

Enhanced electromagnetic catheter tracking with application in high-dose-rate brachytherapy

Elodie Lugez^{*1}, Hossein Sadjadi¹, Chandra P. Joshi², Selim G. Akl³, and Gabor Fichtinger¹

Ontario Consortium for Adaptive Interventions in Radiation Oncology

¹Laboratory for Percutaneous Surgery, Queen's University, Kingston, ON, Canada

²Cancer Centre of Southeastern Ontario, Kingston General Hospital, Kingston, ON, Canada

³School of Computing, Queen's University, Kingston, ON, Canada

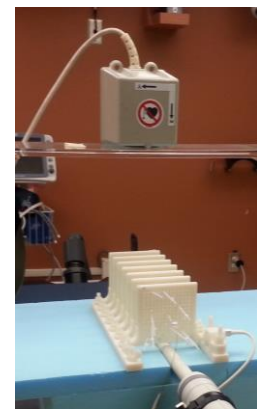
Introduction. Catheter path reconstruction is a necessary step in many interventional procedures, such as cardiovascular interventions and high-dose-rate brachytherapy. To overcome shortcomings in standard imaging modalities, electromagnetic (EM) tracking has been employed to reconstruct catheter paths^[1]. However, EM tracking is prone to measurement errors which can compromise the outcome of the procedure. While several error minimization techniques have been proposed, the tracking error still poses a challenge in accurate path reconstruction. Minimizing these errors is therefore paramount. We address this challenge by means of a specialized filtering technique for catheter tracking.

Methods. EM tracking of catheter paths was improved by means of an extended Kalman filter (EKF), combining both the position and orientation measurements of an EM sensor with the nonlinear kinematic constraints of that EM sensor inside the catheter. The performance of our proposed approach was experimentally evaluated using an Ascension trakSTAR electromagnetic tracker. A 3D printed calibration phantom, illustrated on Figure 1(a), firmly held ten HDR catheters into predefined ground truth paths with mean curvatures varying from 0 m^{-1} to 6.6 m^{-1} . The experimental setup was placed in an HDR brachytherapy suite, pictured on Figure 1(b). The EM sensor measurements were recorded while the sensor was retracted into the paths at various speeds ranging from 8.8 to $25.2 \text{ mm}\cdot\text{s}^{-1}$. We collected raw measurement data and applied our method to improve the tracking performance. Results were compared with the filtered data provided by the manufacturer. Finally, the sensitivity of our nonholonomic EKF method to sensor velocity and path curvature was determined.

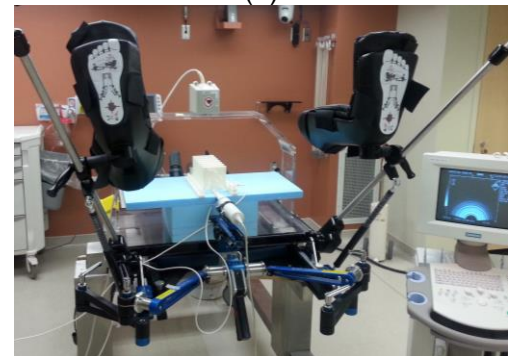
Results. Errors in path reconstruction were reduced from 3.5 to 1.9 mm using the advanced nonholonomic EKF, which outperformed the manufacturer's filters efficacy to reduce errors by 21% . Although path curvature and sensor velocity did not yield a clinically significant trend on the reconstruction performance, the position of the EM field transmitter predominantly impacted path reconstruction accuracies.

Table 1. Path reconstruction results

	Raw measurements	Standard manufacturer filter	Nonholonomic EKF
Accuracy	3.5 mm	2.4 mm	1.9 mm
Precision	1.7 mm	1.0 mm	0.8 mm
95% CI	6.2 mm	3.9 mm	3.1 mm



(a)



(b)

Figure 1. (a) Ground truth phantom firmly holding ten catheters in a predefined path. (b) Experimental setup in the HDR suite.

Conclusions. The nonholonomic EKF has the advantage of exploiting the additional orientation measurements and the sensor kinematic constraints in its formulation. Combined with the position measurements, the advanced filter can successfully improve the accuracy of path reconstruction. In conclusion, filtering using a nonholonomic model is promising for tracking catheters and seems applicable to a plurality of procedures.

Reference. [1] Bharat *et al.*, Electromagnetic tracking for catheter reconstruction in ultrasound-guided high-dose-rate brachytherapy of the prostate. *Brachytherapy*, 13(6):640-650, 2014.