

# Interference during the use of an electromagnetic tracking system under OR conditions

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## Abstract

Many computer-assisted surgery applications use electromagnetic tracking devices and several sources of interference may reduce the accuracy of this type of system in clinical situations. This study aims to quantify interference sources in an operating room (OR) and determine if their impact on the tracking system is excessive for applications requiring millimetric accuracy. Electromagnetic noise levels were measured in a controlled environment and compared with measurements in an OR. Errors generated by this noise remained below the 0.15 mm RMS level. OR equipment was also brought in proximity to the electromagnetic receivers and the errors generated by the ensuing interference were measured. Ferromagnetic and electrical devices can produce large interference (translation errors up to 8.4 mm RMS and rotation up to 166°). However, these devices can be identified and placed at sufficient distances to decrease the magnitude of their interference. In conclusion, in the absence of significant ferromagnetic or electromagnetic distortion caused by equipment often present in an OR, this electromagnetic tracking system provides valid relative measurements with millimetric accuracy to computer-assisted surgical applications. This distortion can be reduced by maximizing the distances to the interfering OR equipment and integrating noise-reducing algorithms in associated software. © 2002 Elsevier Science Ltd. All rights reserved.

*Keywords:* Electromagnetic interference; Tracking device; Operating room

## 1. Introduction

Many medical applications require the use of a three-dimensional (3D) position and orientation measuring tools. The two most common types of tracking devices used for biomechanical applications rely on optical or electromagnetic systems (Eckhouse et al., 1996). With optical systems, the main drawback is the necessity for a free line of sight from the camera to the tracker. Electromagnetic systems do not have this limitation, but several sources of interference may reduce their accuracy. Electromagnetic systems are currently in use for a variety of applications, particularly for the study of kinematics (Biryukova et al., 2000; Bottlang et al., 2000; Dykstra et al., 1993; Steffen et al., 1997), biomechanics (An et al., 1988; Bull et al., 1998; van Ruijven et al.,

2000) and computer-assisted orthopedic surgery (Amiot et al., 1995, 2000; Bottlang et al., 1998).

Three types of sources may interfere with the normal operation of an electromagnetic tracking system in an operating room (OR): background noise originating from ambient electrical devices (for example: wires in the floors or ceiling, lights, MRI device in a nearby section of the hospital, etc.) (Day et al., 1998), electromagnetic fields generated by typical electrical OR equipment as well as the ferromagnetic behavior of metallic instrumentation and tools (Birkfellner et al., 1998; Milne et al., 1996).

Detection of sources of magnetic interference is not simple as there are no visual cues similar to the optical system where loss of signal follows camera obstruction. It is therefore necessary to identify potential sources of interference and take steps to reduce or eliminate their effect. This study aims to quantify the interference level of these sources and determine their impact on accuracy in OR conditions.

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## 2. Methods

The tracking system used in this study (MotionStar system, Ascension Technology Corporation, Burlington, Vermont) has a published 3D RMS accuracy of 0.5 mm (Milne et al., 1996). The system is comprised of a “short range” emitter that produces an electromagnetic field, receivers that measure the field intensity and orientation as well as amplifier cards converting this information into 6 degrees of freedom (DOF) data. A preliminary step was done to identify some average accuracy hardware (2 receivers, 1 emitter and 2 amplifier cards). In this preliminary step, 38 receivers, 6 emitters and 13 amplifier cards were evaluated and a selection process was then based on the mean displacement error of the complete system. A test bench was constructed with two 15 cm diameter PVC tubes on which the emitter and receiver array were mounted. The emitter and receiver arrays were placed approximately 1.5 m from the ground to avoid electromagnetic interference from the displacement device or from wires and metal in

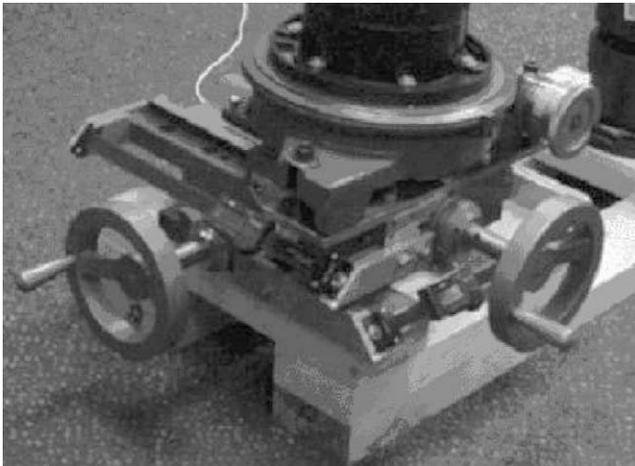


Fig. 1. Receiver array displacement mechanism composed of a rotating table ( $0.005^\circ$  precision) mounted on an XY table (0.01 mm precision) with Mitutoyo Absolute digimatic calipers (0.01 mm precision; 0.025 mm accuracy).

the floor (Day et al., 1998) or ceiling. The receiver array support tube was placed on a rotating table ( $0.005^\circ$  precision) mounted on an XY table (0.01 mm precision). Mitutoyo Absolute digimatic calipers (0.01 mm precision; 0.025 mm accuracy) were fitted to both the X- and Y-axis to allow accurate displacements (Fig. 1).

This setup was installed in the middle of an electromagnetically shielded ferrite-plated anechoic room at the Centre en Recherche Industrielle du Québec (Montréal, Canada), with the MotionStar amplifier cards and computer approximately 1.5 m away. Two receivers were placed 500 mm from the front of the emitter, wires pointing away, 230 mm apart and with the middle point between the receivers located 71 mm to the side of the emitter to allow use of the full range of the XY table. This receiver array was physically displaced with the XY table by increments of 71 mm in order to form a  $3 \times 3$  pattern of measured positions (Fig. 2). At each of these positions, 1000 samples of the 3D position and orientation of the receiver were recorded by the computer to remove any bursts of environmental noise from nearby equipment. A randomized time interval of up to 50 ms between each sample was used in order to avoid any systematic errors due to a fixed acquisition frequency. The average standard deviation for all sets of samples was considered to be the minimum background noise.

For the clinical evaluation portion of our protocol, the MotionStar system was installed in an OR at Hôpital Sacré-Coeur de Montréal. The emitter and receivers were placed on plastic support devices approximately 380 mm above the OR table. The two receivers were 420 mm from the front of the emitter and 115 mm to each side. The MotionStar amplifier cards and computer were located approximately 1.5 m from the back of the emitter.

An initial measurement of both receivers' position and orientation was recorded 5 times (1000 samples each) and averaged to insure the reference measurement stability. Next, the following OR equipment was individually brought close to the side of one of the receivers: anesthesia equipment, an arthroscope, an

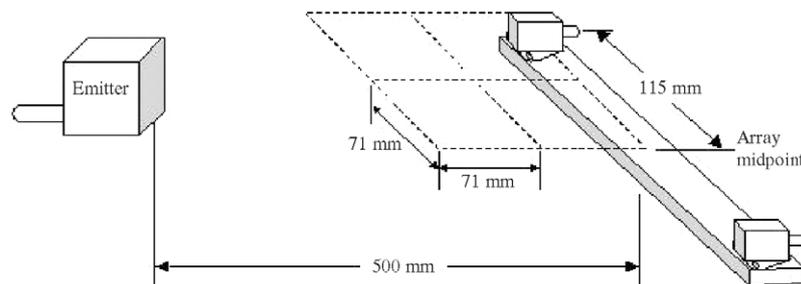


Fig. 2. Experimental setup used to evaluate a controlled environment. The receiver array was displaced with 0.01 mm precision on the dashed pattern and 6 degree of freedom (DOF) measurements were recorded at each of the 9 positions.

oscillating saw, spreaders, a saw guide, scissors, intravenous monitoring equipment, positioning devices, an OR lamp, an OR table (in this case, the plastic supports were simply removed and the receivers placed directly on the table) and an instrument table. Any change in relative position and orientation between the receivers was considered to be interference caused by the specific OR equipment. The standard deviation of the 1000 samples taken with the interference was considered as noise induced by the specific OR equipment.

### 3. Results

Although the background noise levels obtained in the OR (position:  $0.10 \pm 0.03$ ,  $0.067 \pm 0.006$ ,  $0.088 \pm 0.007$  mm. Orientation:  $0.0135 \pm 0.0003^\circ$ ,  $0.014 \pm 0.001^\circ$ ,  $0.0090 \pm 0.0005^\circ$ ) were slightly higher than in the shielded room (position:  $0.09 \pm 0.02$ ,  $0.05 \pm 0.02$ ,  $0.05 \pm 0.01$  mm. orientation:  $0.011 \pm 0.002^\circ$ ,  $0.011 \pm 0.002^\circ$ ,  $0.008 \pm 0.001^\circ$ ), the errors generated by this noise remain below the 0.15 mm RMS level and therefore do not prevent sub-millimeter accuracy. Thus, this should not excessively reduce the MotionStar's accuracy, particularly if averaging algorithms are included in the software.

Increasing the distance from the receiver always reduced interference to levels near the background noise (Table 1). For example, noise generated by an arthroscope (light source and signal processor) at 30 cm distance (31.8 mm) was reduced to 0.2 mm by moving it to 120 cm. Although most metallic objects brought close to the receiver array produced some interference, only the electric and pneumatic devices produced large noise levels in the measurement, particularly with respect to the measured orientations. Orientation errors and noise levels of up to  $166^\circ$  were obtained when additional directional components ( $\Psi$ -axis) were induced by the OR equipment EM fields. All these results concern interference generated to the side of a receiver. Any differences due to interference sources approached frontally or vertically should be evaluated in further studies.

### 4. Discussion

The use of electromagnetic tracking devices inside an OR could be considered problematic because of the potential interference from this specific environment (Milne et al., 1996; Birkfellner et al., 1998). The objective of this study was to quantify this effect with standard OR equipment. However, because of potential functional differences between makes and models, more measurements should be done to evaluate whether all

OR equipment currently in use produces electromagnetic fields similar to those detected in this study.

The noise measured in the shielded room is probably caused by the internal electronic components of the device (Day et al., 1998). The slightly higher background noise levels in an OR can be attributed to the surrounding OR equipment. For some clinical uses however, noise levels could probably exceed the values presented here since the acquisition frequency of the MotionStar system would not support 1000 samples in real-time. The impact of the number of averaged samples on the noise levels should be further investigated.

Noise levels can also be affected by sources of electromagnetic fields like electrical equipment located close to the MotionStar magnetic field. Also, electrical equipment will have more effect on receiver measurements when the receivers are further from the emitter because the relative importance of the interfering field will be greater. These types of errors should be reduced or even completely eliminated by placing potentially noisy equipment as far from the operating field as possible. Considering that magnetic field intensity is inversely proportional to the cube of the distance, a minimal distance should insure that the interference from this equipment is significantly lower than the ambient background noise.

Electrical equipment will also produce distortions of the MotionStar's EM field as shown by the position and orientation errors in Table 1. Ferromagnetic materials produce only this effect on the receivers but do not increase the noise levels. The intensity of the distortion is mostly a function of the distance of the object from the receiver, the quantity of ferromagnetic material present and its conductivity (Birkfellner et al., 1998). As a guideline to avoid any interference from the equipment in an OR, no object composed of ferromagnetic metal like mild steel should be introduced in the MotionStar field during use (Milne et al., 1996). If these items must be used within the field, special care should be taken to evaluate the validity of the measurements.

Potential solutions for OR applications could include field-monitoring devices to detect any interference as well as increasing the electromagnetic output of the emitter to reduce the relative magnitude of surrounding electromagnetic fields. In this case, however, further studies should be conducted to verify that ferromagnetic interference does not also increase, and to insure that no adverse effect occurs due to increased patient exposure to electromagnetic radiation. In all cases however, maximizing the distances to interfering OR equipment and integrating noise-reducing algorithms in associated software should enable the MotionStar system to provide valid and sub-millimeter precision data to OR computer applications.

Table 1  
OR equipment interference on the receiver array

Equipment	Distance of equipment from receiver	Interference-induced translation (mm)	Interference-induced rotation (deg)	Noise					
				X (mm)	Y (mm)	Z (mm)	$\Psi$ (deg)	$\theta$ (deg)	$\Phi$ (deg)
Anesthetist equipment	As close as possible	0.267	0.209	0.14	0.06	0.08	0.01	0.01	0.01
Arthroscopy	30 cm distance	4.081	166.741	10.61	23.59	18.54	172.92	4.00	6.51
	60 cm distance	1.129	0.050	1.55	1.26	5.47	0.37	0.85	0.58
	90 cm distance	0.178	0.102	0.17	0.15	0.28	0.02	0.04	0.02
	120 cm distance	0.128	0.116	0.13	0.08	0.13	0.01	0.02	0.01
Oscillating saw	Active, as close as possible	4.85	164.25	1.45	10.04	1.85	177.06	0.53	0.56
	Idle, as close as possible	6.36	0.26	0.11	0.09	0.08	0.02	0.02	0.01
	Idle, 7.5 cm distance	8.37	0.53	0.08	0.06	0.08	0.01	0.02	0.01
	Idle, 15 cm distance	1.41	0.45	0.10	0.09	0.09	0.02	0.02	0.01
	Idle, 30 cm distance	0.25	0.17	0.09	0.07	0.09	0.01	0.02	0.01
Spreaders	As close as possible	0.099	0.12	0.10	0.07	0.08	0.01	0.01	0.01
	7.5 cm distance	0.178	0.14	0.10	0.07	0.09	0.01	0.01	0.01
	15 cm distance	0.137	0.14	0.09	0.07	0.08	0.01	0.02	0.01
	30 cm distance	0.080	0.12	0.10	0.08	0.08	0.02	0.01	0.01
Saw guide	As close as possible	0.254	0.095	0.13	0.07	0.10	0.01	0.02	0.01
	7.5 cm distance	0.105	0.077	0.10	0.07	0.10	0.01	0.02	0.01
	15 cm distance	0.001	0.055	0.11	0.09	0.09	0.01	0.02	0.01
	30 cm distance	0.083	0.071	0.11	0.09	0.10	0.01	0.02	0.01
Intra-venous monitoring equipment	20 cm distance	5.230	118.950	4.83	6.11	20.02	168.11	2.13	2.66
	30 cm distance	1.944	0.223	2.07	2.11	10.40	1.07	1.16	1.22
Positioning devices	As close as possible	3.014	0.388	0.09	0.05	0.09	0.01	0.02	0.01
	7.5 cm distance	5.039	0.495	0.15	0.08	0.08	0.02	0.01	0.01
	15 cm distance	1.933	0.474	0.10	0.06	0.07	0.01	0.01	0.01
	30 cm distance	0.381	0.146	0.10	0.06	0.07	0.01	0.01	0.01
Scissors	As close as possible	2.830	0.595	0.13	0.07	0.09	0.02	0.01	0.01
	7.5 cm distance	2.400	0.558	0.10	0.08	0.08	0.02	0.01	0.01
	15 cm distance	0.672	0.247	0.11	0.06	0.08	0.01	0.01	0.01
	30 cm distance	0.105	0.136	0.10	0.06	0.07	0.02	0.01	0.01
Lamp	As close as possible	1.297	0.176	0.13	0.07	0.07	0.02	0.01	0.01
	Approximately OR height	0.678	0.185	0.10	0.08	0.07	0.01	0.01	0.01
Instrument table	As close as possible	0.008	0.021	0.16	0.08	0.08	0.01	0.01	0.01
	7.5 cm distance	0.027	0.061	0.12	0.07	0.08	0.01	0.01	0.01
	15 cm distance	0.053	0.057	0.11	0.06	0.07	0.01	0.01	0.01
	30 cm distance	0.050	0.052	0.12	0.06	0.07	0.01	0.01	0.01
OR table	7.5 cm distance	5.698	0.426	0.15	0.08	0.06	0.01	0.01	0.01

The error measurements represent the virtual receiver displacement (3D RMS translation and rotation) perceived by the system as a result of the presence (distance from the side of the receivers noted in the second column) of OR equipment. The noise measurements (presented for each DOF) combine the standard background noise with the equipment interference. Increased distance from the receiver always reduces interference to levels near the background noise.

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