A Comparison of the Accuracy of an Electromagnetic and a Hybrid Ultrasound-Inertia Position Tracking System

Abstract

Results of a comparison study of the tracking accuracy of two commercially available wide-range position tracking systems suitable for CAVEs are presented. An experiment was conducted with Flock of Birds and IS-900 tracking systems installed in the same CAVE environment to compare their accuracy. Another experiment was performed with a newly deployed IS-900 to investigate the impact of different ultrasound emitter configurations on the accuracy of the location tracking. The results show that the IS-900 has a much better accuracy over a larger range of operation than does the Flock of Birds; however, it is sensitive to the optimality of the ultrasound emitters configuration.

1 Introduction

Until recently, electromagnetic position tracking systems—such as Flock of Birds (FoB) from Ascension Technology Corporation and 3Space FASTRAK from Polhemus, Inc.—were the only commercially available choices for large virtual reality (VR) installations such as CAVEs. Although the user's location and orientation can be tracked in other ways (Meyer, Applewhite, & Biocca, 1992)), none of them are particularly suitable for CAVEs. However, the situation is changing as a new generation of wide-range tracking systems is emerging from the research labs. One of these systems is the IS-900 VET from InterSense, Inc., that combines ultrasound and inertia tracking to achieve a high accuracy and high update rate for large tracking areas. It has been previously used to track user's position in an open space and just recently has been modified to work in a CAVE-like environment. Our group was one of the first to install and evaluate IS-900 VET in the CAVE. Since then, we have been frequently asked for the results of our evaluation; therefore, we decided to share them in the form of this report.

In this study, the accuracy of two position tracking devices—namely the electromagnetic extended-range Flock of Birds and the ultrasound/inertia InterSense IS-900 VET—is measured and compared. The measurements are taken on two separate occasions in two different CAVEs equipped with both tracking systems. Accuracy is characterized by the amount of error in tracked position (location and orientation) and is measured as the distance (angle) between the actual sensor position (orientation) and as reported by the system. Other performance characteristics of interest are resolution (the smallest change in the location or orientation the system can detect), update rate (the rate at which the system reports the position), latency (the delay between the movement of the sensor and the report of its new position), jitter (the rapid, repeated changes in the tracked position value when the tracking sensor is held still), and range of operation (the volume in which the tracked position is reported accurately).

2 Position Tracking Principles

A survey of position tracking techniques can be found in Meyer et al. (1992). However, it does not include inertia-based tracking because this technology was not used for this type of applications at the time of the

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publication. Therefore, a more detailed description of the relevant technologies is provided here.

2.1 Electromagnetic Position Tracking

Six-DoF electromagnetic position tracking is based on the application of orthogonal electromagnetic fields (Raab, Blood, Steioner, & Jones, 1979). To date, two varieties of electromagnetic position trackers have been implemented: one uses alternating current (AC) to generate the magnetic field, and the other uses direct current (DC). In an AC system, mutually perpendicular emitter coils sequentially generate AC magnetic fields that induce currents in the receiving sensor that consists of three passive mutually perpendicular coils. Sensor location and orientation therefore are computed from the nine induced currents by calculating the small changes in the sensed coordinates and then updating the previous measurements. Carrier frequencies are typically in the 7–14 kHz range. The excitation pattern and processing are repeated typically at 30–120 Hz.

In contrast to the continuous wave generated by the AC systems, a DC system uses a sequence of DC pulses, which in effect is equal to switching the transmitter on and off. This design is intended to reduce the effect of the field distortion due to the eddy currents induced in nearby metals when the field is changing. The initial measurements are performed with all three antennas shut off so that the x, y, and z components of Earth's magnetic field are measured by the sensor. Next, each transmitter coil is pulsed in a sequence, and the induced current is recorded on each receiving sensor coil after a short delay, allowing the eddy currents to die out. Earth's magnetic field components are then subtracted from the measured values generated in each receiver coil by each pulse. The resulting nine values are then used to compute the location and orientation of the receiver relative to the transmitter. The measurements are typically updated at 30–160 Hz.

The Flock of Birds and 3Space FASTRAK are among the most widely used long-range electromagnetic tracking systems. The 3Space FASTRAK is an AC system, and the Flock of Birds is a DC system. The measurements produced by both systems are rather noisy, and so an additional filtering is implemented. The working range of both systems is claimed to be up to 10 ft. from the transmitter, but their accuracy decreases significantly as the distance between the transmitter and receiver increases (Nixon, McCallum, Fright, & Price, 1998). Also, due to the dependence of the measurements on the local electromagnetic field, they are sensitive to the ambient electromagnetic environment. If there is metal, other conductive material, or equipment that produces an electromagnetic field near the tracker's transmitter or receiver, the transmitter signals are distorted, and the resulting measurements contain both static and dynamic error. Static errors as high as several feet have been observed near the maximum operation range of the tracking system. Several analytical techniques have been proposed to compensate for the field distortions (Kindratenko, 1999; Kindratenko & Bennett, 2000).

2.2 Ultrasound/Inertia Position Tracking

Inertial position tracking is based on the application of multiple gyroscopes and accelerometers to sense the changes in the sensor's position (Foxlin, Harrington, & Altshuler, 1998). The orientation is calculated by integrating the angular rates from three orthogonal angular rate-sensing gyroscopes. The location is computed by double integrating the outputs from three orthogonal accelerometers corrected for the effects of gravity. The double integration results in position drift; therefore, it must be corrected frequently.

Ultrasound position tracking can be implemented using the time of flight of an acoustic wave (frequencies above 20 kHz) (Meyer et al., 1992). Multiple emitters and sensors are required to obtain a set of distances from which the precise position can be calculated. The update rate of such a system is limited by the speed of sound and is typically 20–50 Hz. Also, special precautions have to be taken so that the emitter-receiver line of sight is not blocked. Neither inertial nor ultrasound position tracking alone is acceptable for the large-scale VR applications.

The InterSense IS-900 is a wide-range position tracking system that employs the inertial tracking in combi-

Table 1. *Technical Characteristics of Three Commercially Available Position Tracking Systems*

	IS-900	Flock of Birds	3Space FASTRAK
Resolution: location	1.5 mm	0.5 mm at 30.5 cm	0.06 mm at 30.5 cm
Resolution: orientation	0.05 deg.	0.1 deg. at 30.5 cm	0.025 deg.
Accuracy: location	4 mm RMS	1.8 mm RMS	0.762 mm RMS
Accuracy: orientation	0.2 deg. (P/R) 0.4 deg. (Y) RMS	0.5 deg. RMS	0.15 deg. RMS
Update rate	180 Hz	144 Hz	120 Hz
Latency	4–10 ms		4 ms

nation with the ultrasound tracking (Foxlin et al., 1998). The inertial component delivers high update rates, and the ultrasound component is responsible for keeping the inertial module from drifting. InterSense position sensor consists of an integrated inertial sensing instrument and two ultrasonic receiver modules. A set of ultrasonic emitters—typically mounted above the tracking area and whose position is precisely known in advance—sends out a timed 40 kHz pulse sequence. The rangefinders count time of flight until the pulse arrives and use the speed of sound at the given temperature to compute the distance. The inertial measurement unit is sampled at about 500 Hz, and its outputs are used to compute the orientation and location of the sensor. Partial drift correction takes place immediately after each range measurement is received. This operation mode allows an acceptable location tracking even when the ultrasound sensors are blocked for short periods of time. The location of the ultrasonic emitters has to be precisely known, there should be enough emitters to cover the required tracking space, and they should be distributed evenly so that no dead spots are present (otherwise, lower accuracy and increased jitter are observed).

3 Comparison Study

Table 1 contains the characteristics of the systems under investigation taken from their factory specifications provided by the manufacturers (Ascension Technology, InterSense, and Polhemus). The 3Space FASTRAK characteristics are included for comparison. Although different manufacturers use different ways to measure the performance of their products, it appears from the table that all three systems are perfectly suitable for CAVE-based VR applications. Of course, the factory specs were obtained by the manufacturers in an idealized lab environment that cannot be found in the real-life VR facilities. Our experience with these systems indicates that they do not always perform in reality to the specs. Electromagnetic tracking systems suffer from the interference of external electromagnetic fields and a presence of metal near the transmitter or receiver. This has a profound effect on their accuracy (Nixon et al., 1998), although various calibration techniques (Kindratenko, 1999; Kindratenko & Bennett, 2000) can be applied to decrease the amount of error. From the other side, the IS-900 does not suffer from this type of interference; however, its accuracy still can be affected if the ultrasonic emitters are not installed optimally, some abnormalities are present in the ultrasound sensors, or the location of the UltraSonic SoniDiscs is not known precisely. Therefore, it is expected that, in a typical production environment, both systems are not very accurate. It is our goal here to measure and compare their accuracy.

3.1 Flock of Birds and IS-900 Accuracy Comparison

In the first experiment, the accuracy of the Flock of Birds and the IS-900 installed in the same CAVE environments was compared. Two sets of measurements were taken in two different CAVEs: one located in the Virtual

Reality Lab at the Media Union (MU) of the University of Michigan, Ann Arbor, MI, and another located at the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign.

In the MU CAVE, the FoB transmitter was installed 9 ft. from the floor in the middle of the CAVE, and the IS-900 6 SoniStrip CONSTELLATION array was located 10 ft. from the floor of the CAVE. In the NCSA CAVE, the FoB transmitter was located 8 ft. from the floor and 3 ft. from the front wall of the CAVE, and the IS-900 8 SoniStrip CONSTELLATION array was located 9 ft. from the floor of the CAVE. One can notice that the SoniStrip CONSTELLATION array configurations are different. In both cases, InterSense engineers optimized them to deliver the best possible performance for a given environment.

The experiment consisted of moving the tracking sensor on the regularly spaced x-z grid with known x and z coordinates and constant y coordinate (4 ft. from the floor of the MU CAVE and 5 ft. from the floor in the NCSA CAVE) and zero orientation and recording the sensor's true and tracked position at each grid node. This was done with the help of a device described in detail by Kindratenko and Bennett (2000), the precision of which is ±10 mm and ±1 deg., which is sufficient for the purpose of this experiment. The 4–5 ft. heights were selected as an average height between the tracked user's hand and head in a typical CAVE environment. Figure 1 presents the results of these measurements obtained in the MU CAVE. (Measurements from the NCSA CAVE are similar.) One can immediately notice that the IS-900 has much greater accuracy than the FoB. Both systems performed well near the center of the CAVE, but the FoB performed very poor near the edge of the tracked volume, reporting errors as large as ~ 50 cm in the MU CAVE and ~ 69 cm in the NCSA CAVE. Clearly, the FoB has a smaller useful range of operation than the IS-900. The dots in the plot indicate the FoB measurements after the high-order polynomial fit calibration (Kindratenko, 1999) was applied. Although the calibration allowed a substantial improvement in the tracking precision of the FoB, it is still not as accurate as the IS-900. The average IS-900 error in the tracked location is only 19 ± 10 mm in the MU CAVE and 18 ± 11 mm in the NCSA CAVE. Table 2 summarizes the results for the MU CAVE.

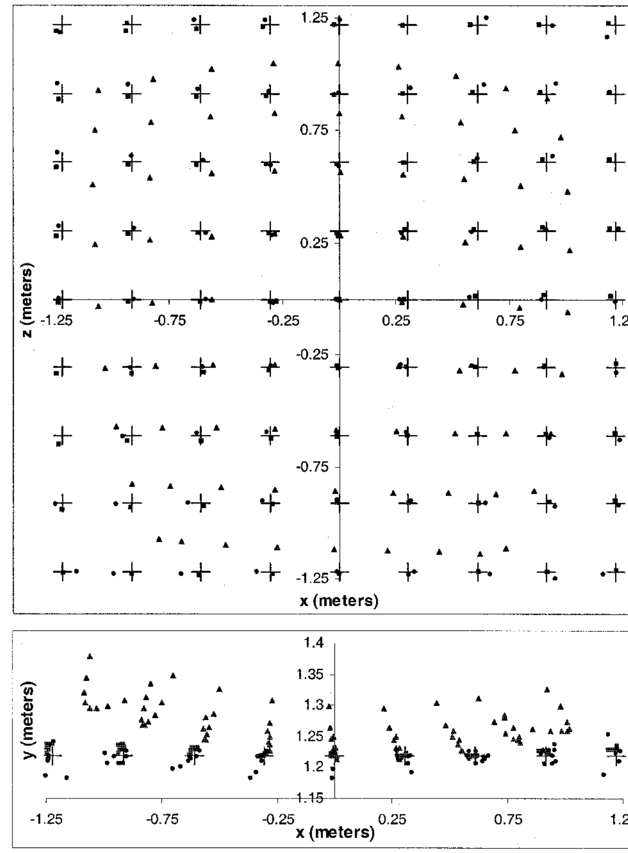

Figure 1. *The xz and xy plots of the true and tracked sensor location. The measurements are shown in the CAVE coordinate system with the origin in the middle of the floor, x axis pointing towards the right wall of the CAVE, y axis pointing up, and z axis pointing away from the front wall of the CAVE. Maximum location error for the IS-900 is 4.5 cm and 49.9 cm for the Flock of Birds. Legends: †—actual receiver location ▲—location tracked by the FoB ■—location tracked by the IS-900 ●—location tracked by the calibrated FoB.*

The results of this experiment consistently show that, in a typical CAVE environment, the FoB is significantly less accurate than the IS-900. Although the FoB can be calibrated, the IS-900 is still more accurate and has a larger range of operation. We also verified if there is any interference between the FoB and IS-900 tracking systems when both are turned on. No measurable interference was observed within the tracked volume used in this experiment. The IS-900 also exhibited considerably lower latency than did the FoB.

Table 2. *Location and orientation errors for the FoB and IS-900 obtained in the MU CAVE. The location errors are measured as the distance between the true location of the sensor and its corresponding tracked location. The orientation errors are measured as the angle through which the measured local coordinate system must rotate to match the true coordinate system*

	IS-900		Flock of Birds		Calibrated FoB	
	Location	Orientation	Location	Orientation	Location	Orientation
Mean	19 mm	3 deg.	159 mm	6 deg.	33 mm	<1 deg.
Stdev	10 mm	1 deg.	110 mm	4 deg.	19 mm	<1 deg.
Min	0 mm	<1 deg.	0 mm	1 deg.	5 mm	<1 deg.
Max	45 mm	6 deg.	499 mm	17 deg.	92 mm	2 deg.

3.2 IS-900 Accuracy as a Function of Ultrasonic Transmitters Configuration

In the second experiment, the dependence of the accuracy of the IS-900 on the optimality of the ultrasonic transmitters configuration was investigated. According to the IS-900 installation guide, UltraSonic SoniDiscs in the SoniStrip array should be evenly distributed so that a homogeneous coverage of the entire tracking space is possible. This requirement is difficult to implement in some CAVE installations because the floor projection mirror in the middle of the ceiling limits the space available for the SoniStrips. We tested two different configurations of the SoniStrip CONSTELLATION array to see what kind of improvements can be achieved by optimizing the SoniStrip location.

The first IS-900 system installed in the NCSA CAVE consisted of six three-sensor SoniStrips located 9 ft. from the floor of the CAVE and arranged in pairs around the mirror as shown in Figure 2, thus creating poor coverage area near the back of the CAVE. Measurements, similar to those described in the first experiments, were taken 5 ft. from the floor of the CAVE. However, instead of acquiring only one measurement, 1,000 measurements were recorded at each location with 10 ms delay, and the average, standard deviation, and min and max values of each coordinate were plotted (figure 2). The bigger the difference between the min and max values at the same location, the more noticeable the jitter is. An average location error for the entire data set is 33 ± 18 mm. Because no ultrasonic emitters were installed near the back of the CAVE, a lot of jitter is observed in that region.

The second time around, the system was reinforced with two additional SoniStrips, and the entire array was reconfigured so that a better overall coverage could be achieved. Figure 3 shows the location of the SoniStrips in the new configuration. The measurements yielded an average location error of 18 ± 11 mm, and some small amount of jitter was found at only a few locations. Clearly, this configuration resulted in a more stable tracking with a better overall accuracy.

Although not very rigorous, this experiment shows how dependent the IS-900 tracking system is on the optimality of the SoniStrip CONSTELLATION array configuration. The basic criteria for optimal IS-900 installation is that the entire tracking space should be evenly covered with the ultrasonic emitters with a clear line of sight between them and the receiving sensors. It is, however, application dependent, and, in each particular case, a different solution has to be found. A suboptimal configuration of the SoniStrip CONSTELLATION array leads to an increased tracking error and a more noticeable jitter due to the appearance of dead spots where the sensor receivers can pick up signals from fewer ultrasonic emitters. We have also found that, with a suboptimal array configuration, it takes more time for the system to recover after the tracking was lost due to the line-of-sight problem. For example, in the first configuration, it could take anywhere from 4 sec. to 10 sec. to recover from lost tracking. In the second configuration it typically takes approximately 2–3 sec. to recover.

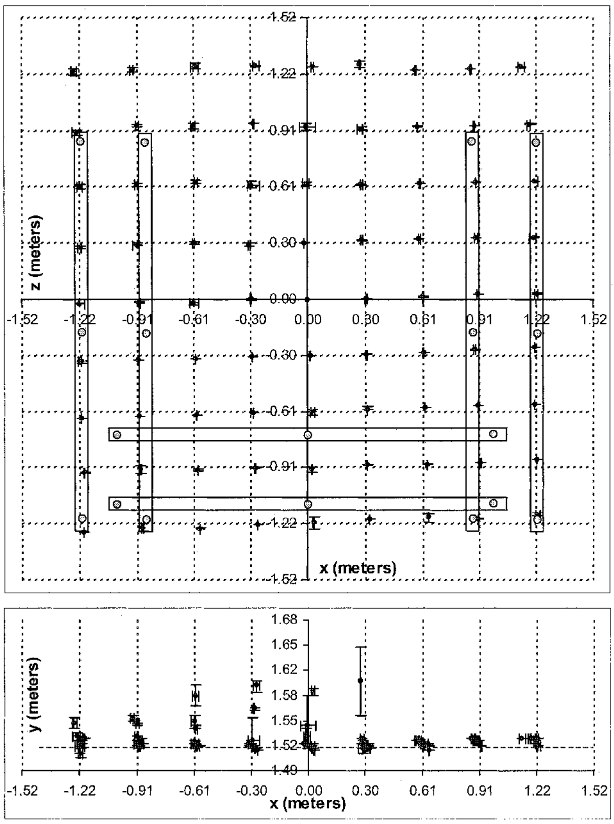

Figure 2. *Location tracking measurements and the SoniStrip CONSTELLATION array configuration for the first IS-900 installation. Rectangles indicate an approximate location of the SoniStrip CONSTELLATION array; small circles inside the rectangles indicate an approximate location of the UltraSonic SoniDiscs. Legends: Dotted lines—the grid on which the measurements were taken ■—an average tracked location for the corresponding grid node ⊢ and ⊥—corresponding min values ⊣ and ⊤—corresponding max values.*

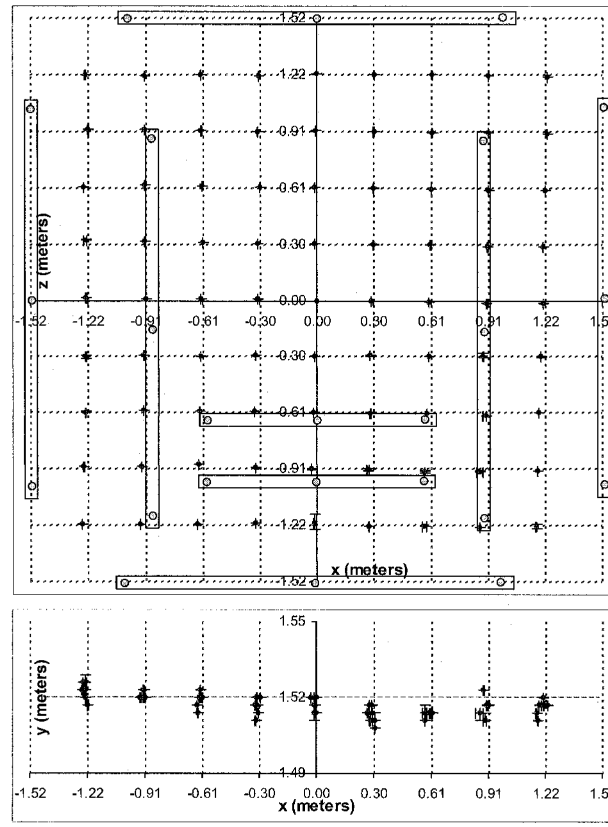

Figure 3. *Location tracking measurements and the SoniStrip CONSTELLATION array configuration for the improved IS-900 installation. The same legends are used as in figure 2.*

4 Conclusions

The technical specifications for the IS-900 and FoB tracking systems show that both devices have very similar performance characteristics. In practice, however, the IS-900 exhibits much higher tracking accuracy for a larger range of operation even when compared to a calibrated FoB. This is primarily due to the ambient electromagnetic environment that interferes with the FoB operation. Although the IS-900 does not suffer from this type of interference, its accuracy still can be affected, to a lesser degree, by a poor spatial distribution of the ultrasound emitters.

In our tests, an average location tracking error produced by the IS-900 was just below 20 mm. Although it may look like this is a considerable error, in practice it is very small compared to what is typically observed with the FoB, and it is certainly sufficiently low for CAVE applications. From our experience, tracker calibration is seldom done, and CAVE users often have no idea how accurate their tracking is.

Once installed, the IS-900 is still not a perfect solution that suits all applications. Its main drawbacks are the line-of-sight problem: it is occasionally possible to lose hand tracking and, to a lesser degree, head tracking, and the heavy head-tracking sensor assembly makes it inconvenient to wear the tracked glasses and especially to pass them from one person to another.

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