Robust feature based pre-registration of 3D MR image to 3D B-mode ultrasound image of the liver

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Introduction and purpose Multimodal image registration has started to be widely used in many medical applications such as image based diagnosis, surgical planning, and image guided intervention. Especially, high quality MR images precisely aligned with real-time ultrasound (US) images can provide useful complementary information to surgeons and radiologists [1-3]. Since most existing registration algorithms are based on an optimization method, the estimation of reliable initial transformation parameters for the alignment is critical to the final registration accuracy. To obtain initial parameters in the liver registration, most existing methods adopt a pre-registration procedure based on several manually-selected point correspondences on vessel bifurcations. However, this manual procedure is time-consuming and not easy to perform due to the different respiratory-phases as well as different coordinate systems between the images [3]. In addition, it is much more difficult to perform the manual pre-registration procedure in an abnormal liver where the anatomical features are not clearly visible. Therefore, the procedure should be not only automatic but also less dependent on the number of the features. In this paper, we propose an automatic and robust pre-registration algorithm which can compensate a large displacement between MR and US liver images. In the algorithm, the inferior vena cava (IVC) and the liver surface are adopted as features, because they can provide consistent feature correspondences regardless of the status of a patient's liver. For the automation procedure, we utilize the rigid geometric relationship between the features in the registration. Reliable initial transformation parameters obtained from the proposed pre-registration algorithm can help to avoid a local minimum in the following precise registration procedure.

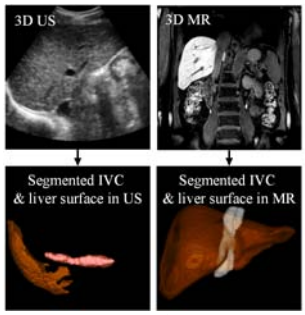

Fig. 1. Segmented features obtained from a 3D US image and its corresponding 3D MR image

Method The proposed pre-registration algorithm based on the IVC and the liver surface, can be described with the following five steps:

Step 1. Acquire a set of 3D MR and 3D B-mode US images at similar respiratory phases.

Step 2. Extract the features on each image. This step is automatically and semi-automatically performed in US and MR images, respectively.

1. Segment a liver surface and determine its sample points.
2. Segment the IVC and extract its centerline.

Step 3. Perform the extracted feature alignment between the images.

1. Transform the MR and US features using an Euler angle rotating matrix $\mathbf{R}_{\text{align}}$ so as to align two IVC centerlines [4]. This step simplifies the subsequent procedures, and increases the robustness by reducing the number of transformation parameters to be computed, from 6 to 2.
2. Generate geometric distance maps between a straight centerline of IVC and sample points of liver surface for MR and US images, respectively.
   a) Fit a straight line to the obtained IVC center line via principle component analysis.
   b) Using a pre-defined sampling interval, determine M sample points on the straight line of US and M' sample points of MR. Note that $M' > M$ because the FOV of MR is always larger than that of US.
   c) Determine N discrete directions perpendicular to a straight line, with a uniform angular interval.
   d) Build two 2D geometric distance maps; one of M x N for US and the other of M' x N for MR, as shown in Fig. 2.
   e) Calculate a distance from a sample point on the straight line to the liver surface and assign it to the corresponding pixel value on a map.
3. Determine the translated and rotating parameters between two transformed images by aligning two geometric distance maps of MR and US. For the alignment, the average of absolute differences is used as a measure.

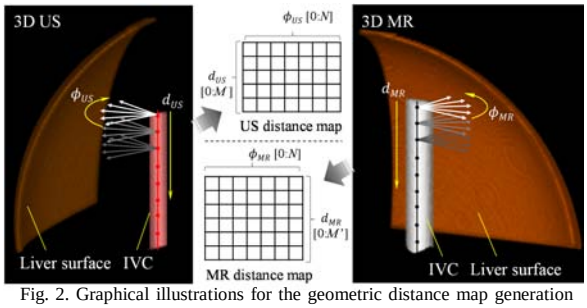

Fig. 2. Graphical illustrations for the geometric distance map generation between IVC and liver surface in IVC-aligned US and MR images

Step 4. Determine 6 rigid transformation parameters by combining the translated and rotating parameters obtained in step 3.3 with inverse matrix $\mathbf{R}_{\text{align}}^{-1}$.

Step 5. Transform the MR image to the US image domain based on the obtained rigid transformation parameters.

Experimental results To evaluate the performance of the proposed algorithm, we use two clinical datasets. For each dataset, a 3D MR image was acquired at an exhalation phase in a breath-hold manner using a Philips Medical Systems Achieva 3.0T. The image dimension is 320 x 320 x 85 with a voxel size of 1.094 x 1.094 x 2.2 mm^3. At a similar exhalation respiratory phase, the corresponding 3D US image was acquired by using a Medison Accuvix XG ultrasound scanner equipped with a mechanical 3D transducer. The image dimension is 200 x 200 x 200 with an isotropic voxel size of 0.46 mm^3. Fig. 3 shows the proposed pre-registration results for the two datasets. For qualitative evaluation, in the figure, we mark several pairs of arrows at the same position in both images. As expected, the figure shows that the proposed algorithm can pre-register MR and US images with reasonably good accuracy, even for a large initial displacement between two images (refer to Fig. 1 for the displacement of dataset 1.). Small images at the bottom right represent the transformed US features that are registered to the MR features in the MR image domain. For the quantitative evaluation, we obtain the fiducial registration error (FRE) by using carefully selected five fiducial point correspondences, mostly on vessel bifurcations. The evaluation results in Table 1 show that the average FRE is less than 5mm with the maximum of 5.3mm. Meanwhile, the average computation time is less than 2 seconds in a standard PC with a 2.7 GHz CPU.

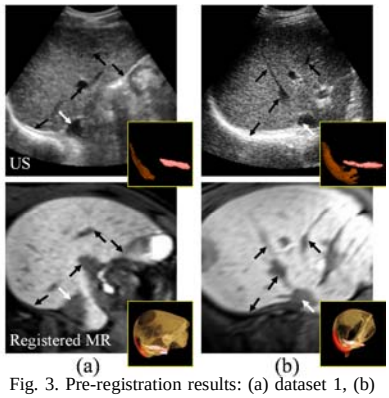

Fig. 3. Pre-registration results: (a) dataset 1, (b) dataset 2.

	Dataset 1	Dataset 2
mean (±STD) [mm]	4.10 (±0.54)	4.39 (±0.62)

Fig. 4. Table 1. Average FRE

Discussion and conclusion In the multimodal registration based on an optimization method, the determination of reliable initial transformation parameters is important to the accuracy of final precise registration. In this paper, we propose a pre-registration algorithm of the liver between 3D MR and 3D US images. From the observation on various clinical datasets, the algorithm proposes to use the IVC and the liver surface as features for pre-registration. Since those features are patient-independent and consistently visible, the algorithm allows us to robustly pre-register the two multimodal images even if the intervention target area in the liver has no visible features. Experimental results show that this automatic algorithm can provide initial transformation parameters that are sufficiently accurate for the following precise registration such as non-rigid registration.

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