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.

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.

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.

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.

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.

Conclusions
- Our method runs on a single commodity PC in real-time (faster than 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.

References