An Energy Competing Regime for Active Contour Segmentation of Liver Boundary

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Context

Liver carcinoma is one of the most unpredictable conditions that can cause a large amount of death every year. Surgical resection is one of the most frequently used curative therapies. However, resectability is an essential question, which depends primarily on the location of a tumor and its spatial relations with major hepatic vessels. If there is no reliable means of classifying these patients before surgery, at least half the patients who are surgically explored for hepatic resection cannot be resected. Thus, as a computer-assisted surgery preparation, accurate imaging and automatic segmentation techniques are required to visually detect the organ and tissue boundaries of interest. Liver surface segmentation is one of the major tasks, with two difficulties: Firstly, in certain scanning planes, the intensities of liver and kidney are similar which makes their contacting boundaries weak and fuzzy; Secondly, in some cases, the liver tail and the top of the heart can easily be visually confusedwhen the aid from adjacent slices is not given. The authors propose a new energy competition strategy for Active Contours to tackle these two problems found in liver weak boundary segmentation.

Imaging and Active Contour Methods Employed

To obtain high quality of imaging, this proposed method employs a Liver Acquisition with Volume Acceleration (LAVA) magnetic resonance imaging (MRI) scan sequence to collect patient data, which combines contrast-enhanced, multi-phasic imaging with effective fat suppression for MR liver imaging, and achieves 25% more resolution with 25% more coverage at a speed unmatched by standard MR, enabling imaging the liver of a patient who has trouble holding his or her breath. To precisely detect irregularly shaped areas with extremely indistinct or fuzzy boundaries during the segmentation process, it integrates "Chessboard Directional Sharpened Geometric (CDSG) Active Contours (Snakes)", a segmentation approach newly proposed by the authors in mid 2006, to enhance the weak-edge search sensitivity with highly improved detection efficiency. CDSG Snakes was developed for automatic measurement of knee cartilage thickness from spoiled-gradient volume images. It integrates general gradient vector flow (GGVF) forces with upwind direction constraints and implements a fast and edge-enhanced directional distance transform method outside narrow bands which are masked over automatically detected bone boundaries. The discrete partial differential numerical solution is built on a level set approach. Under the precisely located constraint of a narrow band, CDSG algorithm proved to be robust in the presence of weak and fuzzy image features and even "invisible" boundaries between contacting cartilages. Compared with the GGVF Snake, CDSG active contour is more tolerant of disconnected fuzzy edges and noise in images; sticks more precisely to the crest of ridges; and is nearly 3 times faster.

Energy Competing Regime for CDSG Active Contours

For accuracy, the detection progress of CDSG is split into 2 steps in knee cartilage boundary detections. First of all, image denoising and bone boundary detection, which is robust and automatically initialized utilizing the result from the adjacent image slices as conditions. Its result helps in the initialization of the subsequent chondral volume segmentation, which helps ensure a precise locating of the effective narrow band detection constraint. This is followed by the cartilage surface enhancement and detection. However, in liver surface segmentation, there is no distinct bone information that can be leveraged to accurately fix a range of search areas. Thus, active contours tend to over search and include other organs. Figure 2 (a) shows an example of active contour segmentation of liver boundary over searched and including heart and right kidney into the detection result. Setting constraints based on a detection result from previous image slices might inherit errors. In order to focus the detection effort of active contours on the weak contacting boundaries between heart and liver and between right kidney and liver, we propose a novel energy competing regime for CDSG Snakes, which comprises a synthetic model as the training data, utilizes the template matching method to locate the weight centre of the liver, integrates general Hough transform (GHT) to automatically measure the scale size of the organ, classifies and enhances weak boundary features in selected directions according to corresponding part of the template, and finally sets a most likely search region – a narrow band. Active contours are closed curves evolving to minimize image energies. In order to avoid introducing artificial ignorance, and also to strengthen the feasibility of training data over a range of tolerance, we set weight parameters to different possible boundary energies, including the weak edge within the search range and the strong boundaries outside the narrow band, to make their attractions toward active contours freely compete with each other and let the snake decide itself to which boundary should it converge. The weight centre, shape and size of object boundaries compared to the training template, the scale measure result from GHT, and the weak boundary feature classification conclusions take part in this voting for energy weight parameter values. In addition, to improve efficiency, CDSG active contours utilize a Distance Transform (DT) as a flexible map to rapidly attract the snake to the vicinity of a target boundary, the task is then passed to a narrow band gradient vector flow (GVF) to detect the boundary of interest (more slowly and precisely) , and then DT disappears to avoid leakage problems. To keep high detection quality intact while enhancing weak boundary features during energy competition, and also to retain CDSG as a fast algorithm, the weak boundary enhancement, energy weight parameter voting and attraction competition only happens in the DT vector map. After active contours have been attracted by the DT force into the GVF vector narrow band, the competition finishes, search range is reset, all boundaries outside this range are removed, and finally GVF probes the boundary of interest in original unenhanced images within a prospective narrow band.

Preliminary Experimental Results and Conclusions

More than 20 real patient LAVA liver images and a small number of standard MR cardiac images have so far been tested to evaluate the performance of the Energy Competing Regime for CDSG active contours, for segmentation accuracy and efficiency. As a constraint for search areas, this method can be easily extended for other active contour approaches. More formal validations of both the accuracy and efficiency of this regime are presently in progress.

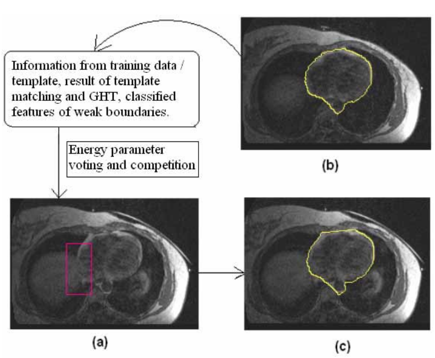

Figure1- Surface segmentation of a heart sample image. Yellow color curves are the segmentation results. (a) the testing image, (b) the training data, (c) the results.

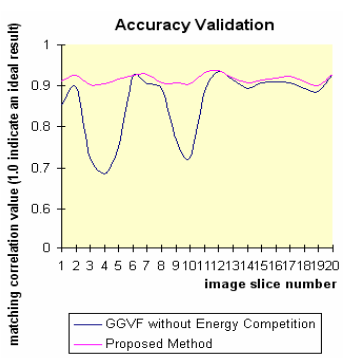

Figure3- Accuracy validation using simple matching correlation.

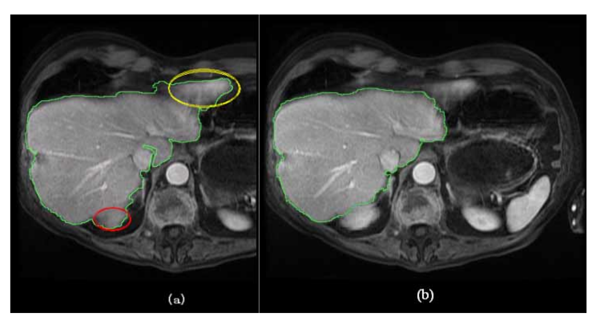

Figure2- Two adjacent LAVA images with similar conditions are shown here to illustrate more results. Green color curves are the segmentation results. (a) is segmented by GGVF active contour without energy competition. (b) is detected by the proposed method. (Yellow circle indicates the heart, while red circle is around the right kidney.)