Real-time Tracking of Liver Landmarks in 2D Ultrasound Sequences

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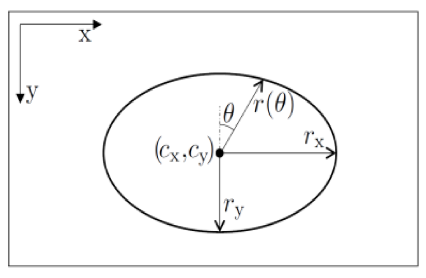
Motivation

- Delivery of focused therapy is affected by internal body motion (e.g. breathing, coughing).
- Inaccuracy of irradiation can be mitigated, if motion is tracked precisely in real-time.
- Our method tracks liver motion in 2D ultrasound image sequences.
- Our tracking is executed in real-time on a single commodity PC.
- We use elliptic and template-based models of vessels [1] in the liver, coupled with a robust optic-flow [4] framework.

Model-based Tracking

- Model-based tracking provides robustness to noise.
- Vessel cross-sections are represented by ellipses.
- This reduced (parametric) shape space enables
    - efficient binary template generation, caching and matching;
    - Kalman Filtering for temporal consistency.

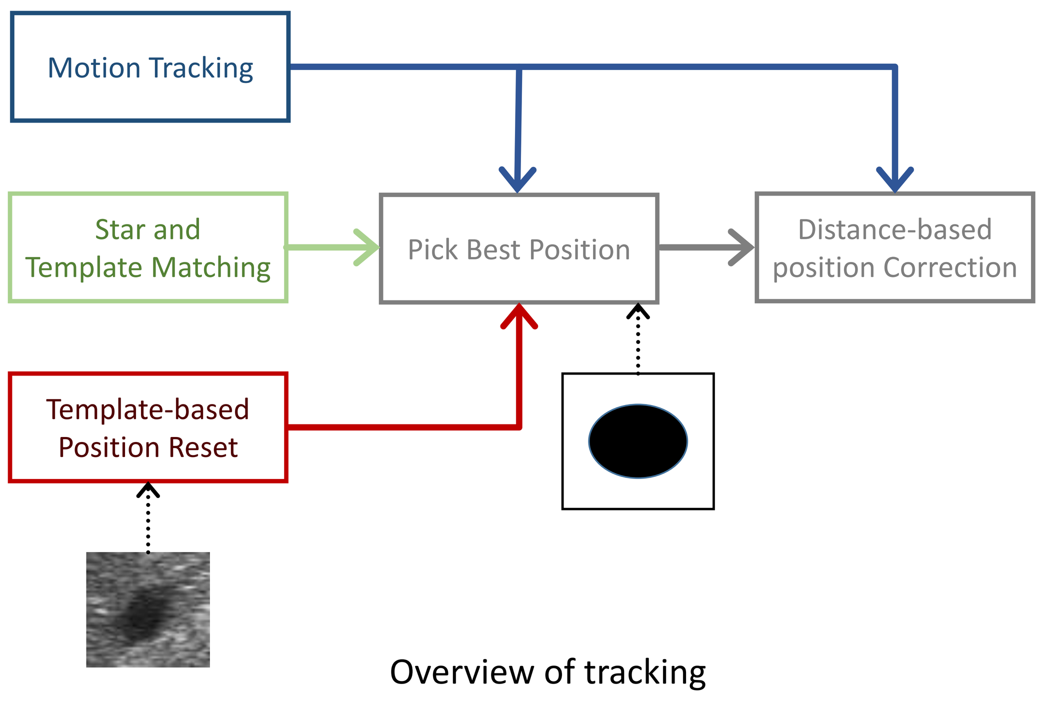


4-parameter ellipse representation

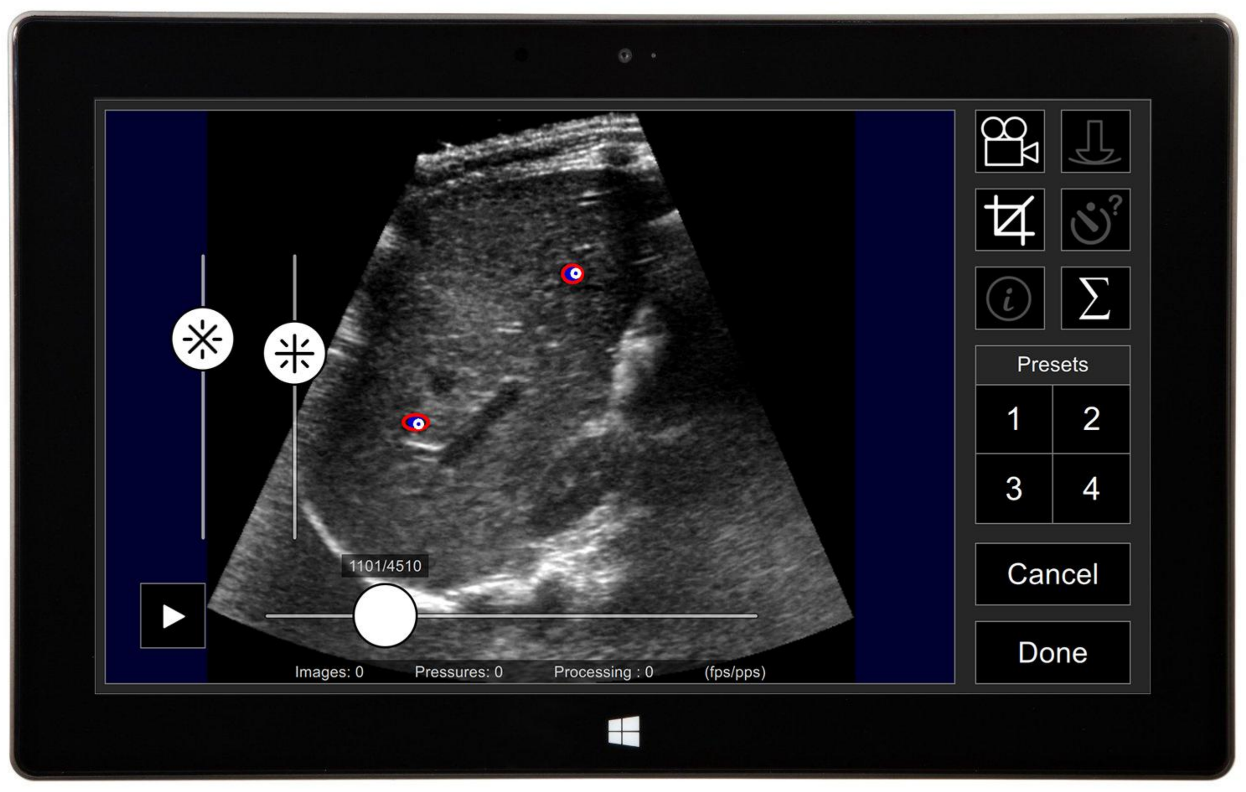
Method Overview

The method is based on our earlier work on tracking superficial veins in ultrasound [1].
Key features of proposed algorithm are:

- Iterative/reference tracking of given landmarks using optic-flow with affine motion models.
- Tracking refinement for vessels using elliptic vessel models.
- Recovery from drift using the initial reference frame.

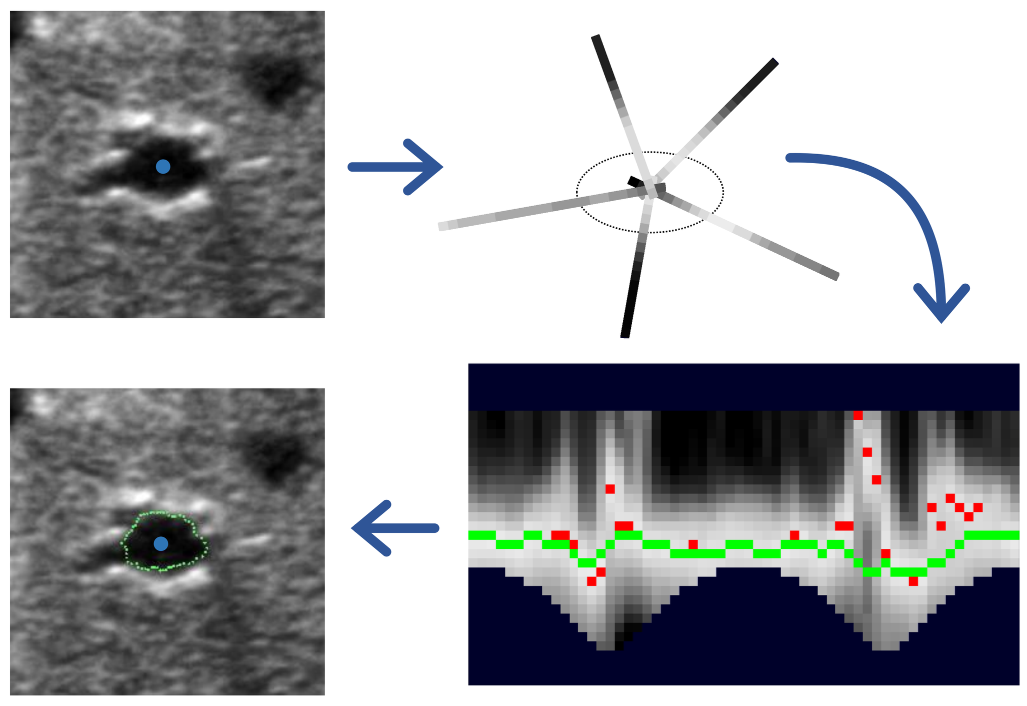


Overview of tracking



Vessel Shape Refinement

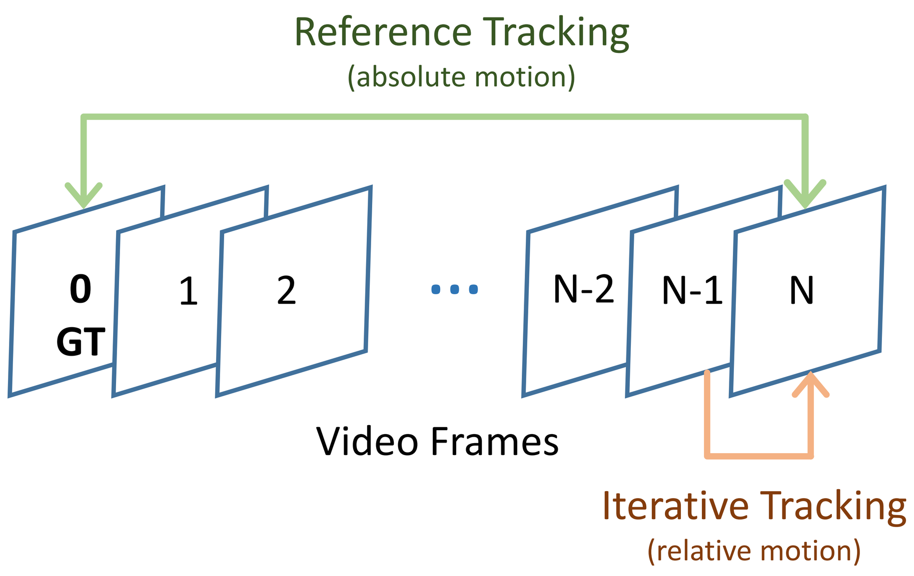
- Star edge-detector provides radial edge candidates for vessel cross-section.
- Dynamic programming filters edge outliers finding a continuous optimal vessel outline.
- Ellipse fitting provides a robust cross-section, as well as parameters for temporal filtering.
- For small vessels, where edge detection is not robust, binary template matching is used.



Vessel outline: Star edge detection and dynamic programming

Motion Estimation

- Landmarks in the initial first frame are used as *reference*.
- Lucas-Kanade [4] optic flow method is used to track sets of points between frames.
- Based on a set of tests, either *Reference* or *Iterative* Tracking is employed.
- If absolute motion from reference can be found successfully, then:

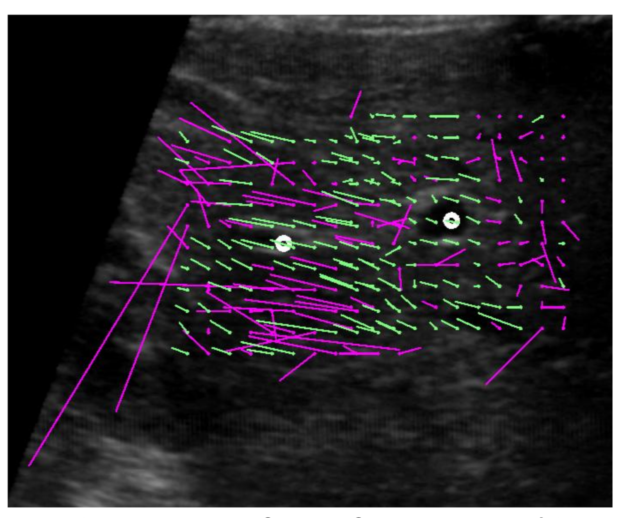


Reference Tracking:

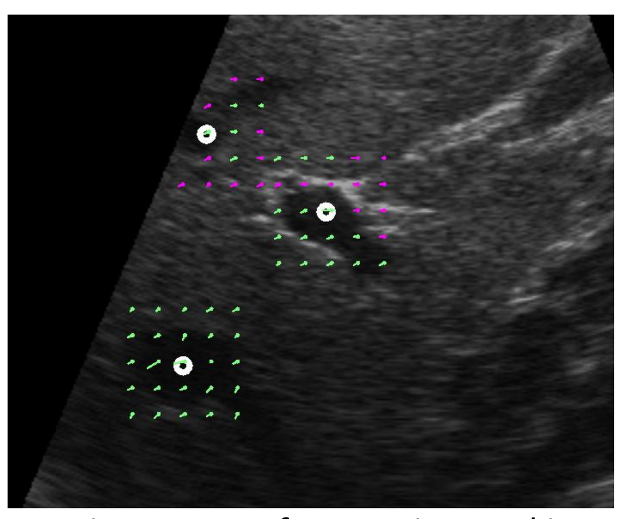
- Lucas-Kanade is applied from and to the initial frame in a large region.
- Bidirectional Filtering checks for the inverse consistency of estimated motion.
- Tracking precision is improved by removing inconsistent motion vectors (outliers).
- If sufficient motion vectors are left after outlier removal, then *success*.
    - Affine transformation from reference is estimated from this set of motion vectors .
    - Reference Tracking recovers precise landmark positions when breathing is in a phase similar to that of the initialization.
- Otherwise:

Iterative Tracking:

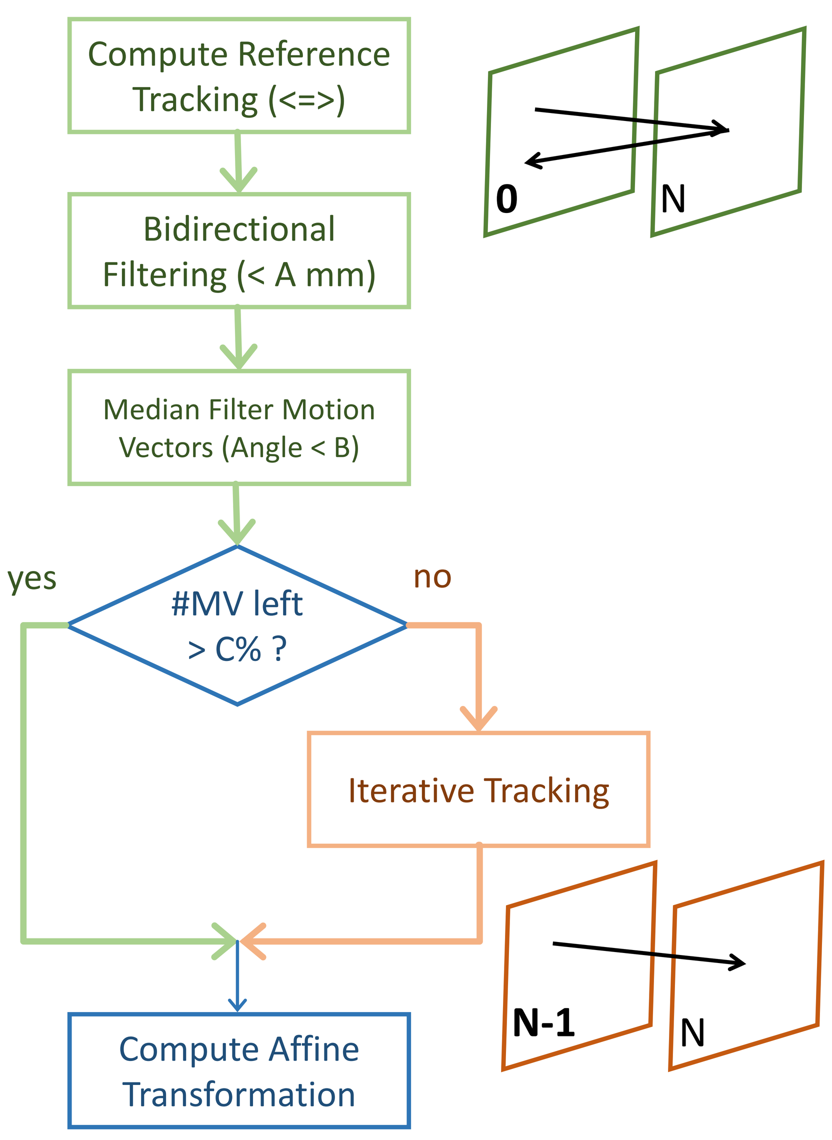
- Lucas-Kanade is applied from the previous frame in a local region.
- Tracking precision is improved by removing inconsistent motion vectors (outliers).
- Affine transformation from reference is estimated from this set of motion vectors .
- Iterative Tracking achieves continuous tracking of landmarks.



Motion Vectors for Reference Tracking
(discarded vectors are magenta-colored)



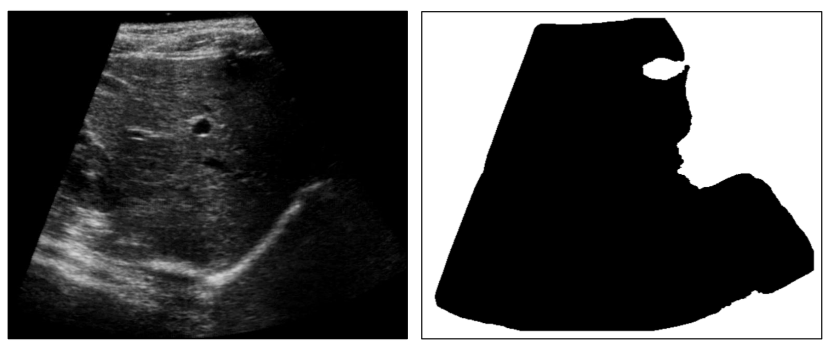
Motion Vectors for Iterative Tracking
(discarded vectors are magenta-colored)



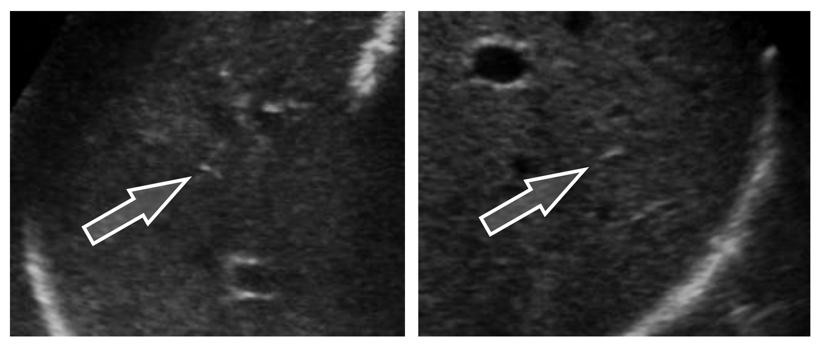
Reference vs. Iterative selection algorithm

Field of View Detection and Non-Vessel Tracking

- Motion Estimation and Vessel Shape Refinement are only performed for points inside the field of view (FOV).
- Per-frame FOV mask is generated via thresholding and hole filling operations.
- During initialization, elliptic vessel templates are used to distinguish vessels from non-vessels.
- Non-vessel structures are tracked using Motion Estimation alone, without the Vessel Shape Refinement step.



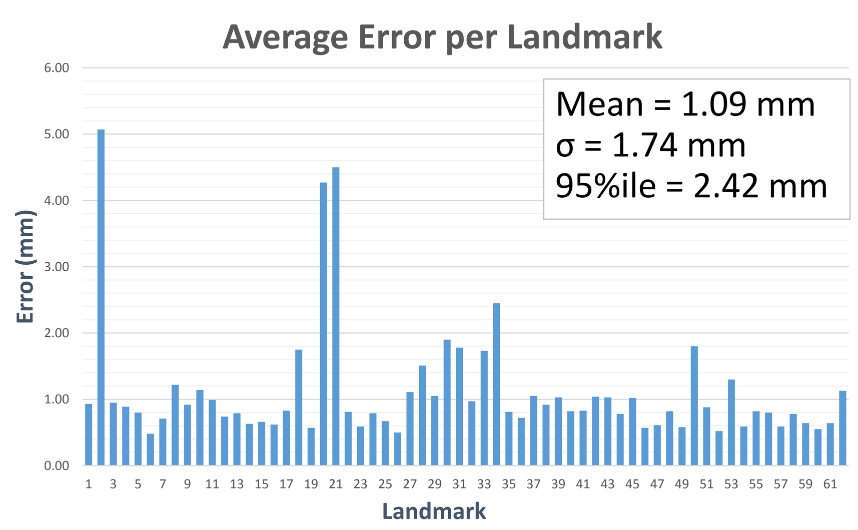
An ultrasound frame and corresponding FOV mask

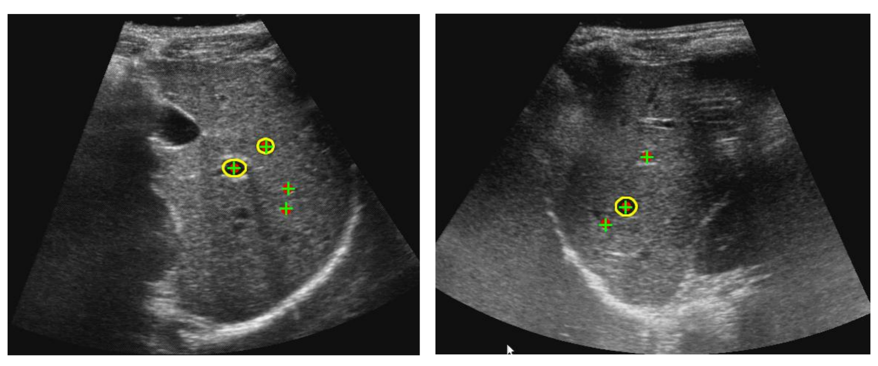


Examples of non-vessel landmarks

Conclusions

- Our method runs on a single commodity PC in **real-time** (faster then US acquisition).
- It can be connected externally to clinical ultrasound machines.
- It was evaluated at the Challenge on Liver Ultrasound Tracking (CLUST) 2015 [2,3], collocated with the MICCAI Conference.
- 24 2D ultrasound sequences with approx 3700 frames each are available from 4 centers.
- Up to 4 landmarks per sequence selected by 3 annotators (inter-annotator error 0.44mm).
- Our method: <u>1.09 mm mean error</u> with 1.74 mm standard deviation.





Tracking examples

Portable setup

References

1. A. Crimi, M. Makhinya, U. Baumann, C. Thalhammer, G. Szekely, O. Goksel: Automatic measurement of venous pressure using B-mode ultrasound. IEEE Transactions on Biomedical Engineering, 2015.
2. Makhinya M., Goksel O., "Motion Tracking in 2D Ultrasound Using Vessel Models and Robust Optic-Flow", Medical Image Computing and Computer Assisted Intervention (MICCAI) Challenge on Liver Ultrasound Tracking (CLUST), Oct 2015.
3. Luca, V.D., Benz, T., Kondo, S., Knig, L., Lbke, D., Rothlbbers, S., Somphone, O., Allaire, S., Bell, M.A.L., Chung, D.Y.F., Cifor, A., Grozea, C., Gnther, M., Jenne, J., Kipshagen, T., Kowarschik, M., Navab, N., Rhaak, J., Schwaab, J., Tanner, C.: The 2014 liver ultrasound tracking benchmark. Physics in Medicine and Biology 60(14), 5571-5599, 2015.
4. Lucas, B., Kanade, T.: An iterative image registration technique with an application to stereo vision. In: Proceedings of Imaging Understanding Workshop. pp. 121-130, 1981.