An application of redundant sensors for intraoperative electromagnetic tracking error monitoring

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Introduction. Intraoperative monitoring of electromagnetic (EM) tracking error is a necessary aspect of quality assurance for electromagnetically-navigated interventions. To maximize their effectiveness, intraoperative solutions must be easy to set up and use, readily interpretable, and unobtrusive to the procedure at hand. Jain *et al.* have described a method of characterizing EM tracking error that uses a constellation of redundant EM sensors that are rigidly fixed to a tool in the workspace[1]. Our goal was to develop a practical means of intraoperative error monitoring using redundant sensors. Additionally, we aimed to ensure reproducibility by building on an open-source medical image computing platform.

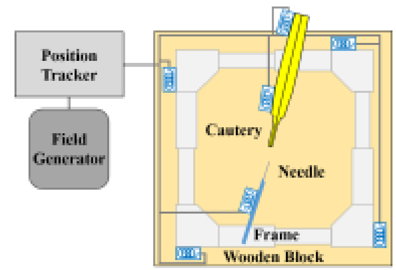

Figure 1. Hardware configuration diagram of a mock breast cancer surgery setup where redundant EM sensors are used to characterize tracking accuracy.

Methods. For testing purposes, a setup like Ungi *et al.*'s navigated breast cancer surgery setup was used[2]. EM sensors were affixed onto a rigid, rapid-prototyped frame placed around the workspace as well as onto surgical tools such as a needle and cautery (Figure 1). As an indicator of real-time tracking error, we compared the inter-sensor distances and angles to baseline measurements (Figure 2). EM tracking data was relayed to the 3D Slicer platform using the PLUS software toolkit[3]. A 3D Slicer software module was developed to calculate the difference between real-time measurements of the inter-sensor translations and rotations, compared to their respective baseline measurements. These differences were used as indicators of EM tracking error. Two linear support vector machine-based classifiers were developed to use these readings as an indicator for EM tracking error. One classifier was developed using readings from the four sensors on the frame (Classifier A) and another classifier was developed using readings from the two sensors on the cautery (Classifier B).

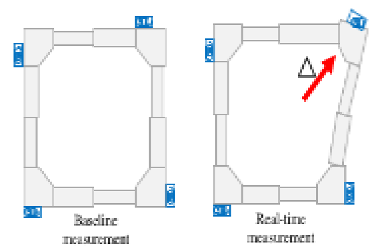

Figure 2. A diagrammatic representation of how measuring the geometry of a constellation of redundant sensors could indicate tracking error (Δ).

Results. It was determined that measuring discrepancies in inter-sensor geometry between baseline and real-time measurements was a valid indicator for tracking error. Classifier B outperformed Classifier A as shown in Table 1. The main concern with classifier performance was sensitivity—or ability to warn surgeons of legitimate tracking errors that could compromise surgical outcomes.

Table 1. Classifier Performance Measures

Classifier A		Classifier B	
Specificity	85 %	Specificity	93 %
Sensitivity	42 %	Sensitivity	82 %
Accuracy	63 %	Accuracy	86 %

Conclusion. It was found that tracking errors were better detected by affixing an additional sensor on the tool of interest than placing extra sensors around the tool workspace. While more data is needed to improve classifier sensitivity, the results above demonstrate a proof-of-concept for practical monitoring of EM tracking error using redundant EM sensors. With further improvements, this method may be feasible for clinical use.

References. [1] Jain *et al.*, Patent WO 2011110966 A2, 2011.
[2] Ungi *et al.*, *IJCARS*, 2015.
[3] Lasso *et al.*, *IEEE Trans Biomed Eng.*, 2014.