion wavelet decomposition level and given step length N to calculate the center frequency.

1) Do QWT of I_1 and I_2 to get quaternion expression in one real part and three imaginary parts;
2) Put the quaternion into magnitude-phase form;
3) Calculate the phases shift $(\Delta\phi_1,\Delta\theta_1)$ between I_1 and I_1 shifting N steps, and estimate the center frequency (u_1,v_1);
4) Estimate the image block shift $r=(r_1,r_2)$ with $\Delta\phi,\Delta\theta)$ between I_1 and I_2;
5) Collect all the blocks shift, and obtain a global motion vector using affine transform;
6) Project the I_2 into coordinate of I_1 through (13) and fuse the corresponding pixels;

-**Output**: The panoramic image.

IV. Experimrental Results and Discussions

The basic assumption for ultrasound EFOV technology is that the examiner moves the probe along the surface of the object. Meanwhile translation direction is almost parallel to the scanning plane. In the process of moving probe, the speed remains constant to guarantee a series of images with small displacements.

We conduct the experiments using color doppler ultrasound system SonoScape 'A6' developed by our laboratory. We acquire a series of 259 frames ultrasound images. For step 4) in the algorithm 1, we can achieve motion estimation as red arrows labeled in figure 3. Finally, we get EFOV image through the algorithm procedure in figure 4.

From the result of motion estimation in figure 3, we find that most of the estimated shift directions accord with the examiner moving direction while there are minor estimation errors for an approximate translation in the labeled white square caused by QWT phase estimation, and that the direction in the white square goes against the whole translation trend. In figure 4, we find that the trend of the probe moving along the arm muscle tissue has been exploited. The panoramic image reflects the reasonable tissue textures of which visual perception is acceptable, but at the same time we find there are slight seams between two successive frames marked in the white squares. Deep reasons and the solution for estimation errors need to be discussed. We will focus on more excellent fusion methods based on magnitude and phases of QWT. Besides, program runtime needs to be considered.

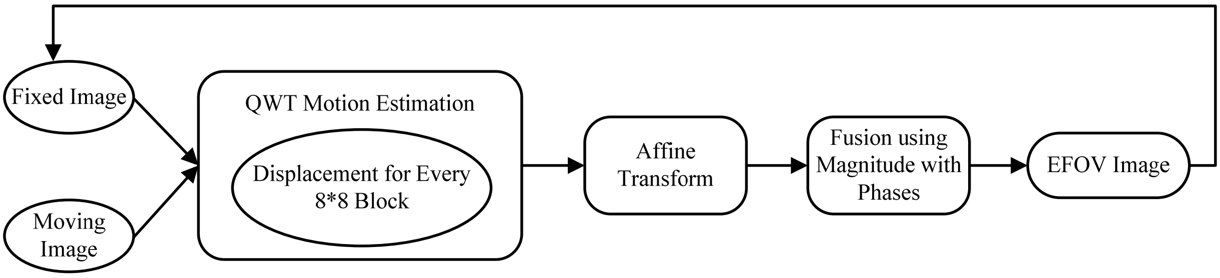

Fig. 2. Block diagram of proposed algorithm

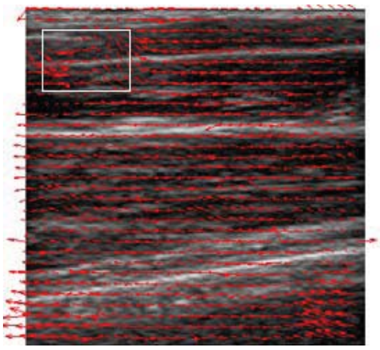

Fig. 3. Result of motion estimation

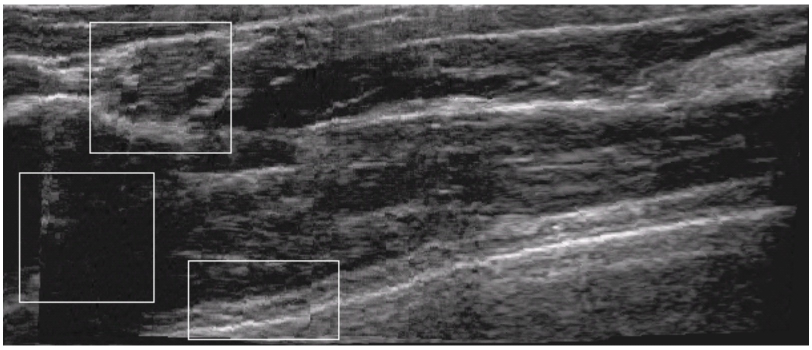

Fig. 4. Result of EFOV ultrasound based on QWT

V. CONCLUSIONS

In this paper, we introduce an ultrasound EFOV imaging framework from a novel point of view based on motion estimation in the light of the QWT's up to date development. First, put the ultrasound video frames into QWD from spatial domain. The algorithm uses two phases in the result of the QWT for the input images to estimate the motion of image sequence in the light of shift theorem and the third phase with magnitude to fuse the registered images. Finally, the visual perception needs to be improved.

VI. ACKNOWLEDGMENT

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