

P5-234-M: Deformable Registration of Bronchoscopic Video Sequences to CT Volumes with Guaranteed Smooth Output

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Objectives

Flexible bronchoscopy is a clinical procedure for diagnosis and treatment of lung diseases. Transbronchial biopsy is commonly performed after suspicious lesions have been identified on CT images, so it will definitely be beneficial to transfer this 3D information to the operating room. Since bronchoscopy is an inherently monitor-based procedure, augmentation of video images with guidance or targeting information is straightforward and promises high clinical acceptance due to smooth integration into the clinical workflow. While accuracy and computational speed are clearly important for real-time applications like intraoperative navigation, smoothness of the output is no less relevant. Less jitter of augmented reality overlays increases operator comfort and acceptance. Smooth output may provide benefits when further processing the output like for motion models, or temporal and spatial synchronization of multiple video sequences in the case of repeat examinations or clinical studies.

Methods

A continuous description of the bronchoscope trajectory is defined by spline interpolations. Control points are initialized from EM measurements.

Then, position and orientation of each control point are optimized for similarity between real and virtual bronchoscopic images, tension (i.e. deviation from original measurements), and bending:

$$E(p, q) = \underbrace{S(p, q)}_{\text{similarity}} - \lambda_1 \cdot \underbrace{R_T(p, q)}_{\text{tension}} - \lambda_2 \cdot \underbrace{R_B(p)}_{\text{bending}},$$

After a limited number of iterative updates, the next control point is considered. During optimization, only data for a neighborhood of frames needs to be available, so frames can be processed in sequence like with previous approaches.

We compared our method to four previously published approaches. Data was recorded using a dynamic motion phantom with a closely human-mimicking surface (cf. Figure 1).

Ground truth data was independently and repeatedly collected from two experts by manually adapting the position and orientation of the virtual bronchoscopic image via mouse and keyboard, until they matched the real image as closely as possible.

Results

Intra-expert agreement, i.e. mean standard deviation, was 1.44-1.66 mm and 3.94-5.80°. Inter-expert agreement, i.e. standard deviation of means, was 1.26 mm and 4.78°.

For four dynamic phantom data sets, the accuracy of our method is between 4.13 and 5.93 mm, which is equivalent to previous approaches.

Computation time is 0.98 seconds per frame. We significantly improve inter-frame smoothness from 2.35-3.08 mm to 1.08-1.51 mm (cf. Table 1 and Figure 2).

Smoothness	Data set 1	Data set 2	Data set 3	Data set 4
Solomon et al. 2000	2.86 ± 1.62 mm 2.11 ± 8.21°	3.47 ± 1.72 mm 3.84 ± 8.59°	3.01 ± 1.65 mm 3.81 ± 11.25°	3.46 ± 1.73 mm 3.83 ± 8.81°
Mori et al. 2005	3.35 ± 2.09 mm 3.50 ± 9.68°	3.87 ± 2.31 mm 4.74 ± 8.63°	3.61 ± 2.18 mm 6.05 ± 14.51°	4.04 ± 2.35 mm 5.63 ± 10.74°
Luo et al. 2010	2.86 ± 2.11 mm 3.22 ± 10.42°	3.43 ± 2.30 mm 4.54 ± 8.83°	3.11 ± 2.20 mm 5.17 ± 12.35°	3.54 ± 2.35 mm 5.36 ± 10.69°
Luo et al. 2010	2.35 ± 1.88 mm 2.12 ± 8.24°	2.95 ± 2.09 mm 3.94 ± 8.92°	2.71 ± 2.08 mm 3.84 ± 11.32°	3.08 ± 2.28 mm 3.96 ± 9.35°
Proposed Method	1.23 ± 0.76 mm 1.96 ± 5.82°	1.51 ± 1.04 mm 3.18 ± 6.23°	1.12 ± 0.69 mm 3.22 ± 11.71°	1.08 ± 0.77 mm 3.62 ± 9.66°

Table 1: Smoothness comparison of approaches.

Discussion

The accuracy of our method is equivalent to previous approaches, with a significant improvement in smoothness. The actual limit to smoothness is unknown, but we attribute most of the remaining inter-frame distance to the real bronchoscope motion.

Due to the smoothness constraint, our method by design provides a more realistic and physically plausible solution to the tracking problem, which has significantly less jitter. This quantitative result is confirmed by video output, which is much more consistent and robust, with fewer occasions of tracking loss or unexpected movement.

We expect our method to be robust against transient artifacts occurring in real clinical images, like specular reflections or bubbles, since groups of frames are matched and smoothness is enforced.

The next step will be applying the proposed method to trajectories recorded during actual interventions in humans. Since the dynamic motion phantom sequences were recorded anticipating the real procedure, data acquisition can be brought to the operating room with minimal interruption to the surgical workflow.

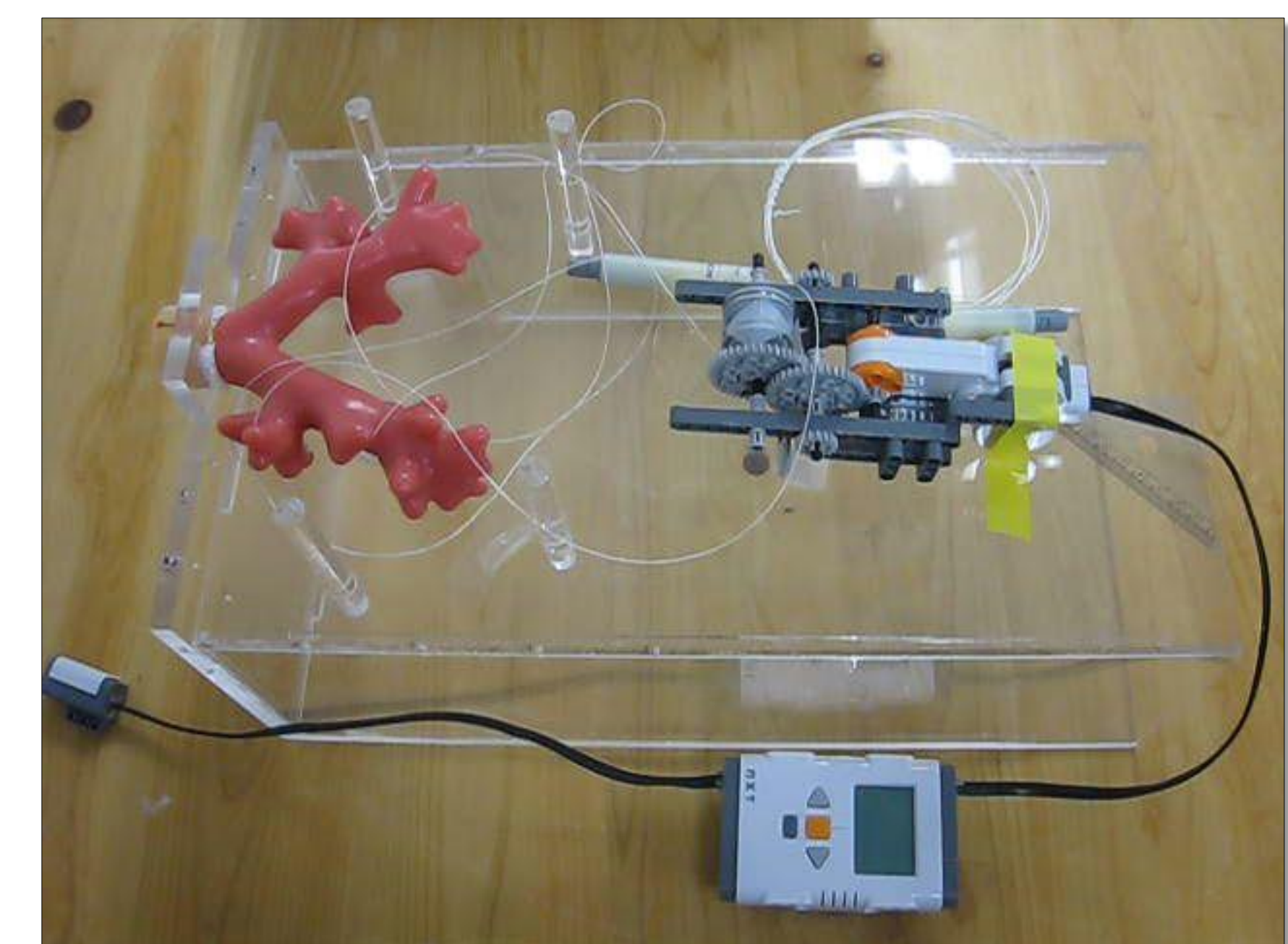


Figure 1: Dynamic motion phantom

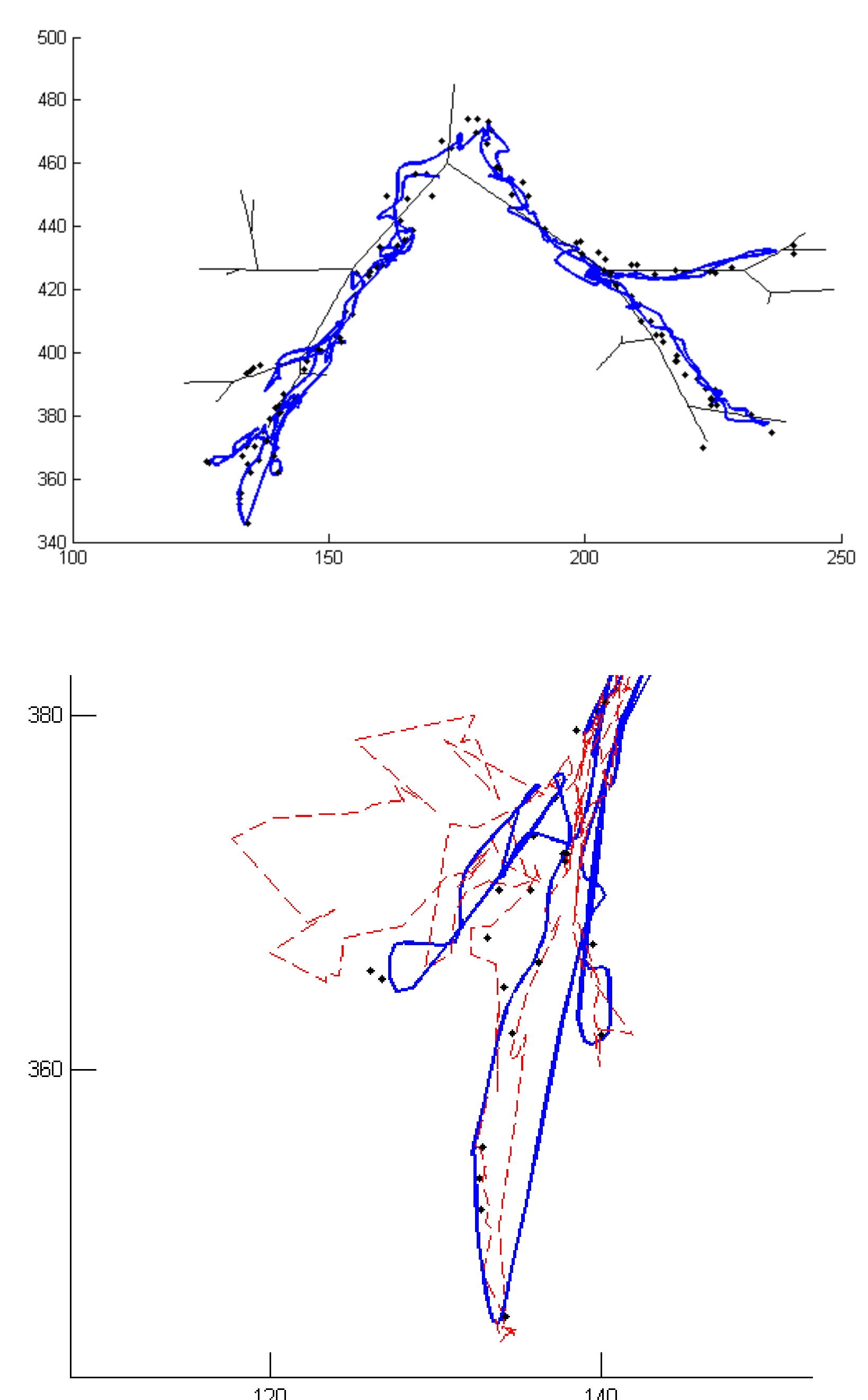


Figure 2: Airway structure and trajectory from proposed method (blue) and previous approach (red)

Bibliography

Reichl et al. MICCAI 2011; Solomon et al. Chest 118:1783-1787; Mori et al. MICCAI 2005; Luo et al. SPIE MI 2010; Luo et al. ACCV 2010; Soper et al. TMI 57:736-745