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

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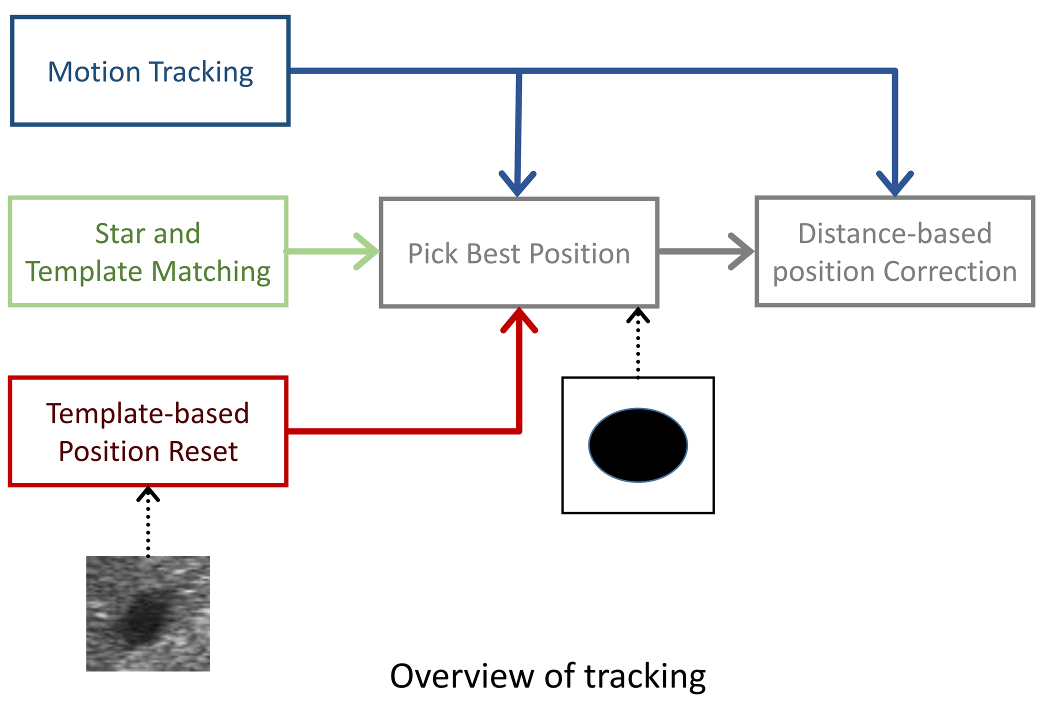
Motivation

- 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.

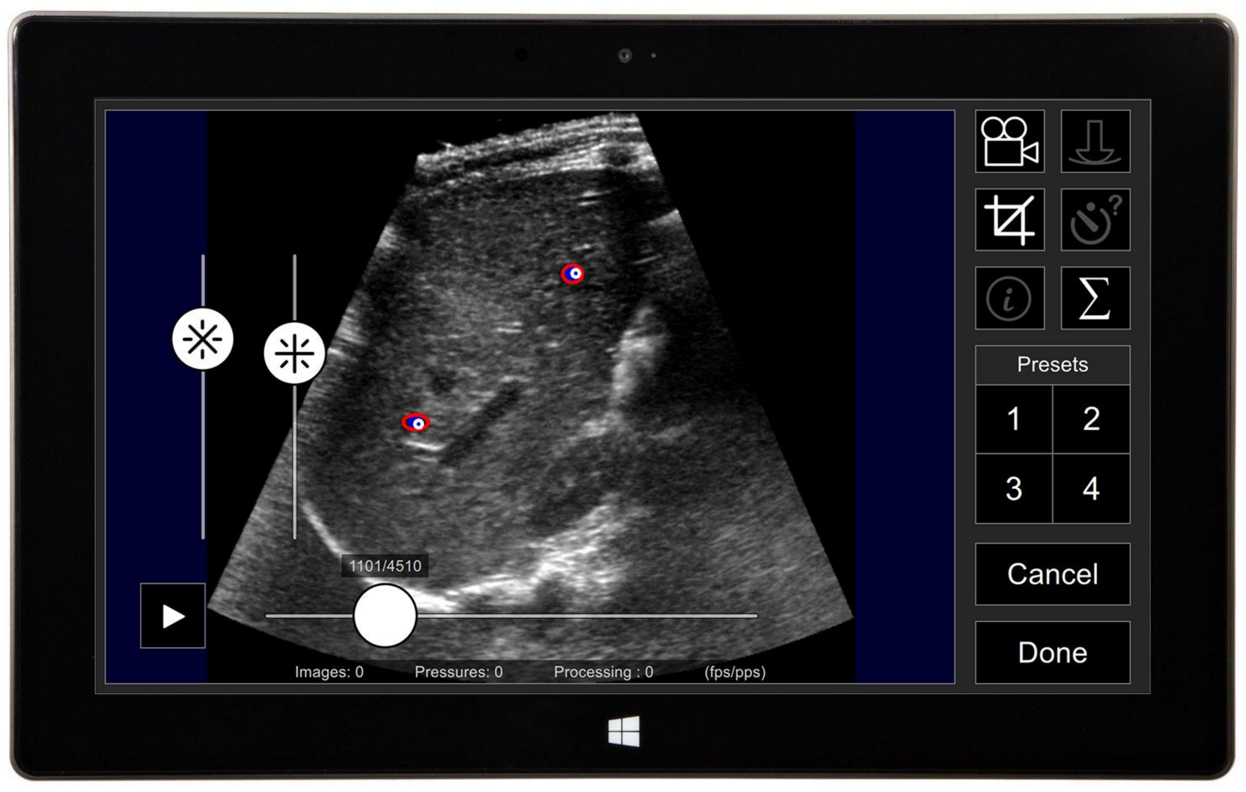
Method Overview

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.

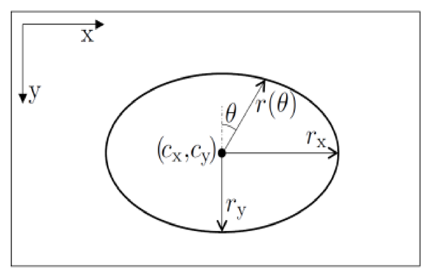


Overview of tracking



Model-based Tracking

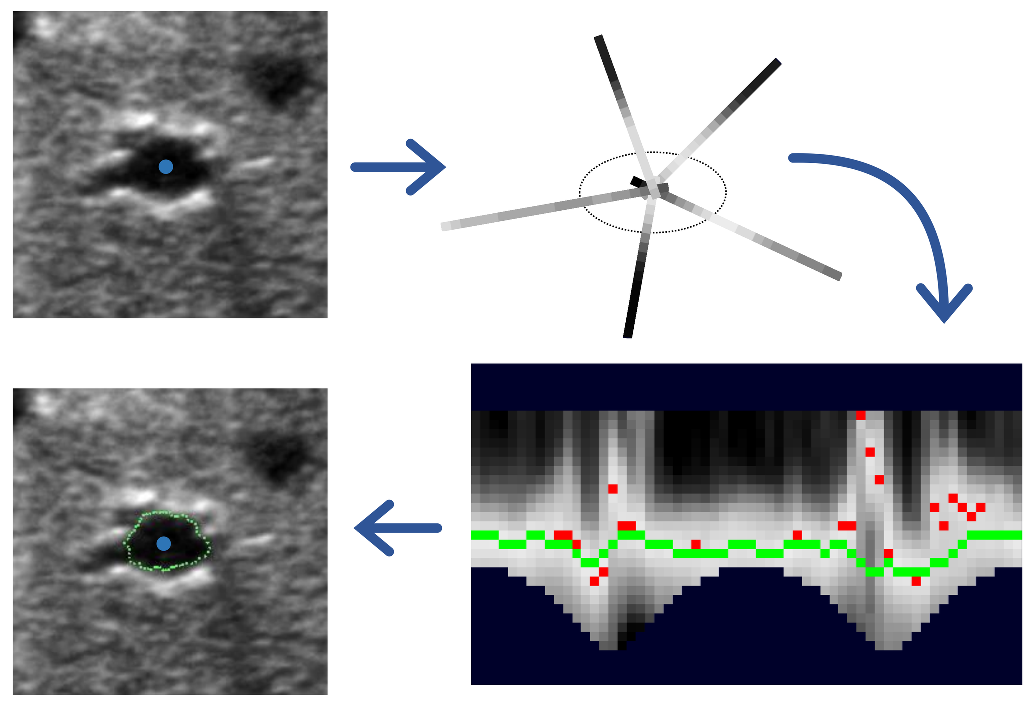
- Model-based tracking provides robustness to noise.
- Vessel cross-sections are represented by ellipses.
- This reduced (parametric) shape space enables
  - efficient binary template generation, caching and matching;
  - Kalman Filtering for temporal consistency.



4-parameter ellipse representation

Vessel Shape Refinement

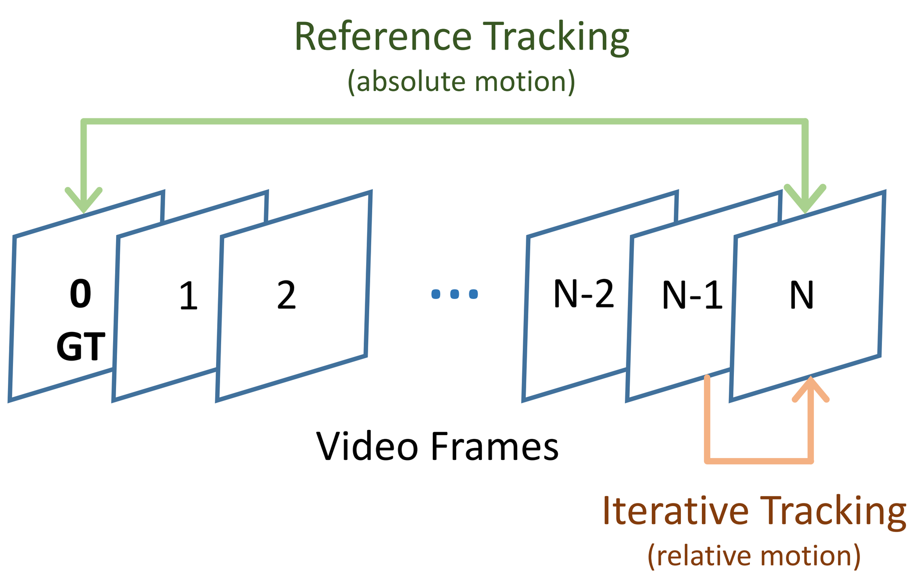
- Star edge-detector provides radial edge candidates for vessel cross-section.
- Dynamic programming filters edge outliers finding a continuous optimal vessel outline.
- Ellipse fitting provides a robust cross-section, as well as parameters for temporal filtering.
- For small vessels, where edge detection 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:

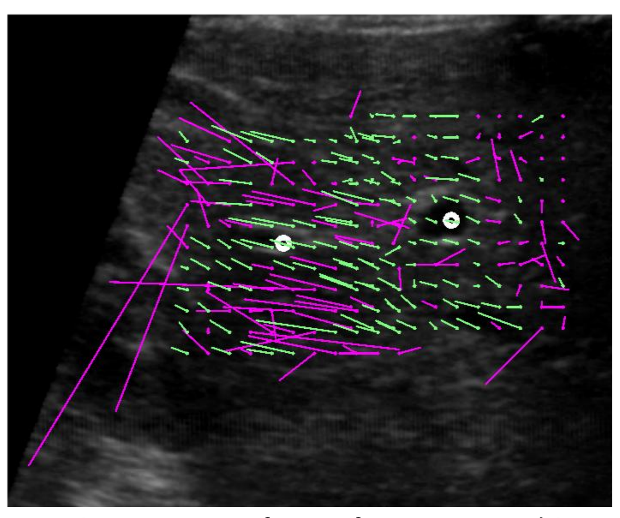


Reference Tracking:

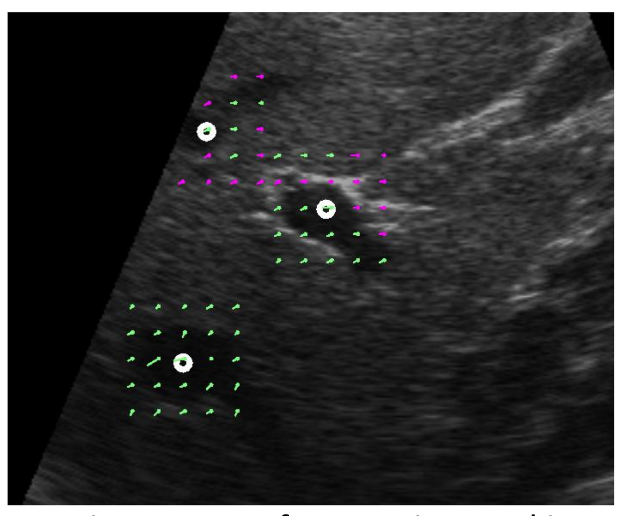
- Lucas-Kanade is applied from and to the initial frame in a large region.
- Bidirectional Filtering checks for the inverse consistency of estimated motion.
- Tracking precision is improved by removing inconsistent motion vectors (outliers).
- If sufficient motion vectors are left after outlier removal, 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:

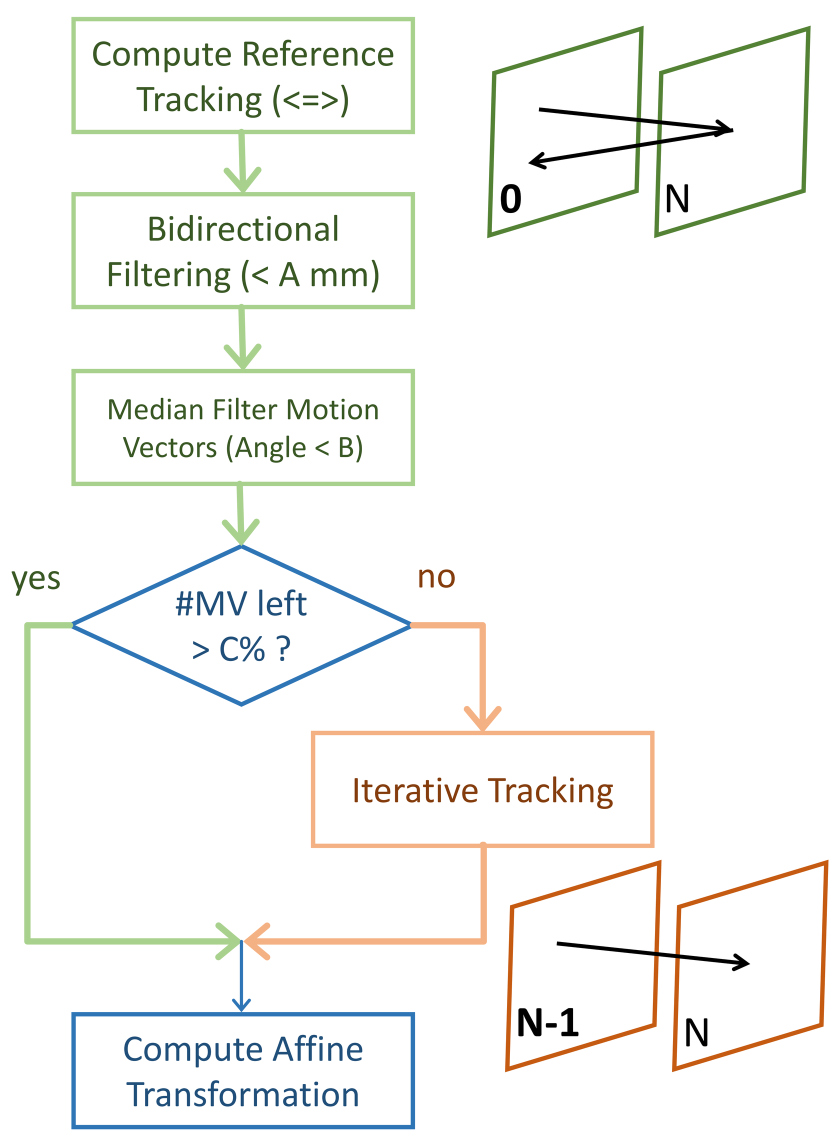
- Lucas-Kanade is applied from the previous frame in a local region.
- Tracking precision is improved by removing inconsistent motion vectors (outliers).
- Affine transformation from reference is estimated from this set of motion vectors .
- Iterative Tracking achieves continuous tracking of landmarks.



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



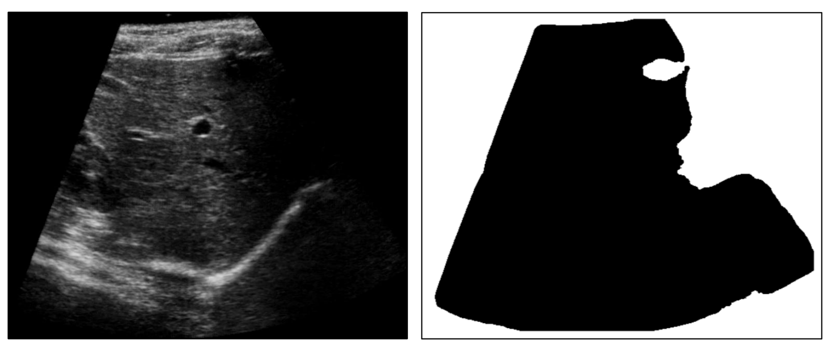
Motion Vectors for Iterative Tracking
(discarded vectors are magenta-colored)



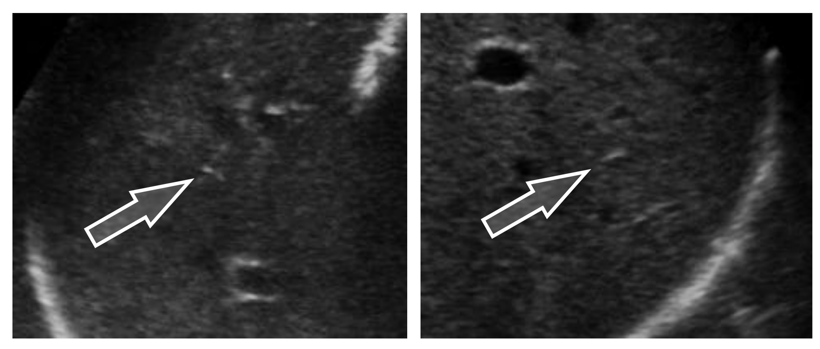
Reference vs. Iterative selection algorithm

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.



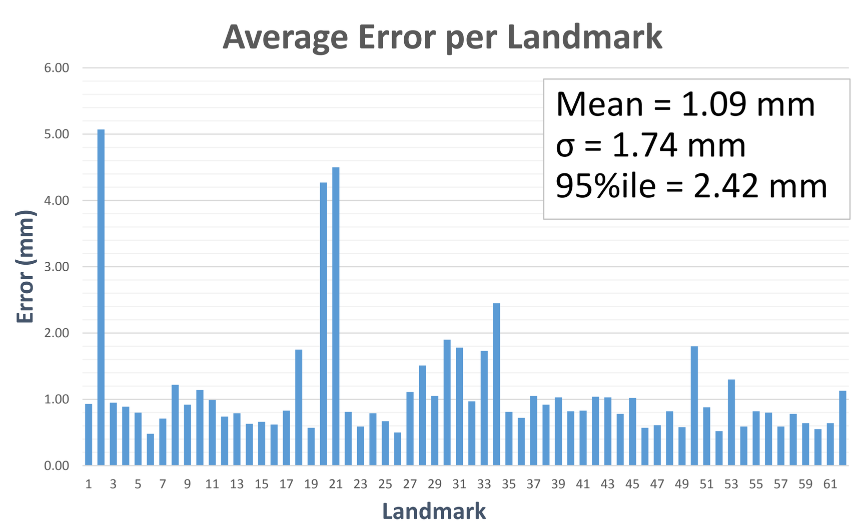
An ultrasound frame and corresponding FOV mask

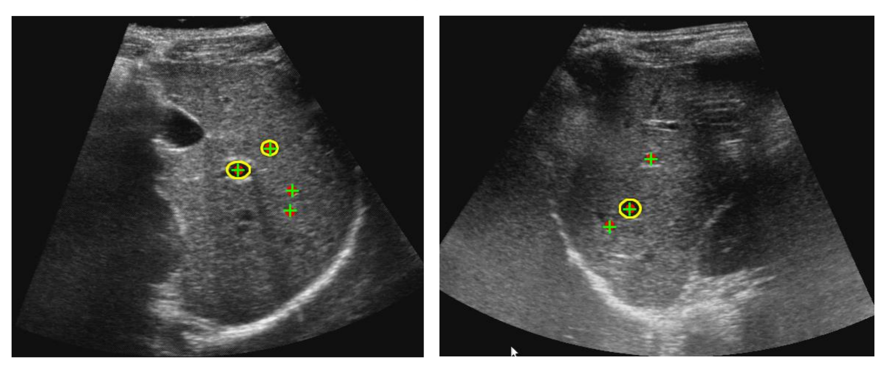


Examples of non-vessel landmarks

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: 1.09 mm mean error 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.
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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.