Model-Based Respiratory Motion Compensation for Image-Guided Cardiac Interventions

Matthew Schneider¹, Hari Sundar², Joachim Hornegger³, Chenyang Xu²
¹ Pattern Recognition Lab, Friedrich-Alexander University, Erlangen, Germany
² Siemens Corporate Research, Princeton, NJ, USA

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Introduction

Clinical Application: Percutaneous Coronary Intervention (PCI) for Chronic Total Occlusions (CTO)

- Occluded arteries account for 20-30% of the documented coronary artery disease that is encountered in catheterization labs today (CTO: total occlusion for more than 30 days).
- PCI: minimally invasive procedure in interventional cardiology performed under live fluoroscopy to provide functional revascularization of the occluded artery, e.g., coronary stenting or balloon angioplasty.
- Guidewire crossing is performed “blindly” running the risk of perforating or even dissecting the artery wall (less than 10% of CTO cases treated by PCI).
- Preoperative information can be incorporated into the into the interventional suite to provide additional visual information and facilitate guidewire navigation.

Objective: Computation of motion-compensated overlay of preoperative CT data with intraprocedure live fluoroscopy.

Method

Motion Model Estimation:

- Unconstrained rigid 2-D/3-D registration [3] of preoperative CT data [1] with cardiac-gated angiography at different breathing phases to sample respiratory profile.
- Definition of low-dimensional parameterization for the patient-specific respiratory profile based on the most significant modes.
- Respiratory motion model as prior: reasonable restriction of the search space for intraoperative re-registrations based on 2-D guidewire tracking [4].

Preprocessing

Original Image  Vessel Segmentation  Distance Transform

Clinical workflow for motion-compensated CT guidance using a patient-specific respiratory motion model.

Results

- Motion model validation based on simulated, phantom, and clinical data (two CTO cases).
- Average 3-D registration error of less than 2 mm even for intraoperative settings with monoplane image data or missing contrast information based on 2-D guidewire tracking.

Conclusions

- Low-dimensional motion model is able to capture the subject-specific respiratory motion profile and has a smoothing effect on the cost function.
- Model-constrained registration provides better robustness and faster convergence without compromising on registration accuracy particularly for weak data constraints.
- Live fluoroscopy with motion-compensated CT guidance becomes feasible.

Normalized cost function for clinical case in the proximity of the gold standard (origin) for (a) varying principal components \( c_{2,3} \) (model-constrained registration) and (b-d) different combinations of translation \((t_x, t_y, t_z)\) and rotation \((R_x, R_y, R_z)\) (unconstrained registration).

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Clinical Application:

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