A Simple Setup to Measure the EM Tracking Accuracy of a Window Field Generator

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Abstract:

Surgical navigation relies on the accurate intra-operative tracking of surgical tools, with the majority of available systems utilizing optical or electromagnetic methods for tool localization. Electromagnetic (EM) tracking allows the tracking of instruments near the tip of the tool, however these systems are highly susceptible to environmental influences. The aim of this work was to design and evaluate a simple setup for the assessment of EM tracking accuracy that could be easily transferred and applied in a variety of clinically relevant settings to allow simple assessment of environmental effects. The setup should allow one to ensure that the specific tracking system will function as expected (i.e. as in the lab) in specific clinical setting under realistic conditions. The developed setup and initial baseline measurements are described within.

Keywords: EM Tracking, Accuracy Evaluation, Window Field Generator

1 Introduction

Surgical navigation relies on the accurate intra-operative tracking of surgical tools, with the majority of available systems utilizing optical or electromagnetic methods for tool localization. While optical tracking systems generally provide higher accuracy, the tools must remain visible to the tracking system at all times, preventing tracking of the tool at or near the tip. This can be particularly problematic in cases in which long or flexible instruments are utilized. In contrast, electromagnetic (EM) tracking allows the tracking of instruments near the tip of the tool (as line of sight is not required), however these systems are highly susceptible to environmental influences.

The characterization of tracking accuracy is a challenging and complex task, with accuracy and precision values reported by system manufacturers often varying widely depending on the specific method of evaluation. Furthermore, these reported values are often not relevant to the accuracy achievable for the final application in the OR. A significant body of research exists on the evaluation of EM tracking systems (e.g. [1], [2] and [3]), however, while often comprehensive, this work is typically difficult to transfer to a specific surgical application.

Thus, the aim of this work was to design and evaluate a simple setup for the assessment of EM tracking accuracy that could be easily transferred and applied in a variety of clinically relevant settings to allow simple assessment of environmental effects. The setup should allow one to ensure that the specific tracking system will function as expected (i.e. as in the lab) in specific clinical setting under realistic conditions. The developed setup and initial baseline measurements are described within.

2 Materials and Methods

2.1. Setup

For the position measurements five EM sensors (NDI Aurora 5DOF Sensor 0.5 mm x 8 mm) are fixed inside a cube made of PMMA (polymethyl methacrylate) with an edge length of 98 mm. The sensors are centered in the sides of the cube, pointing in the following direction: +x, −x, +y, −y and −z[1]. For the remainder of this abstract the sensors will be referred as sensor +x, sensor −x and so on.

To reduce the environmental influence, the WFG was placed onto a wooden table. On the WFG a plastic plate was positioned at four different heights (56 mm, 94 mm, 133 mm and 171 mm). The plastic plate was equipped with three

[1] The sixth sensor, pointing in the +z direction, was broken. Therefore just five sensors were used.

parallel square rods, which were 120 mm apart. These rods separate the plate into three different tracks, referred as track A, B and C (see
Figure 1 for the entire setup).
All components of the setup are made out of non-ferromagnetic materials to prevent influence on the tracking accuracy. The plate is always aligned in a way that the surface is parallel to the WFG and the tracks are pointing in the y-direction of the WFG-coordinate system. Therefor moving the sensor cube along one of the three tracks, the x- and z-value should stay constant.

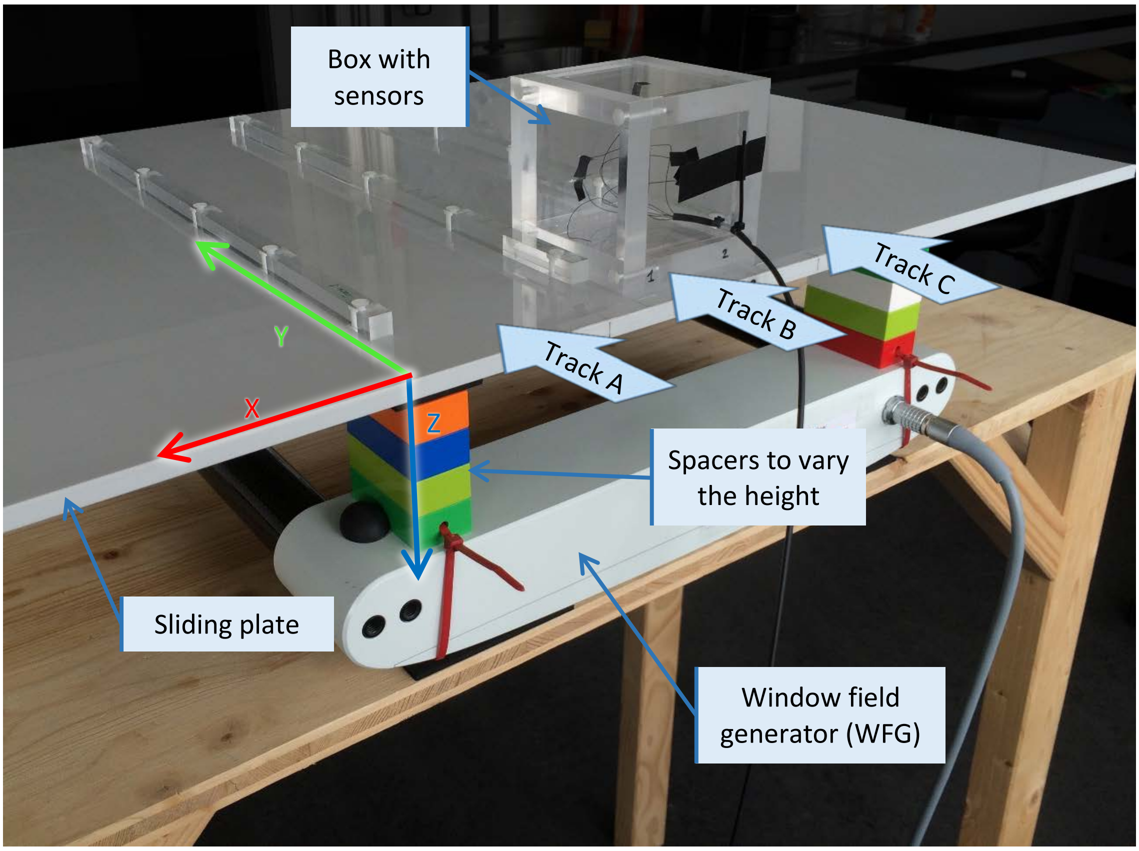

Figure 1: The setup for the measurements on the wooden table. The cube with the sensors is currently placed on the starting position on track B, while the height of the sliding plate is 94 mm (i.e. the second lowest configuration). Additionally the coordinate system of the WFG is shown: the x-direction to the left, z is going down and y parallel to the square rods, i.e. the cube will be moved in y-direction.

2.2. Measurements

For each measurement series the positions of the five sensors are recorded during a time span of 15 seconds. During these measurement, the cube with the sensors is manually moved along one of the three tracks. At each of the four heights three such measurement series are performed for each track, resulting in 36 measurement series (4 heights × 3 tracks × 3 repetitions). Since the tracking system is running at 40 Hz approximately 600 positions per sensor per series are stored.

2.3. Data Evaluation

Position influence

As no ground truth data is available, it is not possible to draw absolute conclusions. Each movement of the cube, and therefore the movement of each sensor, was along one of the three tracks, describing a line in 3D space. Therefor all points from each sensor for each track at each height are fitted to a line, resulting in a total of 60 lines (4 heights × 3 tracks × 5 sensors). In a second step the residual for each point is calculated (i.e. Euclidean distance to the corresponding line).

To evaluate the dependency of the location in the tracking volume, the values are separated depending on their position in the field of the WFG (grouped into 9 intervals per track), resulting in a total of 540 cells (4 heights × 3 tracks × 9 intervals × 5 sensors). Then the average of the residuals from all points in each cell was calculated. This gives an indication of the precision in the different locations of the tracking volume.

Sensor orientation influence

All five sensors are oriented differently and are rigidly mounted into the cube, therefore the real distances between them should stay constant over all measurements. The absolute distances between all sensors were calculated at each measurement, i.e. 10 distances per measurement. Then the medians from all measurements were calculated and subtracted from the corresponding distances to normalize them, i.e. the values correspond to the errors.
These errors indicating of how much the distance between a pair of sensors varies. Since all sensors are oriented differently, we wanted to derive conclusions about the influence of the sensor orientation on the tracking accuracy by looking at each sensor against all others except the one pointing in the opposite direction (e.g. for sensor +x these are the sensors +y, −y and –z but not sensor –x).

3 Results

3.1. Position influence

A total of ~108’000 positions (4 heights × 3 tracks × 3 repetitions × 5 sensors × 600 positions) were acquired. All points together with the fitted lines are shown in Figure 2. It can be seen, that the largest error is on the bottom right line (corresponding to the sensor –x in track C at the lowest level). Note that the lines from the sensors +y and −y are overlapping as well as the line of the sensor −z from the level below.
In Figure 3 the precision in each of the 540 cells is shown. The average value over all cells is 0.34 ± 0.31 mm. It can be seen that the values are generally small in the center of the tracking volume and increasing towards the border. No correlation between the heights and the precision can be seen. As expected from the residuals the largest values are in the center of the bottom right with a value of 4.86 mm.

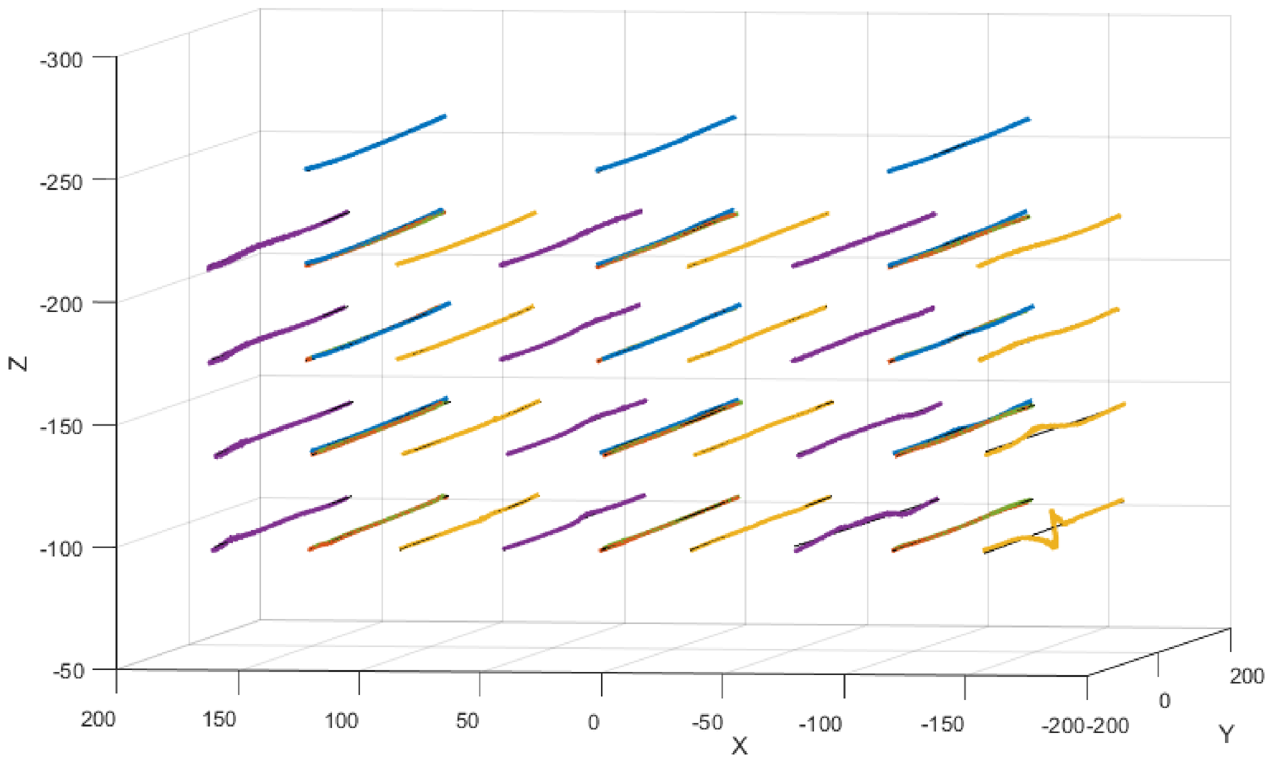

Figure 2: All data points together with the fitted lines. It can be seen, that on the bottom right line there is a large displacement.

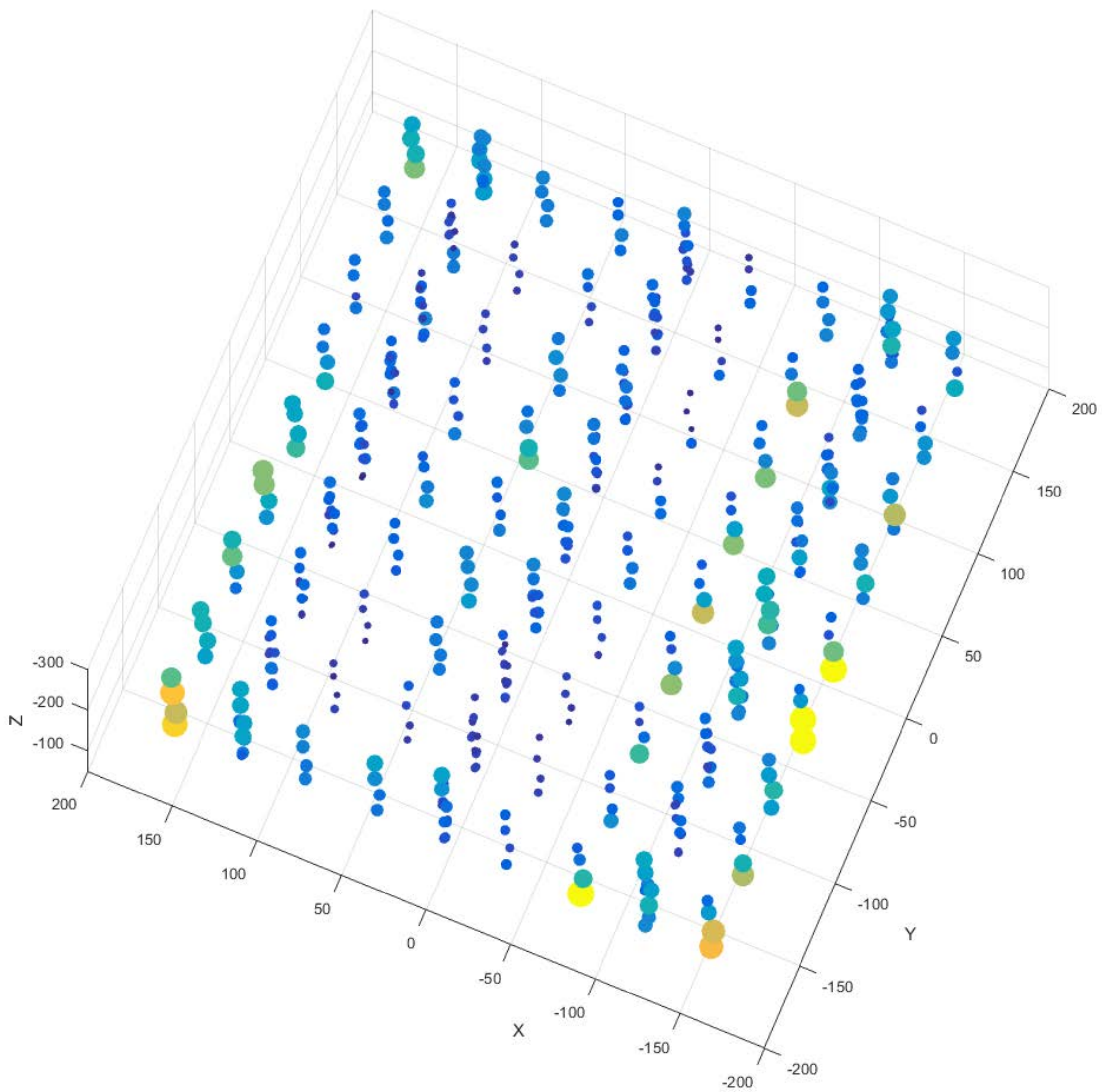

Figure 3: The precision in each of the 540 cells. For better visualization, the values are limited to 1.5 mm (i.e. the largest blobs are indicating ≥ 1.5 mm), while the precision in four cells is actually lower: 1.52 mm, 2.2 mm, 2.53 mm and 4.86 mm.

3.2. Sensor orientation influence

The normalized distances (i.e. errors) were calculated for each pair of sensors for all measurements resulting in a total of around 160’000 error values. By looking at the average error value from one sensor against each other perpendicular to it, it is possible to see various patterns depending on the orientation of the sensor. Unfortunately it is currently not possible to derive clear conclusions from these measurements regarding the influence of the sensor orientations.

4 Discussion

This work has presented a simple setup to allow the evaluation of EM tracking accuracy under a variety of environmental influences, as well as initial baseline accuracy measurements under laboratory conditions.
As expected, tracking accuracy was highest towards the center of the tracking system workspace and decreased towards the edges. No significant relationship between accuracy and the distance from the field generator could be observed. Significant artifacts were observed on the bottom right edge of the workspace. The reason for this remains unclear, however the exact same pattern were observed in all three repetitive measurements.

While this setup is significantly simpler than previous approaches for the measurement of EM tracking accuracy, the measurement process takes less than five minutes and can be simply transferred to a clinical setting for assessment of clinically relevant environmental factors. These influences can be either related to the OR room itself like the lights and OR table or other systems which need to be placed nearby such as the navigation system, C-arm, endoscopes and other surgical tools. The approach can also provide a means of ensuring that the tracking system is functioning as expected before the performance of a procedure.

First preliminary results regarding the influence of fluorescent lights show that this seems to have an effect on the EM tracking. For this additional measurement the sensor cube was placed in the center of the field. Switching on the fluorescent light led to an increased jitter from 19.63 µm to 35.91 µm (+ 83%).

The major drawback of the developed approach is that the setup is not appropriate to derive absolute conclusions regarding the influence of the location inside the field nor the orientation of the sensors.

Future work will involve the evaluation of the EM tracking accuracy under clinical conditions, in particular in an angio suite, taking into account the influence of the OR table, the lightning conditions as well as the C-arm and other equipment.

In conclusion this work has presented a simple approach for the measurement of EM tracking accuracy which can be used to evaluate the accuracy under various clinical relevant conditions. In the baseline measurements it was shown, that the accuracy under laboratory conditions is in line with the findings reported in the literature. Unfortunately we are not able to derive clear conclusions regarding the orientation of the sensors.

5 References

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