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Short Communication

Effect of metal and sampling rate on accuracy of Flock of Birds electromagnetic tracking system

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Abstract

Electromagnetic tracking devices are used in many biomechanics applications. Previous studies have shown that metal located within the working field of direct current electromagnetic tracking devices produces significant errors. However, the effect of sampling rate on the errors produced in a metallic environment has never been studied. In this study, the accuracy of Ascension Technologies' Flock of Birds was evaluated at sampling rates of 20, 60, 100, and 140 Hz, in the presence of both aluminum and steel. Aluminum interference caused an increase in measurement error as the sampling rate increased. Conversely, steel interference caused a decrease in measurement error as the sampling rate increased. We concluded that the accuracy of the Flock of Birds tracking system can be optimized in the presence of metal by careful choice in sampling rate.

Keywords: Electromagnetic tracking device; Flock of Birds; Accuracy; Error; Metal interference; Frequency

1. Introduction

Due to low cost, electromagnetic tracking devices have been commonly used in ergonomic and kinematic studies (Brenneke et al., 2000; Johnson and Anderson, 1990; Pascoal et al., 2000; Van Herp et al., 2000). The accuracy of such systems has been studied extensively (An et al., 1988; Bottlang et al., 1998; Bull et al., 1998; Day et al., 2000; Milne and Lee, 1999). Previous investigators have also shown that metal objects in the environment introduce measurement errors in both alternating current (AC) and direct current (DC) tracking systems (McGill et al., 1997; Milne et al., 1996). These errors are caused by the development of eddy currents in nearby metals, which may produce secondary magnetic fields and interfere with the field emitted from the transmitter (Raab et al., 1979). Pulsed DC devices are less susceptible to these errors since measurements can be taken once the DC field has reached a steady magnetic state in which the initial eddy currents are decayed or dying out and no new eddy currents are being produced (Kalawsky, 1993; Milne et al., 1996). Altering the frequency of the sampling rate may further impact the affect of metal objects on the accuracy of DC electromagnetic tracking devices. In theory, sampling at a higher frequency allows less time for a steady state to be reached and may result in larger errors. However, the interaction of various metals and sampling rates has not yet been studied.

Therefore, the purpose of this study was to assess the effect of sampling rate on the accuracy of the Flock of Birds system (Ascension Technology, Burlington, VT) with metals present in the environment.

2. Materials and methods

Testing was performed on a custom-made acrylic sheet that allowed the sensor, rigidly fixed to a polyvinyl-chloride (PVC) platform, to be advanced through six positions (Fig. 1). To determine the effect

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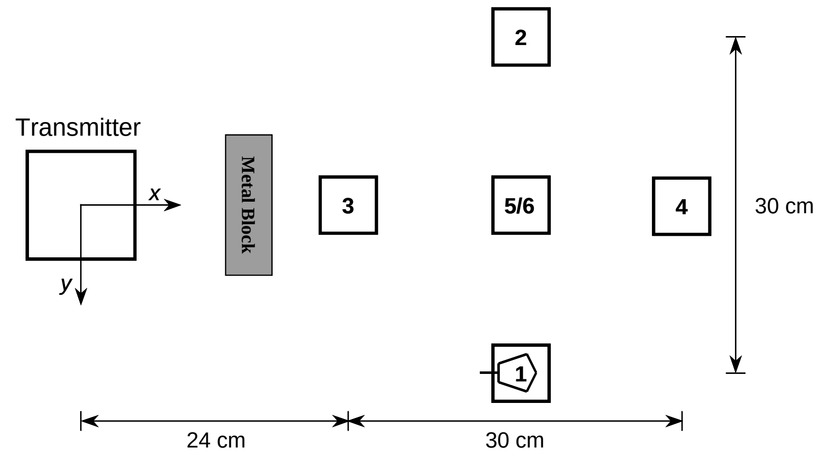

Fig. 1. 1 Top view of the experimental setup including the transmitter, measurement positions 1–6, and the location of the metal block when used. Measurements for positions 1–5 were taken with sensor rigidly fixed to a $5 \times 5 \times 15$ cm PVC platform, while measurements for position 6 were taken using a $5 \times 5 \times 30$ cm PVC platform. The platforms were placed on a flat sheet of acrylic. Note the sensor was 15 and 30 cm above acrylic sheet at test positions 5 and 6, respectively. The block of metal was placed 15 cm away from the center of the transmitter.

of metal on accuracy at different frequencies, a $5 \times 5 \times 15$ cm block of steel (ASTM A-513) and aluminum (6061 T6) were placed 15 cm away from the transmitter in the $+x$ direction. One trial consisted of measurements taken at 20, 60, 100, and 140 Hz at the six fixed positions, without metal, with aluminum, and with steel. Data were collected for one second. Three fully randomized trials were run.

The data received for each position measurement was based on a coordinate system centered inside the transmitter. To eliminate the error associated with the uncertain location of the origin of the transmitter coordinate system, we calculated the distance between two positions along the same axis by adding the absolute value of their coordinate measurements in the corresponding direction. Positions 1 and 2 were used to calculate a distance along the y-axis, positions 3 and 4 were used for the x-axis, and positions 5 and 6 for the z-axis. Mean distances were calculated in the x, y, and z directions by averaging analogous results from the three trials according to frequency and type of interference. Error was defined as the absolute difference between the mean distance and the known x, y, or z distance of 30, 30, and 15 cm, respectively. For example, the y-axis error was determined by comparing the known distance between locations 1 and 2 (30 cm) to the difference in measured y-coordinates when the sensor was placed at locations 1 and 2. Standard error of measure was also calculated.

A two-way ANOVA was used to test the effect of sampling frequency (four levels) and metal type (three levels) on error. Main effects and interaction effects were examined and a Bonferroni correction factor was used to control Type I error probability. All statistical analyses were performed using Systat (SPSS Science, Chicago, IL).

3. Results

Interference of aluminum affected measurement accuracy to a greater extent as the sampling rate increased (Fig. 2B). Conversely, interference of steel affected measurement accuracy to a lesser extent as the sampling rate increased (Fig. 2C). The amount of error due to steel interference was greater in comparison with aluminum.

Errors due to the interaction of sampling rate and metal in the environment were statistically significant in the x direction ($p < 0.0001$), y direction ($p < 0.0001$), and z direction ($p = 0.0016$). For the main effects, errors due to frequency were significant in the y direction ($p < 0.0001$) across all environments, while errors due to metal type were significant in the x direction ($p < 0.0001$), y direction ($p < 0.0001$) and z direction ($p < 0.0001$).

4. Discussion

The results of this study showed that in a metallic environment the accuracy of the Flock of Birds electromagnetic tracking device can be affected by the sampling rate. The device was found to be more accurate in an aluminum environment at lower frequencies whereas measurements were more accurate at higher frequencies with steel interference.

The differences in the results for the aluminum and steel may be explained by examining the magnetic permeability of the two materials. Although aluminum is highly conductive, it is a paramagnetic material and has very little magnetic permeability. In response to each transmitter pulse, eddy currents form in the aluminum due to its conductivity. Although these currents interfere

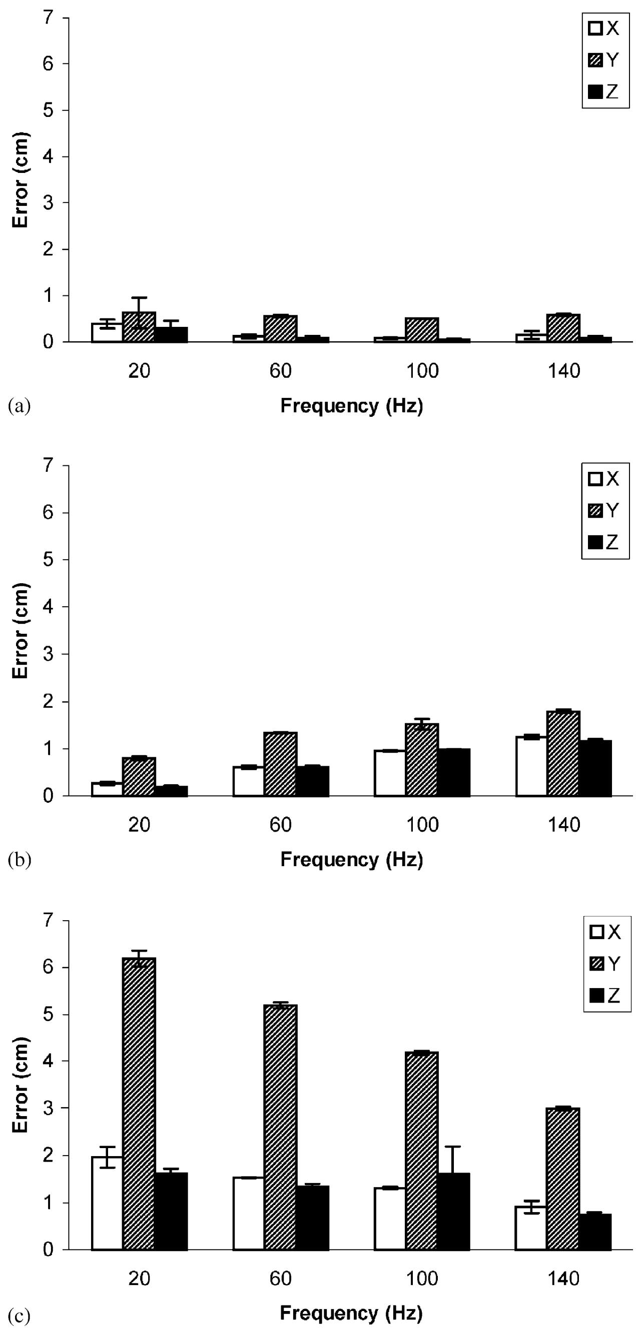

Fig. 2. The mean (SEM) of error compared to the know values on the testing apparatus for (A) air, (B) aluminum, and (C) steel ($n = 12$). Errors due to the interaction of sampling rate and metal in the environment were statistically significant in the x direction ($p < 0.0001$), y direction ($p < 0.0001$), and z direction ($p = 0.0016$).

with the field produced by the transmitter, they are relatively short-lived and decay quickly. In order to minimize measurement error, position data is collected at the end of each pulse, after the eddy currents have had an opportunity to decay. Increasing sampling rate with aluminum in the environment leads to increased measurement error since the eddy currents have less time to decay before data is collected.

Steel is also a conductive material and experiences eddy currents in response to the transmitter pulses. However, steel is a ferromagnetic material with high magnetic permeability. Consequently, the eddy currents in steel can be sustained for a longer period of time. Additionally, these eddy currents lead to the creation of a secondary magnetic field, which further distorts the pattern emitted by the transmitter. The distorted field is very difficult to characterize or determine analytically. In this experiment, the distortion pattern was such that increasing the sampling rate resulted in a decrease in measurement error.

Conductive materials with low magnetic permeability are likely to behave similarly to aluminum in the formation and decay of eddy currents. As a result, the measurement errors produced with these materials in the test environment may be able to be decreased by decreasing the sampling rate and allowing more time for the eddy currents to decay. However, the secondary magnetic field formed by conductive materials with high magnetic permeability will likely create complex patterns of distortions in the emitted transmitter field. For these materials, testing the laboratory setup may be the best method to determine the effect of sampling rate on measurement error.

Previous studies have tested the effect of steel interference on measurement accuracy. Using the standard default frequency of 103 Hz, Milne et al. (1996) found steel interference to produce significant measurement error. In the present study, we also found steel interference to produce significant error at 100 Hz, with an increase in error at lower frequencies of 20 and 60 Hz. Stone et al. (1996) mapped out a safe working region for operating the Flock of Birds in a material-testing environment (MTS). In doing so, they discovered the optimal frequency to be 40 Hz, while 20, 80, and 144 Hz were found to be unacceptable. This does not agree with our results, which show higher frequencies to be a better choice when steel is in the environment. One reason for the discrepancy might be that the MTS machine is not solid steel but is made up of several metals. Also, it may possess a motor that may act to further alter the magnetic field. In these two studies, choice of frequency did play a role in experimental results, but it was not singled out and tested for accuracy at consistent rates.

There were a few limitations in this study. All measurements were taken in static positions. Also, only two types of metal were tested, so our results do not extend to arbitrary types of metallic interference. However, metal interference should always be examined in each laboratory setup, so studies of this type cannot be generalized to all laboratory settings. The primary conclusion of this study is that it may be possible to mitigate the effect of metal by careful selection of sampling rate. The determination of optimal sampling rate should be done for each laboratory situation.

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