

# Intraoperative visualization and assessment of electromagnetic tracking error

Vinyas Harish<sup>1</sup>, Tamas Ungi<sup>1</sup>, Andras Lasso<sup>1</sup>, Andrew MacDonald<sup>1,2</sup>, Sulaiman Nanji<sup>2</sup>, Gabor Fichtinger<sup>1</sup>

<sup>1</sup>Laboratory for Percutaneous Surgery, Queen's University, Kingston, Canada

<sup>2</sup>School of Medicine, Queen's University, Kingston, Canada

## ABSTRACT

**Purpose:** Electromagnetic tracking allows for increased flexibility in designing image-guided interventions, however it is well understood that electromagnetic tracking is prone to error. Visualization and assessment of the tracking error should take place in the operating room with minimal interference with the clinical procedure. The goal was to achieve this ideal in an open-source software implementation in a plug and play manner, without requiring programming from the user.

**Methods:** We use optical tracking as a ground truth. An electromagnetic sensor and optical markers are mounted onto a stylus device, pivot calibrated for both trackers. Electromagnetic tracking error is defined as difference of tool tip position between electromagnetic and optical readings. Multiple measurements are interpolated into the thin-plate B-spline transform visualized in real time using 3D Slicer. All tracked devices are used in a plug and play manner through the open-source SlicerIGT and PLUS extensions of the 3D Slicer platform.

**Results:** Tracking error was measured multiple times to assess reproducibility of the method, both with and without placing ferromagnetic objects in the workspace. Results from exhaustive grid sampling and freehand sampling were similar, indicating that a quick freehand sampling is sufficient to detect unexpected or excessive field distortion in the operating room.

**Conclusion:** The software is available as a plug-in for the 3D Slicer platforms. Results demonstrate potential for visualizing electromagnetic tracking error in real time for intraoperative environments in feasibility clinical trials in image-guided interventions.

**Keywords:** 3D Slicer, Electromagnetic Tracking, SlicerIGT, Intraoperative, Image-Guided Therapy

## 1. PURPOSE

Electromagnetic (EM) tracking is commonly employed in image-guided interventions because tracked instruments do not need to constantly stay within sightlines of the tracking hardware. The small size of EM sensors and their ability to be placed within objects provide a greater deal of flexibility for use than optical tracking. Thus, EM tracking is used in a wide range of procedures including tracked ultrasound imaging, needle navigation, tumour surgery navigation and more. However, ferromagnetic materials compromise the accuracy of EM trackers by creating Eddy currents and magnetization fields that distort the electromagnetic field created by field generators<sup>1, 2</sup>. Accuracy and precision are paramount in surgical procedures, hence it is crucial to be able to identify when the integrity of a tracking system is being adversely affected.

Several methods have been investigated to detect, quantify, and visualize EM tracking error caused by field distortion. Krücker *et al.* propose software to compare accuracy of needle positions to a reference position on a CT scan.<sup>3</sup> However, this method does not offer real-time feedback and requires access to a CT scanner. Nafis *et al.* have developed similar methods of measuring EM tracking error using a sizeable granite block as well as a glass surface that could be placed on a LEGO base<sup>1,2</sup>. In these set-ups, the experimenters used pointer motions restricted by different objects with limited visualization options. Although these set-ups work well for determining the tracking error caused by the patient beds or other such large, static objects—they cannot be used for the testing in a real, complex surgical setup. Lugez *et al.* used 3D printed spherical and cube phantoms with a plurality of pre-defined sampling points to measure EM tracking error<sup>4</sup>. Methods such as that of Lugez *et al.* are time-consuming and may not be ideal for cases where the rapid, repeated assessment of EM tracking error must be done throughout an intervention. Each of the aforementioned techniques uses their own software, limiting the application of their methods for different research groups, therefore posing inherent limitations in terms of reproducibility and ease of use. Most importantly, requiring phantom objects in the workspace in which a surgeon would be working with various tools prevents measurements with the surgical tools in real life situations. Thus, although tests can be done to determine how sensitive a tracking system is to field distortion—they may not be necessarily indicative of what a surgical team can expect to see within an operating theatre. To ensure maximum confidence in the successfulness of an image-guided intervention, the assessment of EM tracking error must be done in the same environment the intervention will be taking place with the same tools that will be used.

To create a plug and play, real-time assessment system for EM tracking error, we built upon the 3D Slicer<sup>5</sup> platform. 3D Slicer is software tailored for medical image computing that is both freely available and open source. By enabling the speedy prototyping of new algorithms for visualization, data transmission and user interface development, 3D Slicer promotes translational clinical research. Moreover, these new algorithms that are developed are freely available for all users in the form of extensions that can be easily downloaded and installed. An extension was created that allows users to assess and visualize EM tracking error in conjunction with the existing range of functionality of the 3D Slicer platform.

## 2. NEW OR BREAKTHROUGH WORK TO BE PRESENTED

We developed a method for real-time intraoperative visualization and assessment of EM tracking error, which is simple and reproducible and its results are easily interpretable. The implementation is built upon the foundations of 3D Slicer and PLUS<sup>6</sup>, yielding a solution that integrates into image-guided intervention systems in a plug and play manner.

## 3. METHODS

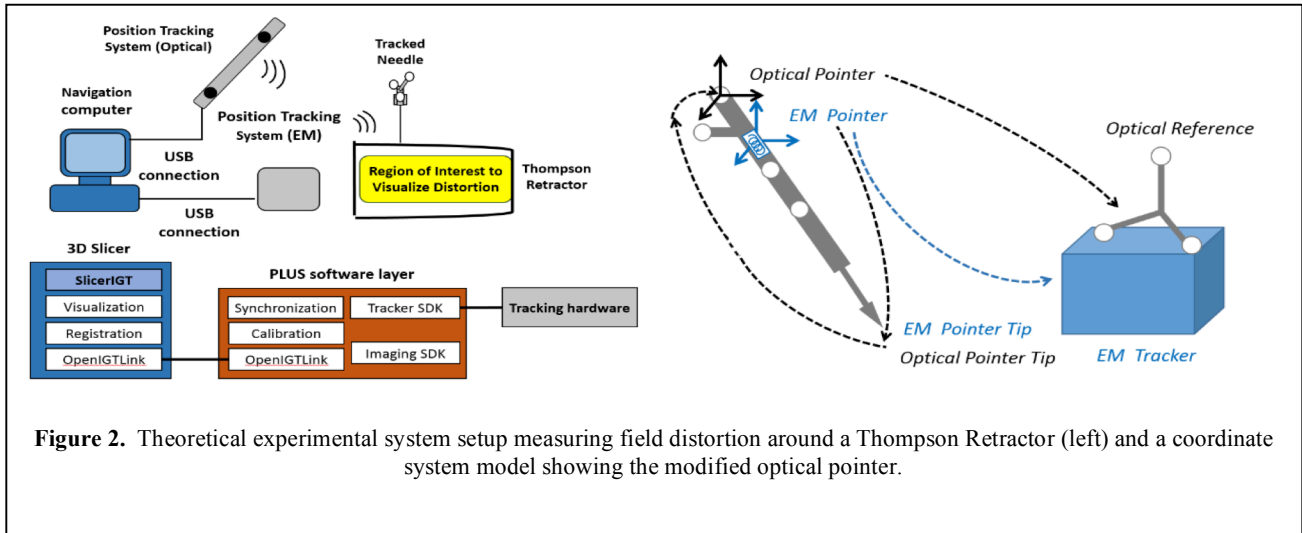
### 3.1 Setup

A Polaris optical tracker's passive probe tool (Northern Digital Inc., Waterloo, ON, Canada) was modified by attaching an EM sensor compatible with the Ascension 3D Guidance trakSTAR system (Ascension Technology Corp, Shelbourne, VT, USA) (Figure 1). Tracking information from these devices was sent to a laptop running the PLUS toolkit<sup>6</sup> that relayed the data to 3D Slicer<sup>5</sup> via the OpenIGTLink<sup>7</sup> (Figure 2). PLUS was developed to allow users to acquire tracking and imaging data from a wide range of hardware that can be used in image-guided interventions. The library is tailored to make commonly done procedures related to tool calibration and data processing easier by providing software tools and extensive documentation<sup>6</sup>. OpenIGTLink was developed to standardize how data is exchanged between various components of image-guided intervention systems. Over a peer-to-peer network protocol, all relevant images and data for tool-tracking and device control are transferred continuously, in real-time<sup>7</sup>. The specifications of what images, tracking data and other information PLUS



**Figure 1.** Hot glue was used in order to attach the Ascension's EM sensor to the optical pointer. The EM sensor is attached to a pencil serving as a modified tip which is itself attached to the pointer.

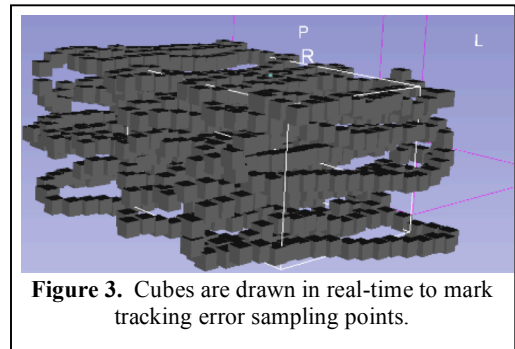
has to acquire, process and transfer are all set in a configuration file. A “scene” file describes how to receive, process and visualize data in the 3D Slicer program. Users can implement our method without having to do any programming, with only using configuration files. The user has access to a wide array of modules that are built into the 3D Slicer software platform without having to change the configuration file. For example to pivot calibrate a tracked needle, the user would just have to put the modified EM tracking pointer down and could continue with the intervention procedure. Depending on the complexity of the procedure, multiple tool setups can be used and switched between at ease through the selection of different configuration files at any time.



### 3.2 Implementation

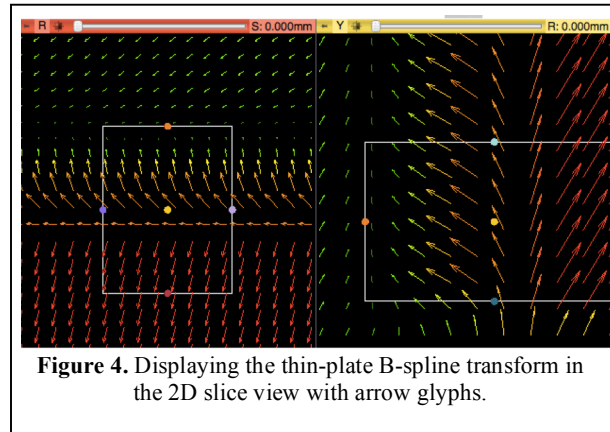
Previously a 3D Slicer module was designed to visualize 3D displacement fields caused by non-rigid volume transformations<sup>8</sup>. This module allows for a user to visualize transforms in a plethora of ways, with minimal time required for computation. This module was used to visualize position errors due to error sources such as random noise and EM field distortion at the location of the EM sensor in various points through space using a thin-plate B-spline transform. The error calculated as the difference between EM and optical tracking was mapped using the position of the optical tracker, as optical tracking was considered ground truth.

Prior to data collection, a pivot calibration is done using the modified tool. A pivot calibration is needed since the EM reference sensor is not located exactly at the tip of the optical pointer. Fiducial registration is needed in order to properly represent the physical space of the surgeon’s workspace on the image displayed on the computer running 3D Slicer. As the pointer is moved through space, cube polygons are generated in real-time in the designated region of interest (ROI) to show the location of sampling points (Figure 3). Once the experimenter collects enough data (e.g. the cubes fill as many voxels in the ROI as possible) the thin-plate B-spline transform can be visualized in a variety of ways including grids, glyphs and contours (Figures 4,5). Visualization of the data can also be done in real time during the data collection. In the case of real time visualization, a user can see an initially clean grid become increasing warped as they collect data close to a metallic object. The colours on the grid would also turn from black and green to red, much like the visualization shown in Figure 6. Finally, as this module is built into the 3D Slicer platform, users have at their disposal a wide variety of tools built into the platform such as the ability to replay data collection. The error field can be interpreted in relation to the intervention plan and thus show expected error in the surgical outcome relative to the plan.

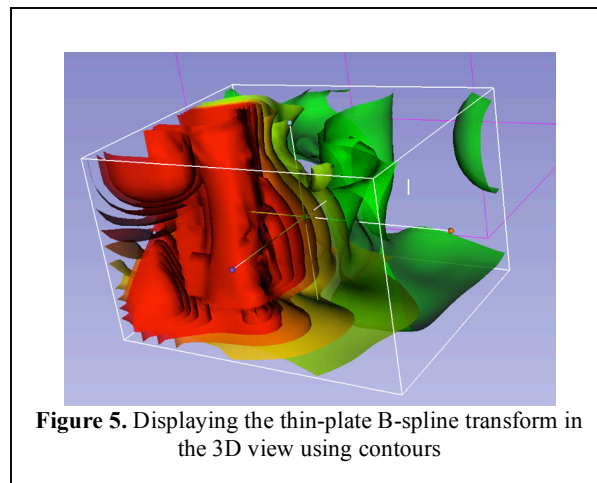


### 3.3 Testing

We tested the difference between free-hand data sampling and systematic grid sampling similarly to Nafis *et al.*<sup>2</sup> and Haidegger *et al.*<sup>9</sup> A square piece of fiberglass was placed in the center of a ROI 20 cmx15 cmx10 cm in size, and LEGO towers were used to collect data points at heights of 0, 5 and 10 cm along a plane created by the fiberglass. The modified pointer was moved along the fiberglass surface in a sinusoidal pattern in order to systematically collect data along the entirety of the plane. As this test was done to evaluate the precision of the freehand method of data collection in a controlled environment, there were no ferromagnetic materials present in the ROI that could have caused EM field distortion. Freehand sampling was also done in a sinusoidal pattern, however no aids such as the fiberglass platform were used.

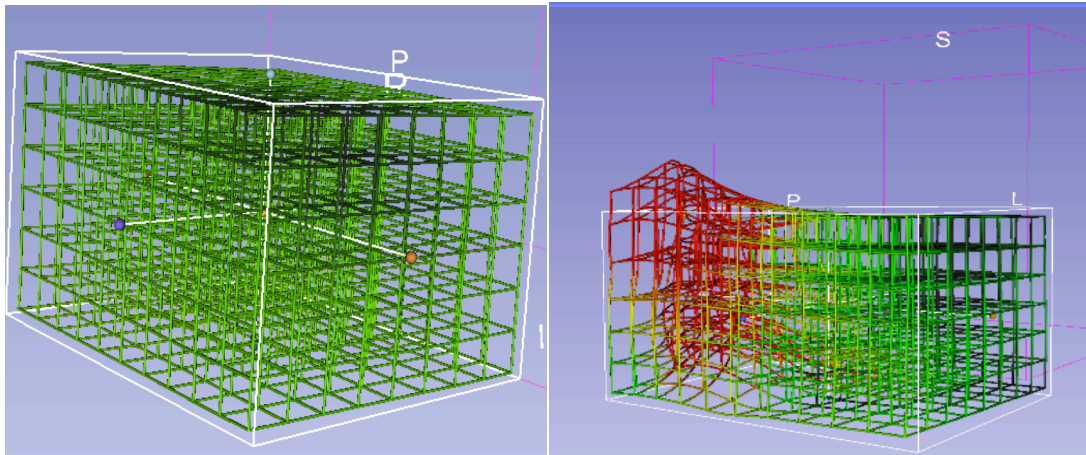


Data collection was done at each of the three heights five times and compared to freehand data collection done in the same ROI (which was also done five times). Following the aforementioned test to establish the precision of the system in a controlled environment using a fiberglass surface, various metallic objects such as a steel rod and metallic surgical retractor kit were placed in the center of the same ROI and freehand data collection was done around these objects five times. The visual aid of the cubes that are generated on the computer running 3D Slicer ensures that the user obtains the highest possible density of points during the sampling period.



## 4. RESULTS

Freehand measurements taken in a controlled, metal free environment report a distortion of 1.16 mm (STD 0.71 mm). In environments with a metal rod and a metallic surgical retractor kit the distortions were 4.27 mm (STD 2.92 mm) and 8.26 mm (STD 2.08 mm) respectively. Figure 6 shows a visual depiction of the tracking error in a metal free field (left) and a field with a metal rod (right). Differences between freehand and systematic sampling were measured in parallel planes placed 5 cm apart in the field (e.g. using the LEGO towers built at varying heights). The average difference was 1.8 mm.



**Figure 6.** Modelling a clean field (left) and a field with the metal rod in it (right) using the grid view.

These results show that quick freehand sampling allows for approximate assessment of significant metal-induced EM tracking error across the field. When tracking error needs to be quantified, a more exhaustive sampling method needs to be performed by collecting a large number of data points in a large number of passes over the field. Real-time feedback, as shown in Figure 3, assists the user.

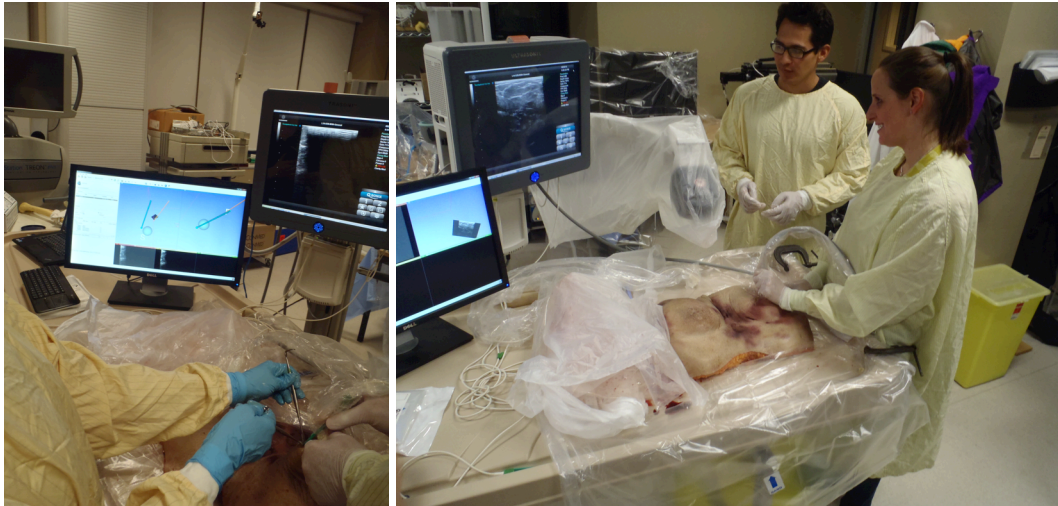
## 5. CONCLUSION

### 5.1 Summary

We presented a promising tool for visualization and assessing EM tracking error in real operating room settings. Our solution is built upon a widely-used, free, open source platform. The main limitation in our system stems from the inherent error in the tracking hardware. When multiple temporal calibrations are done and the rate that the stylus is moved is controlled, reported results regarding the time offset vary by up to 20 milliseconds. Thus, even when the stylus is moved at a very careful rate of 10 cm/s the standard deviation in the EM tracking error can be up to 2 mm. However, this error is inevitable based on the quality of the tracking systems. Altogether, our EM tracking error visualization technique seems applicable to a variety of uses and operating room settings and thus may serve as a useful adjunct in safety and feasibility clinical trials of image-guided intervention systems.

### 5.2 Current work

Our tool for the assessment and visualization of EM tracking error lends itself to use in testing procedures that have been previously suggested in proof of concept studies. One such study that our software can be applied to for testing is the resection of breast cancer tumours. The novel method proposed by Gauvin *et al.* involves the use of 3D Slicer and tracked ultrasound to provide surgeons with a margin of safety for the resection of the tumour in real-time<sup>10</sup>. The margin of safety is displayed by 3D Slicer and can also indicate when a scalpel has entered the margin by changing colour. In order to localize the tumour, multiple metal hook and wire systems are used. Our tool can be used to evaluate the effects that these hooks have on the EM tracking system's performance and ultimately the safety and feasibility of Gauvin *et al.*'s intervention system.



**Figure 7.** The intervention system proposed by Gauvin *et al.*

## ACKNOWLEDGMENTS

Gabor Fichtinger is supported as a Cancer Care Ontario Research Chair in Cancer Imaging. Vinyas Harish was supported by the Work Study Program at Queen's University.

## REFERENCES

- [1] Nafis, C., Jensen, V., Beaugerard, L., et al., "Method for estimating dynamic EM tracking accuracy of Surgical Navigation tools," Proc. SPIE 6141, (2006).
- [2] Nafis, C., Jensen, V., von Jako, R, "Method for evaluating compatibility of commercial Electromagnetic (EM) micro sensor tracking systems with surgical and imaging tables," Proc. SPIE 6918, (2008).
- [3] Krücker, J., Xu, S., Glossop, N., et al., "Electromagnetic Tracking for Thermal Ablation and Biopsy Guidance: Clinical Evaluation of Spatial Accuracy," Journal of Vascular and Interventional Radiology. 18(9), 1141-1150 (2007).
- [4] Lugez, E., Sadjadi, H., Pichora, D.R., et al., "Electromagnetic tracking in surgical environments: usability study," International Journal of Computer-Assisted Radiology and Surgery. (to appear).
- [5] Fedorov, A., Beichel, R., Kalpathy-Cramer, J., et al., "3D Slicer as an image computing platform for the quantitative imaging network," Magnetic Resonance Imaging. 30(9), 1323-1341 (2012).
- [6] Lasso, A., Heffter, T., Rankin, A., et al., "PLUS: open-source toolkit for ultrasound-guided intervention systems," IEEE Trans Biomed Eng, (2014).
- [7] Tokuda, J., Fischer, J.S., Papademetris, X., et al., "OpenIGTLink: an open network protocol for image-guided therapy environment," International Journal of Medical Robotics and Computer Assisted Surgery. 5(4), 423-434 (2009).
- [8] King, F., Lasso, A., Pinter, C., et al., "A tool for intraoperative visualization of registration transformations," Proc. SPIE 9036, (2014).

[9] Haidegger, T., Fenyvesi, G., Sirokai, B., et al., "Towards Unified Electromagnetic Tracking System Assessment—Static Errors," IEEE Engineering in Medicine and Biology Society, (2011).

[10] Gauvin, G., Yeo, C.T., Ungi, T., et al., "Real-Time Electromagnetic Navigation for Breast Tumor Resection: Proof of Concept," The 7th Hamlyn Symposium on Medical Robotics, 39-40 (2014).