EFFECT OF MOBILITY DEVICES ON ORIENTATION SENSORS THAT CONTAIN MAGNETOMETERS

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INTRODUCTION

Gyroscopes, accelerometers, and magnetometers can be used separately to gather orientation data but each has limitations. Combining these sensors improves the data quality.

Accelerometers can measure a sensor's angle with respect to gravity, but cannot provide information on rotation about the vertical axis. Therefore, gyroscopes are typically used to measure angular velocity [1]. Small gyroscope signal offsets lead to large integration errors, but a magnetometer can correct for these errors by using the earth magnetic field as a reference [1]-[3]. Unfortunately, if the earth magnetic field is disturbed by a ferromagnetic object, the magnetometer output will reflect this disturbance and produce inaccurate orientation data, most notably affecting rotation about the vertical axis [2],[3].

Several studies have explored the use of inertial sensors combined with magnetometers for motion analysis applications. A hybrid system using gyroscopes, accelerometers, magnetometers, and a pentiometer, was used to measure 3D kinematics during bending tasks [4]. Roetenberg et al. [5] combined accelerometers, gyroscopes, and magnetometers to measure displacement from a known source, and Pfau et al. [6] used the accelerometer-gyroscope-magnetometer approach to measure equestrian trunk movement. In each of these studies an acceptable range of error was observed.

When validated against optoelectric methods, orientation sensors produced comparable results [4]-[7]. RMS ranged from less than 2 degrees [7] to approximately 10 degrees [4].These studies all used magnetometers combined with the inertial sensors, potentially contributing to the error observed.

This study examines the feasibility of using commercially available orientation sensors that contain magnetometers in a rehabilitative setting where assistive devices are used.

METHODS

Equipment

Data were collected using an orientation tracking system (Xsens, Enschede, Netherlands), consisting of two orientation sensors (MTx) and a data-logger (XBus). Each orientation sensor contained three orthogonally mounted accelerometers, gyroscopes, and magnetometers. A sensor fusion algorithm calculated the absolute 3D orientation of each sensor by combining output from all three components [8].

Testing Protocol

The two sensors were affixed to a Plexiglas "L" that was secured to a plastic box (Fig.1). The effect of three different mobility devices on sensor output was examined; a knee-ankle-foot orthosis (stainless steel uprights), a walker (Evolution model), and a wheelchair (Quickie GTi model).

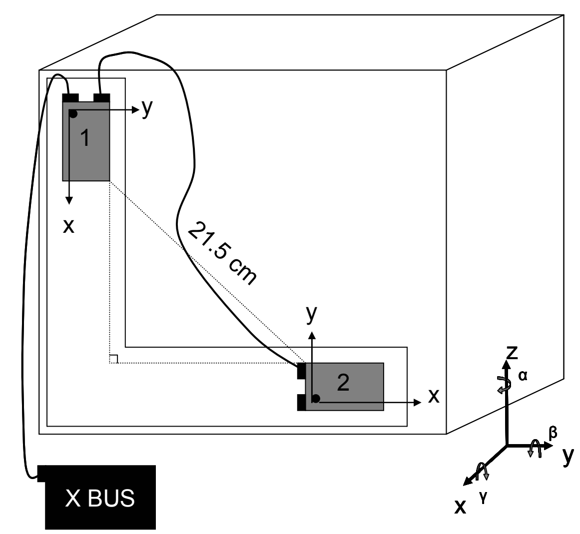

Figure 1: Experimental set-up.

For each device, the following protocol was used:

1. *KAFO*: The plastic box was set on a large cardboard box and data were collected for 10 s. The KAFO's thigh section was moved within two cm of sensor 1 and then removed. The device movement step was repeated five times. The process was completed for the joint and foot components of the KAFO.
2. *Walker*: The plastic box was set on a plastic platform on the ground and data were collected for 10 s. The walker was rolled over the experimental set-up, and then removed. The device movement step was repeated five times.
3. *Wheelchair*: The plastic box with sensors affixed was suspended from the ceiling. The wheelchair was pushed until the box was suspended within the seat area of the wheelchair and sensor 2 was approximately 3 cm from the seat cushion. The wheelchair was pulled away. The device movement step was repeated five times.

<u>Data Analysis</u>

The Xsens output yielded a directional cosine matrix for each sensor. The orientation of sensor 2 was calculated in relation to sensor 1. Euler angles (α,β,γ) were then extracted, representing the relative angles between the two sensors in 3D.

For all trials, the first 5 s of data were discarded since the sensors need this time to reach steady state. For each device, baseline and peak relative angles were calculated. Baseline angles were calculated by averaging the relative angles between 5-7 s of data collection (200 data points). Peak angles were extracted and averaged for each trial, for each device. The difference between the baseline and average peak angle were calculated for each device. Peak values were extracted from the same range of data points for each axis.

RESULTS

Since the sensor position did not change, any fluctuation in relative angle can be considered error due to the disturbance of the earth magnetic field. Where this interference was evident, the relative angle about the vertical axis fluctuated. Figure 2 shows the presence of five peaks, one peak for each trial. Table 1 contains data for trials where magnetic disturbance was observed about at least one axis.

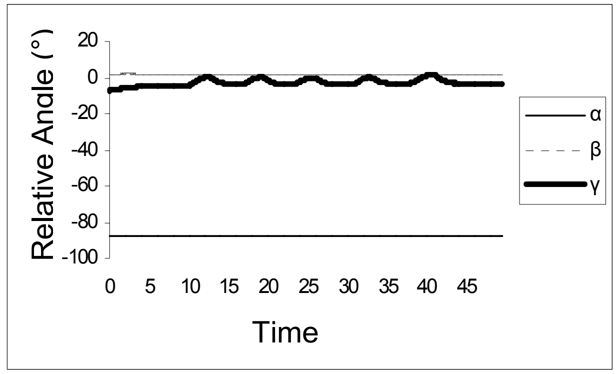

Figure 2: Relative angles observed when the joint component of a KAFO with stainless steel uprights were moved to closed to the sensor.

Table 1: Average difference (standard deviation) between baseline and average peak relative angles for trials where disturbance was evident about at least one axis.

Device		α	β	γ
KAFO (stainless steel)	Joint	0.08 (0.06)	0.10 (0.09)	5.10 (0.62)
	Foot	0.01 (0.04)	0.07 (0.06)	1.43 (0.17)
Walker (Evolution)		0.81 (0.14)	0.22 (0.05)	15.29 (1.65)
Wheelchair (Quickie GTi)		3.30 (0.52)	0.89 (0.13)	35.29 (3.58)

For the KAFO, the thigh section caused no disturbance to the earth magnetic field resulting in a fixed relative angle throughout all five trials. Table 2 shows the average relative angle (calculated for the duration of data collection, excluding the first 10 s) and compared to the baseline angle.

Table 2: Difference between baseline and average relative angle for KAFO when no disturbance was observed.

Device			α	β	γ
KAFO (stainless steel)	Thigh	Baseline	-87.58	1.87	-4.24
		Average	-87.96 (0.13)	1.54 (0.09)	-5.88 (2.09)
		Difference	0.37	0.33	1.64

DISCUSSION

When various mobility devices were moved close to the sensor(s), the relative angles fluctuated about the vertical x-axis (γ). Since baseline values were established before a mobility device was introduced to the system and the experimental set-up remained stationary for the duration of data collection, the observed fluctuations were due to disturbance of the earth magnetic field.

The magnetic of disturbance varied for each mobility device; the thigh section of the KAFO did not cause disturbance while the wheelchair caused a disturbance of 35.29°. This may be due to the following factors;

1. *Type of metal in each device.* The content of the alloys in each device are unknown. The amount of iron may have varied in the alloys used in each device.
2. *Device component.* Not all aspects of each device contained metal. For example, the thigh aspect of the KAFO contains no metal so there was no disturbance.
3. *Number of sensors exposed to device*. The disturbance for the wheelchair and walker was markedly higher than for the KAFO. This may have been related to the testing protocol. The KAFO was moved close to sensor 1, but the walker was rolled over both sensors, disturbing both signals.

XSens has an add-on that can reduce the error caused by ferromagnetic interference of the earth magnetic field. However, this cannot correct for instances where the relationship between the sensor and the ferrous material varies [9]. In cases of wheelchairs and walkers, where the arms and legs are always moving in relation to the mobility device, this add-on is not applicable.

CONCLUSION

Magnetometers can be problematic when used in an orientation sensor to conduct motion analysis in the proximity of ferromagnetic objects. Therefore, care must be taken when using such orientation sensors on people with mobility deficits, who use an assistive device. When using these sensors, pilot testing may be useful to determine whether the metal in an assistive device will have a detrimental affect. Pilot testing may also be used to identify optimal sensor placement.

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