A HANDHELD INTERACTIVE 3-DIMENSIONAL MOTION TRACKING DEVICE FOR UBIQUITOUS COMPUTING ENVIRONMENT

Il Hong Suh, Myung Kwan Park, Sanghoon Lee*

School of Electrical Engineering & Computer Science, Hanyang University, Korea
Department of Computer Control Engineering, Dongyang University, Korea*
Phone: +82-31-400-5172, Fax: +82-31-408-5802, E-mail: ihsuh@hanyang.ac.kr

ABSTRAT

This paper describes a handheld interactive 3-Dmotion tracking device for ubiquitous computing, where relative low accuracy and relatively long ranges, wireless communication will be achieved by means of low cost accelerometers and gyros with contemporary microprocessor. However, there are two key problems; one is the bias drift problem and the other is that single or double integration of acceleration signal suffers not only from noise but also from nonlinear effects caused by gravity. Several algorithms are proposed to cope with such problems, and verified by some successful experimental results

1. INTRODUCTION

Virtual environments are synthesized worlds created by coupling 3D interaction devices and displays with powerful multimedia computers. We use virtual world or virtual environments to refer in general to computer-based system that are 3D rather than 2D, interactive as opposed to passive, under such virtual environments, it may be essential to provide a sense of spatial “presence” to the user, which will be visual, auditory, or tactile. For such purpose, there have been head-tracked displays (both visual and audio), hand trackers, and haptic displays.

Spatial tracker systems should be capable of measuring and reporting information about position, orientation, acceleration, or joint angles. For example, six degree-of-freedom (6DOF) sensors provide both 3D position and 3D orientation information. Two 6DOF tracker technologies are currently in popular use; electromagnetic and ultrasonic. However, these technologies cannot create self-contained systems not requiring external transmitter and receiver. Furthermore, electromagnetic trackers are sensitive to metallic objects and magnetic fields. On the other hand, ultrasonic trackers are sensitive to noise and reflections, and require a direct line of sight between transmitter and receiver. Several other technologies for tracking position or orientation are gyroscopes, magnetic compasses, inclinometers, and accelerometers, which can be used to create self-contained, wearable systems that do not require an external transmitter or receiver. Here, it is remarked that in the design of self-contained spatial tracker system, trade-off must be made relatively high accuracy, short range and tethered system versus relatively low accuracy, long range and wireless systems[1].

In this work, a design experience of a low cost 6 DOF hand motion tracker system will be described, where relative low accuracy, and relatively long range wireless communication will be achieved by means of low cost accelerometers and gyros with a contemporary microprocessor. To be specific, it is remarked that INS(Inertial Navigation System) using accelerometers and gyros is a self-contained device which requires no external electromagnetic signals. However, there are two key problems; one is the bias drift problem. These errors would be accumulated and the accuracy is deteriorated as time increases due to integration[2]. The other problem is that single or double integration of an acceleration signal suffers from not only noise but also nonlinear effects caused by gravity[3][4]. Actually, such a signal integration may often lead to divergence far from a true value. To cope with a bias drift problem, noise and the nonlinear gravity problem, several algorithms are here proposed. Especially, for the effective real time signal processing, software agents are designed in such a way that an agent takes change of signal processing and state recognition of a sensor where 3 agents for 3 accelerometers and 3 agents for 3 gyros are designed. And our proposed algorithms are experimentally shown to be effective.

2. SIGNAL PROCESSING FOR 6-DIMENSIONAL SPATIAL TRACKER

Fig. 1 shows the block diagram of our designed spatial tracker system. Output signals of the accelerometers $(\alpha_x, \alpha_y, \alpha_z)$ and gyros $(\omega_x, \omega_y, \omega_z)$ are analog signals whose voltages are proportional to acceleration, angular velocity in each axis, respectively. The accelerometers and gyros outputs can be measured directly with A/D converter inside the microprocessor. UART of the microprocessor packetizes the sensor data and transmits them via radio frequency module at a rate of at least 62Hz. The receiving station then relays the sensor records via serial connection to the personal computer.

In this work, our software structure for spatial tracking system is organized as in Fig. 2. For real timeness of our spatial tracking system, sensor agents are designed in such a way that an agent takes change of signal processing and state recognition of a sensor. Here 3 agents for 3 accelerometers and 3 agents for 3 gyros are designed. These agents are working in parallel to process the data from DAS (Data Acquisition System) whose occurrence would be signaled as an event. Thus, agents could perform necessary signal compensations, whenever they get an event without checking time and condition for the compensation. An event is usually signaled when starting or stopping motions of the spatial tracking is detected by rotate- or position-detector-object. These two detector-objects employ velocity information from corresponding sensor agents to effectively determine the occurrence of an event. And in the spatial-tracker-object, reference coordinate is reconfigured to reduce any possible accumulated errors, whenever stopping motion is detected.

Fig. 3 shows internal state diagrams of gyro agent and accelerometer agent, where signal processing could be specialized and thus simplified to meet state characteristics. Specifically, in Fig. 3, two states are considered : Stop and Move. Output velocity of Stop-state is given as zero, and expected actual velocity of each sensor is computed only in a Move-state.

Stop-state of the gyro agent can be detected by checking if angular velocity of the gyro is null. But, in case of accelerometer agent, null velocity does not necessarily imply stop motion, since there exists a constant velocity moving state. Thus, Move-state of the accelerometer agent is made to differentiate acceleration state and deceleration state.

Fig. 4 shows our proposed signal processing algorithm which

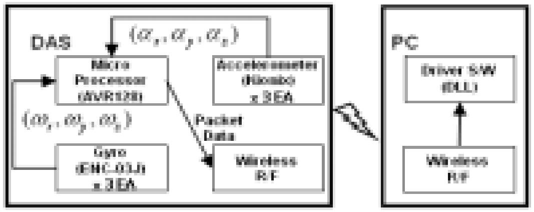

Figure 1 : Spatial tracker system block diagram

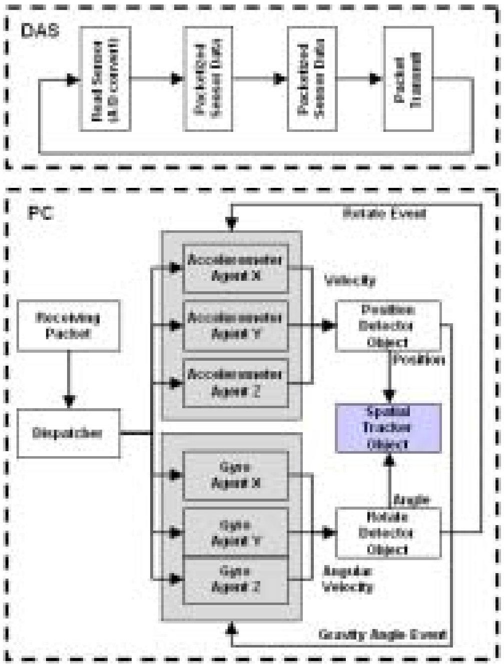

Figure 2 : Spatial tracking system software structure

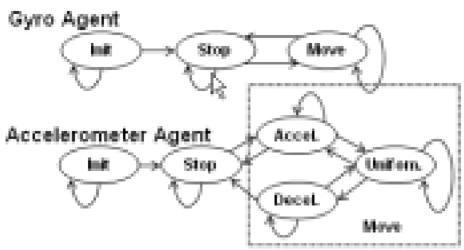

Figure 3 : State Diagram of Sensor Agent's

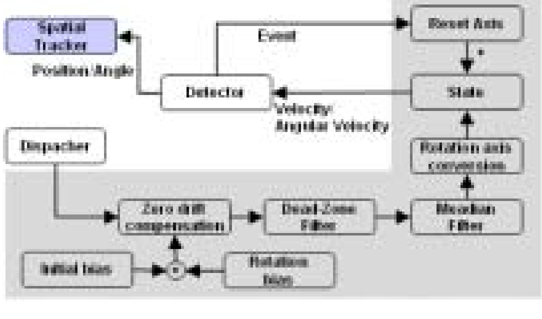

Figure 4 : Signal processing flow in the Sensor Agent

would be performed whenever sensor data from dispatcher flow into the sensor agent. Followings are summary of our primary signal processing algorithms;

2.1 Zero bias drift compensation

The accelerometers and gyros have zero bias drift due to slight misalignment and the effect of temperature. When the measured acceleration $\alpha_m(t)$ and angular velocity $\omega_m(t)$ involve constant errors α_e and ω_e, α_e and ω_e can be obtained by $\alpha_e = \frac{1}{M}\sum_{N=1}^{M}\alpha_m$, and $\omega_e = \frac{1}{M}\sum_{N=1}^{M}\omega_m$, where M is the number of samplings of stationary accelerometer and gyro data which is taken to know zero bias drift error. Then $\alpha_r(t)$ and $\omega_r(t)$ are actual acceleration and actual angular velocity can be given by

$$\begin{aligned} \alpha_r(t) &= \alpha_m(t) + \alpha_e \\ \omega_r(t) &= \omega_m(t) + \omega_e \end{aligned} \quad (1)$$

2.2 Noise reduction by Dead-zone filtering and Median filtering

The accelerometers and gyros may have small error signals, since they may be sensitive to hand vibration. For reduction of this type of small error signal, the dead zone k is established as

$$y(t) = \begin{cases} f(t), & |f(t)| \geq k, \\ 0 \quad , & |f(t)| < k. \end{cases} \quad (2)$$

Here, the value of k has been obtained after some experiments to provide better filtering results.

On the other hand noise reduction by median filtering is employed to reduce random peak noise, since it looks like a low pass filtering. Specifically, the filter replaces the center value in the window with the median value of all the points within the window given by

$$y[n] = \frac{1}{N+M+1}\sum_{k=-N}^{M} y[n-k] \quad (3)$$

2.3 Gravity compensation by rotation axis conversion

The coordinates of the spatial tracker system are fixed with respect to body of sensor system. Thus, when body of the spatial tracker system (hand) is rotated those coordinates hardly agree with absolute coordinates that fixed on the floor. Here, it is noted that before integrating the signal from the accelerometer, we have to compensate nonlinear gravity effect. For this, it is essential for us to know how much body of the spatial tracker system is rotated with respect to the absolute reference coordinate.

To be specific, following rotation axis conversion technique is employed;

Let ${}^{A}a = \begin{bmatrix} a_{x_1} \\ a_{y_1} \\ a_{z_1} \end{bmatrix}$ be the measured accelerometer signals and let ${}^{B}a = \begin{bmatrix} a_{x_2} \\ a_{y_2} \\ a_{z_2} \end{bmatrix}$ be the desired modified signals. Then ${}^{B}a$ can be obtained by

$${}^{B}a = R_z(\theta)R_y(\theta)R_x(\theta)\,{}^{A}a, \quad (4)$$

where

$$R_x(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix}, \quad R_y(\theta) = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix},$$

$$R_z(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Here, θ will be estimated or measured by gyro signals.

2.4 Detection of Stop motion and reconfiguration of reference coordinate

Spatial tracker states can be classified as Move-state and Stop state. In a Move-state gravity effect on accelerometer (dc-component) is made to be compensated by utilizing angular velocity from gyro sensors, and compensated velocity information is integrated to get the moving distance. But, in a Stop-state, any possible accumulated errors of gyro sensor is made to be compensated by employing magnitude of gravity effect obtained from accelerometer sensor. And then, reference coordinate is reconfigured for position error not to be accumulated. Here, algorithms to detect Move-state and

Stop-state can be summarized as in Table I.

Table I. Summary of State Transition Conditions.

Sensor	State Transition	Conditions
Gyro	Stop→Move	$\mid \omega_r(t) \mid > th_{move\_gyro}$
	Move→Stop	$\mid \omega_r(t) \mid < th_{stop\_gyro}$
Accelerometer	Stop→ Accel	$\mid \alpha_r(t) \mid > th_{move\_acce}$
	Accel.→Uniform	$\mid \alpha_r(t) \mid < th_{move\_acce}$
	Uniform→Decel	$\mid \alpha_r(t) \mid > th_{move\_acce}$
	Decel.→Uniform	$\mid \alpha_r(t) \mid < th_{move\_acce}$ and $\lvert v_r(t) \rvert > th_{stop\_acce}$
	Decel. →Stop	$\mid \alpha_r(t) \mid < th_{move\_acce}$

The values of th_{move_acce}, th_{stop_acce}, th_{move_gyro}, and th_{stop_gyro} have been obtained after some experiments to provide better signal processing results.

3. EXPERIMENTS

3.1 Experimental Set-ups

For our experiments, the KX120-L20 (Kionix) accelerometers are used since they are low cost, low powered and complete 2-axis accelerometer with a measurement range of +/-2g. The KX120-20L can measure both dynamic acceleration (e.g., vibration) and static acceleration (e.g., gravity)[5]. And the Murata ENC03J gyros are used to measure angular velocities, where the gyro is capable of measuring angular velocity up to +/-300 deg/sec and has dynamic response up to frequency 50Hz with a linearity 5% full scale [6].
The microprocessor used in a data acquisition board is ATMEL ATmega323. It has 32Kbyte flash, 1Kbyte EEPROM, 2Kbyte of SRAM, 8 channels 10-bit ADC and serial communication interface. The commercially available radio transmitter/receiver pair of 433MHz frequencies is employed. Our own developed spatial tracker system is shown in Fig. 5. The robot arm is used to move the spatial tracker system a Samsung FARAMAN-AS1. Fig. 6 shows a photograph of spatial tracker evaluation hardware setup.

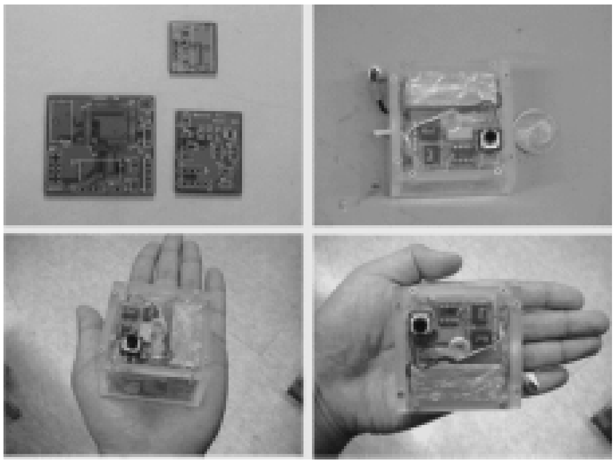

Figure 5 : Developed Spatial Tracker System

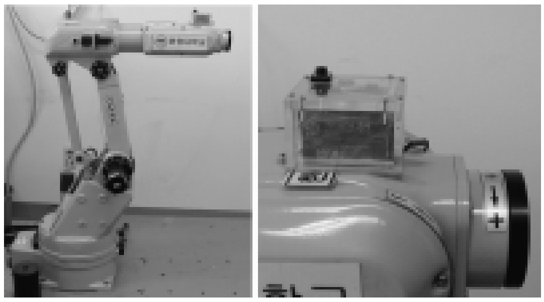

Figure 6 : Experiment Setup to Evaluate the Spatial Tracker System

3.2 Evaluation methods and Experimental results.

To show the validity of proposed algorithms, several spatial tracking experiments are performed for the case that (i) spatial tracker repetitively moves from left to right three times without rotation angles, (ii) the spatial tracker repetitively rotates from counter clockwise direction about 90 degrees to clockwise direction about 90 degrees three times, (iii) spatial tracker repetitively moves from a location to another location three times with arbitrary direction and orientation.

Case (i) : Fig. 7 and Fig. 8 show the results of the experiment for the case (i). This experiment shows the effect of zero bias drift and random small errors caused by hand(robot) vibrations. Fig. 7 shows accelerometer output signal of the X-axis. In Fig. 7, when the proposed algorithms are not applied, integration errors diverge far from a true value after double integration of acceleration data caused by zero bias drift and random small error signals. When the proposed algorithms are applied, zero bias drift is compensated. Fig. 8 shows the position trajectory along the X-axis.

Case (ii) : Fig. 9, Fig. 10 and Fig. 11 show the results of the experiment for the case (ii). This experiment shows the effect of nonlinear gravity caused by rotation around Y-axis. Fig. 9 shows accelerometer output signals of X- and Z-axes. From Fig.9, it is observed that undesired dc-offset could be generated by static acceleration (gravity) which stemmed from the rotation of gyro. Such a gyro output signal of Y-axis is shown in Fig. 10. When the proposed algorithms are applied, nonlinear gravity effect could be compensated by rotation axis conversion techniques. Fig. 11 shows compensated angle trajectory around Y-axis.

Case (iii) : Fig. 12, Fig. 13 and Fig. 14 show the results of the experiment for the case (iii). This experiment shows the combined effect of case (i) and case (ii) problems. Fig. 12 shows accelerometer output signals of X- and Z-axes. From Fig. 12, it is observed that there are undesired accumulated integration errors and dc-offset. When the proposed algorithms are applied, undesired accumulated integration error could be reduced and nonlinear gravity effect could be well compensated. Fig. 14 shows trajectories of position and rotation when the proposed algorithms are applied.

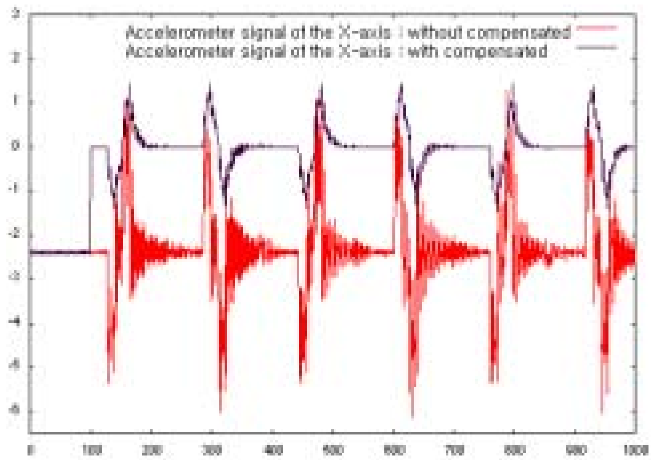

Figure 7 : Accelerometer output signal of X-axis(m/sec^2)

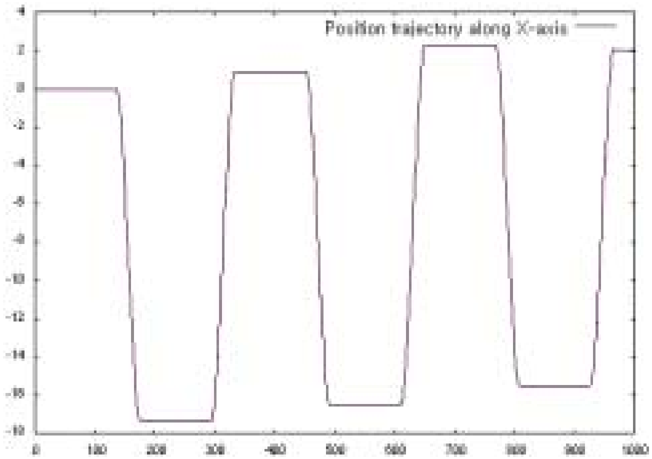

Figure 8 : Position trajectory along X-axis with compensation algorithms(cm)

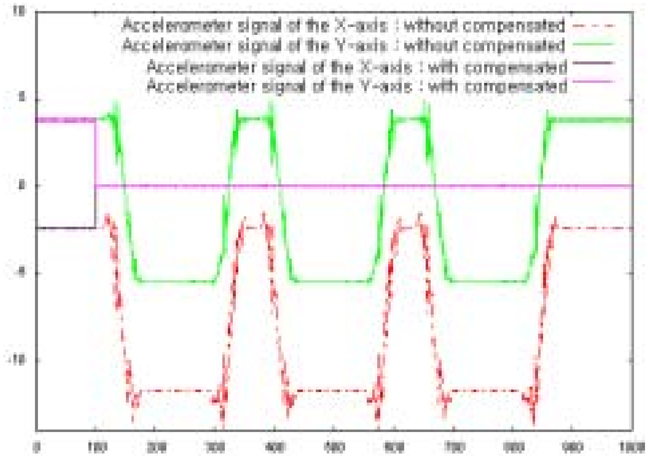

Figure 9 : Accelerometer output signals of X- and Z-axes(m/sec^2)

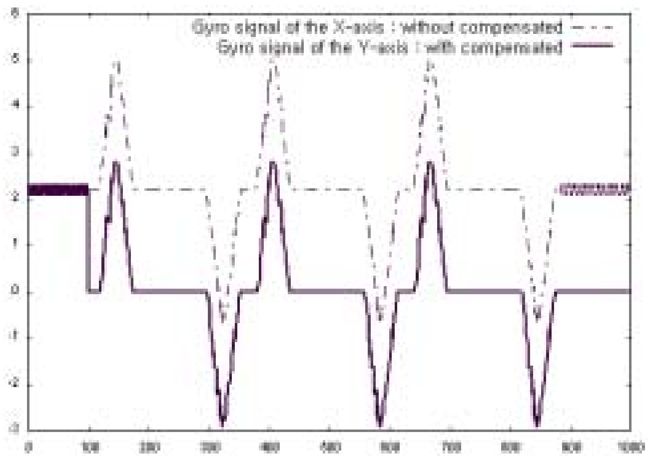

Figure 10 : Gyro output signal of Y-axis(deg/sec)

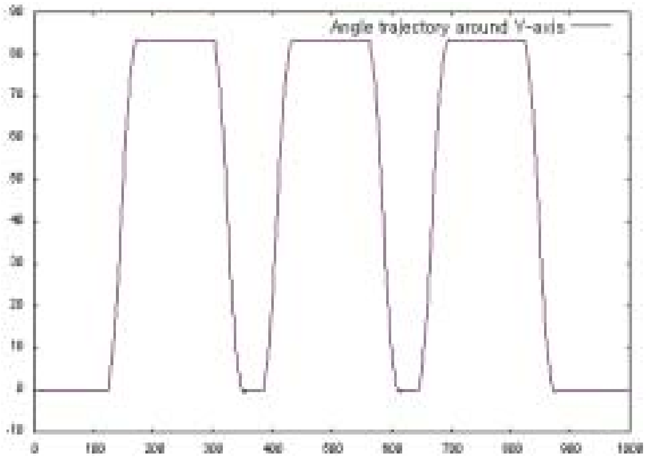

Figure 11 : Angle trajectory around Y-axis with compensation algorithms(deg)

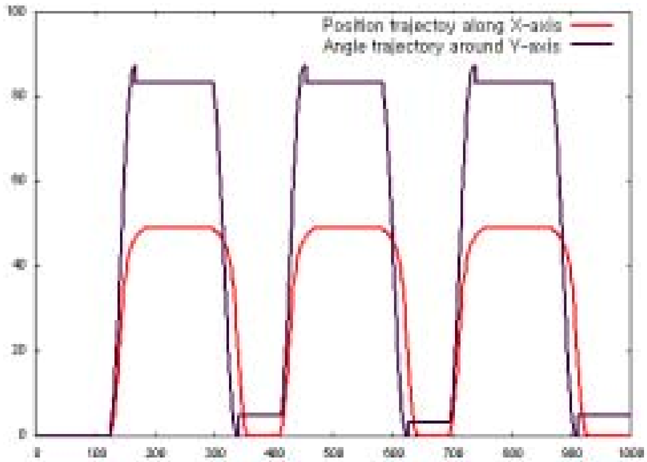

Figure 14 : Position and Rotation responses with compensation algorithms (cm, deg)

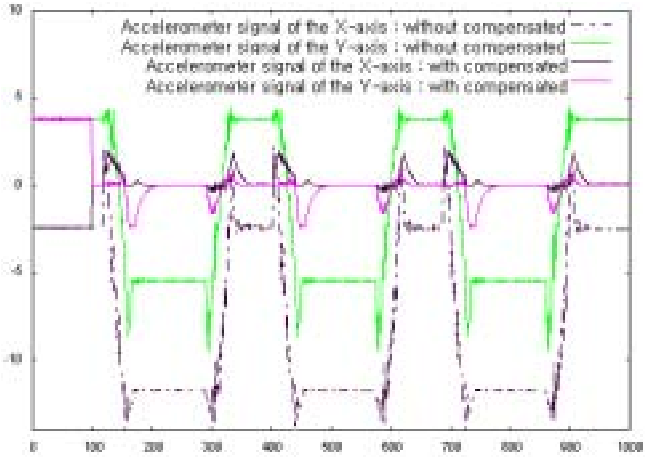

Figure 12 : Accelerometer output signals of X- and Z-axes(m/sec^2)

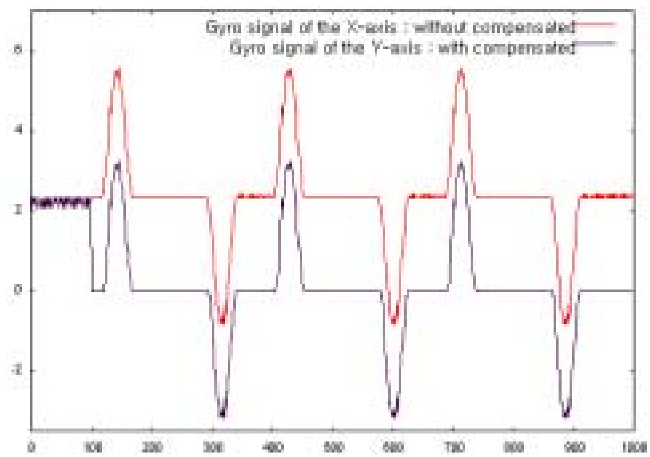

Figure 13 : Gyro output signal of Y-axis(deg/sec)

4. CONCLUDING REMARKS

In this work, a design experience of a low cost spatial tracker system was reported. Our developed spatial tracker system was composed of three accelerometers and three gyros with a contemporary microprocessor. From experiment results, it can be concluded that the performance of our proposed spatial tracker is shown to be acceptable as a device for low cost 6 DOF hand motion measurement system. The proposed method is expected to be used for hand motion tracking as well as interaction with 3D virtual environment.

5. REFERENCES

[1] B. Maclntyre, and S. Feiner, "Future Multimedia User Interfaces," *Multimedia Systems* (1996)4 : pp.250-268, Springer-Verlag

[2] G.. Pang and H. Liu, "Evaluation of a low-cost MEMS Accelerometer for Distance Measurement," *Journal of Intelligent and Robotic Systems*, pp.249-265, 2001

[3] F. Viksten, "On the use of an accelerometer for identification of a flexible manipulator," *Master thesis in Automatic control at the department of electrical engineering Linkoping University*, Sweden, 2001

[4] K. Sagawa *et al.*, "Unrestricted measurement method of three-dimensional walking distance utilizing body acceleration and terrestrial magnetism," *Proceedings of the International Conference on Control, Automation and Systems*, pp.707-710, 2001

[5] Kionix, *KX110-L20, KX120-L20* data sheet 2002

[6] Murata Manufacturing Co., *Gyrostar: Piezoelectric vibrating gyroscope ENC series data sheet 2001*