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Intraoperative Tracking of Anatomical Structures Using Fluoroscopy and a Vascular Balloon Catheter

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Abstract. We present preliminary work on a novel technique for tracking anatomical structures during medical procedures. A vascular balloon catheter is placed within a vessel in the structure of interest and is inflated using a radio-opaque contrast material. The balloon catheter is tracked over time using a fluoroscopy system, and three parameters of motion are determined (two of translation, one of rotation) for each view via analysis of the balloon image. These methods are applied to three patient data sets to estimate liver motion during a respiratory cycle.

1 Introduction

We propose the use of a stable intravascular fiducial, in the form of a contrast-filled balloon catheter, to track the motion of soft tissue structures during image-guided procedures. This fiducial produces a consistent image and can be tracked through a series of frames. The fiducial can also be used to correlate images or other data from different stages of a procedure, such as pre-intervention angiography. We have analyzed three series of abdominal patient images containing such fiducials and report the results below.

2 Materials and Methods

Image Acquisition. The images for this study were acquired at North Carolina Memorial Hospital (Chapel Hill, North Carolina, USA) using a Siemens Neurostar biplane fluoroscopy suite. Dr. Weeks captured the images as part of two TIPS procedures in two different patients. A balloon catheter (Meditech Occlusion Balloon, Boston Scientific) was placed in each patient's hepatic vein in the liver as part of the customary procedure for imaging the portal vein. The balloon catheter was inflated using iodinated contrast and a series of fluoroscopic images was captured over a full respiratory cycle. The Institutional Review Board for the School of Medicine has approved the use of these images for research purposes.

Image Analysis. Simple thresholding is performed to create a binary map of the radio-opaque objects in the scene. Connected components analysis is then used to label each distinct region in the binary image. Each region is analyzed to determine its centroid, area, major and minor axis lengths for the best-fitting ellipse, and angular displacement of the major axis relative to the x-axis. The selection of the correct balloon region is performed using a weighted least-squares approach on position and area. Estimated parameters are provided for the first image in the series, while the remaining iterations use the results from the previous step as parameter estimates.

3 Results

The three series of images were analyzed to determine the 2D position, balloon orientation, major and minor axis lengths for the best-fitting ellipse, and the balloon area for each frame. All results are given in Table 1. Image scale varies by series.

Table 1. Results from analysis of fiducial balloon in three series of fluoroscopic images

Results given as mean ± standard deviation	**Series Liv01 (n=21)**	**Series Liv02 (n=11)**	**Series Liv03 (n=11)**
Balloon area (pixels^2)	932.3 ± 33.2	1580.6 ± 36.5	3173.3 ± 75.6
Major axis length (pixels)	44.49 ± 0.74	59.83 ± 0.99	92.08 ± 1.33
Minor axis length (pixels)	28.65 ± 0.46	36.04 ± 0.39	46.23 ± 0.77
Orientation (degrees)	22.27 ± 1.53	24.36 ± 0.67	15.71 ± 0.46
Craniocaudal position (pixels)	636.5 ± 16.0	567.7 ± 8.9	606.0 ± 13.9
Transverse position (pixels)	132.4 ± 2.8	325.6 ± 3.6	324.3 ± 3.8

4 Conclusions

The small variances of the axes lengths and area measures suggest that our methods yield stable estimates of the balloon parameters. As expected, the liver showed very little rotation over the image sequences. The dominant motion was craniocaudal translation, which is consistent with the motion of the attached respiratory diaphragm. These preliminary results suggest that our proposed methods can yield reasonable measurements of the orientation and position of a contrast-filled balloon catheter placed in the liver. Additional studies will be needed to determine the accuracy and precision of these methods across a spectrum of patients and imaging circumstances.

We plan to perform several new studies in the coming months to improve the characterization of our methods. First, we will measure the intrinsic uncertainty of our methods by imaging our fiducial on a precision motion stage and comparing our calculated trajectories to the actual trajectories on the stage. We will then extend our methods to 3D tracking from biplane views and test them using fluoroscopic images from a diverse set of patients. Finally, we plan to investigate the use of Kalman filtering to predict balloon motion and reduce our search space within each image.