Catheter Tip Localization using IVUS Sensor

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The use of catheter-based techniques to diagnose and treat cardiovascular diseases is the most common and least traumatic interventional treatment in general use. However, catheter-based interventions can be highly challenging in difficult regions of the vasculature where cardiac and respiratory motion complicates accurate localization and targeted delivery. In addition clinicians are required to operate without direct view and access to the vessel region and fluoroscopy is used to guide the catheter while exposing both the patient and the interventionalist to harmful radiation. The use of injected contrast agents to obtain a better view of the vessel can cause further harm to patient’s kidneys especially in long procedures where high doses may be used. In recent years, many studies have been proposed to support the clinician in the difficult task of catheter navigation, to reduce the exposure to X-rays, and to limit the use of contrast agents. For example, techniques to register pre-operative 3D models to intra-operative data, such as fluoroscopy images \cite{1} or electromagnetic localization \cite{2}, can be used to help the physician to visualize the catheter in the vessel. However, these procedures are particularly complex due to the non-rigid deformation between the two views.

In this study we propose an approach for providing information about the position of the tip of the catheter during an intervention by using information on the insertion length and the real-time inside view of the vessel lumen obtained by an IntraVascular UltraSound (IVUS) sensor \cite{3}. IVUS is an established intravascular imaging technique that provides a transversal scan of the vessel which allows the estimation of the lumen shape. We assume that the initial position of the catheter tip is known and is mapped into a pre-operative 3D model of the vessels. The ideal navigation path of the catheter in the circulatory system is computed as the central line of the vessels that is obtained by a skeletonization algorithm applied to the 3D model. From the ideal path a probabilistic map of the possible positions of the catheter for a certain insertion length is assessed by modeling possible bending and localization uncertainty. The possible catheter tip positions and orientations are used to extract multiple vessel transversal sections from the 3D model and to thus extract the estimated vessel shape that the IVUS sensor would observe. These contours are then compared to the actual IVUS scan data in order to match the best estimate of the catheter position and orientation that maximizes the similarity between the observed and model generated views. A Bayesian estimation technique is used to estimate the catheter position over time while it advances in the vascular system toward the target area where the procedure is to be performed. This approach is extensively tested in phantom experiments simulating the insertion of the catheter with an IVUS sensor at the tip. Results show the possibility of obtaining a reliable estimate of the catheter position without the need of fluoroscopy during the insertion.

\textbf{References}

