A Fast and Robust Method to Extract Respiratory Motion from Liver Ultrasound Images

J. Wu[1], C. Li[2], S. Huang[1], F. Liu[1], B.S. Tan[3], L.L. Ooi[4], J. Liu[1]
[1]Singapore Bioimaging Consortium, Agency for Science, Technology and Research, Singapore
[2]Department of Bioengineering, National University of Singapore, Singapore
[3]Department of Diagnostic Radiology, Singapore General Hospital, Singapore
[4]Department of Surgery, Singapore General Hospital, Singapore

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Purpose

Motion compensation is a topic in image-guided interventions, and a few methods have been proposed to model the respiratory motion [1-4] with the use of internal or external landmarks as the surrogate respiratory signal. These landmarks are either tracked using special optical or electronic devices [1-2], or using the build-in capabilities of magnetic resonance (MR) systems [3-4]. However, these devices confront surgical robots with certain restrictions. For example, there should be no optical or magnetic obstructs on the sight line of the tracker. To overcome these problems, and particularly, to further reduce the cost of our surgical robot, and make it simple and portable, we avoid using these extra tracking devices, and, instead, we attempt to use the liver motion identified from intra-operative ultrasound (US) images as the respiratory signal. Therefore, we propose a fast and robust method to extract the respiratory motion of the liver from US image sequences.

Methods

Our method consists of three basic consecutive steps: namely image acquisition, preprocess, and frame-by-frame matching process.

For data acquisition, we used a 2D US device (Terason t3000 with a 5C2 transducer, image resolution of 640×480 pixels, pixel size of about 0.4×0.4 mm^2, and temporal resolution of 15 FPS) to acquire images from volunteers. While obtaining the images, a NDI Aurora electromagnetic (EM) tracking system is used to simultaneously record the motion of the umbilicus, each US image corresponding to an EM signal. The motion of the umbilicus, as the reference respiratory motion, is used to verify the respiratory motion extracted from the image sequences.

Subsequently, the acquired 2D US image sequence is loaded into our software platform, and then processed by a median filter (9×9 pixels) to smooth the present speckles. A template image region (65×65 pixels) is then manually selected from the reference image of the image sequence, where the template region should contain salient characteristic, such as the liver boundary or vessels.

Using the template region, a frame-by-frame matching process, based on normalized correlation, is executed. For this process, we present a novel adaptive search strategy, which makes full use of the inter-frame dependency of the image sequence. Our search strategy assumes that the motion extent of the liver tissue is small for two successive frames. Therefore, any specified image region on the former frame should appear in the small neighbor of the same position on current frame. The optimal matching position on the former frame can be used as the center of the search space on the current frame. Based on this principle, a serial of relatively small search spaces (17×17 pixels) are formed along the image sequence. This search strategy narrows the search range of the optimal matching, thus, greatly reduce the search time, and make the matching process more robust and accurate.

Results

In order to validate our method, three exemplary regions (Fig. 1a) on the reference image are selected as matching templates, and the identified motion curves (Fig.1b-d, in red) are visually compared to the reference motion of the umbilicus (in green). It is observed that the identified results are highly consistent with the reference motion. Furthermore, the indentified motion curves are also quantitatively compared with the reference motion curve using mean squared error (MSE). For convenience of quantification, all motion curves are linearly normalized to the interval of 0 to 1. For template regions A, B, and C, the calculated MSEs are 0.0023, 0.0122 and 0.0021 respectively, which shows strong consistency of our extracted results with the reference motion. The template region B has slightly larger MSE than other regions because this region is close to the scanning margin of the US probe, and loses some information about the liver boundary (Fig. 1a). In addition, for an image sequence of 256 frames, using adaptive searching strategy can extract the respiration curve in about 5 seconds, while using center-invariant searching, with the search space of 129×129 pixel, needs about 300 seconds. Therefore, a great speedup of the order of tens can be achieved using our proposed searching technique.

Conclusion

A fast and robust method has been proposed to identify the respiratory motion of the liver from the US image sequences. Using the adaptive search strategy, the method is able to achieve fast motion estimation within several seconds. The experiments also demonstrate that our method can produce accurate and robust results comparable to that of the EM tracking system. This will be of great help for US-guided surgical robot to have a build-in respiratory motion tracking system, resulting in more compact and flexible design at low cost.

References

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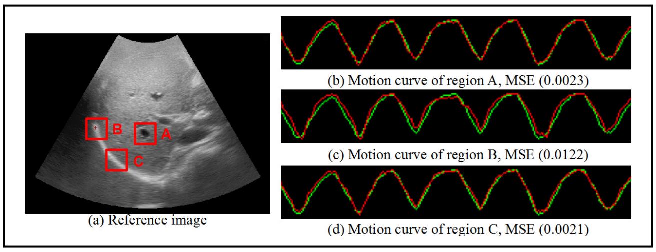

Fig. 1. Consistency is visually compared between the motion curves (in red) identified from different regions, and the EM-tracked reference motion of the umbilicus (in green). The quantitative analysis is also performed using MSE