DYNAMIC CALIBRATION OF A GYROSCOPE USING A COMPOUND PENDULUM

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A novel method of dynamic calibration of a MEMS type gyroscope is presented in this paper. A compound pendulum installed with a potentiometer as angular and angular speed reference was used to justify the scale factor and zero bias of a gyroscope. Two gyroscopes, i.e. IDG300 and IDG500, were studied. It was found that scale factor of IDG300 matched with the manufacturer's datasheet while IDG500 did not matched.

1. Introduction

Microelectromechanical systems (MEMS) type accelerometers and gyroscopes are getting popular in all sort of motion relevant applications [1-4] such as virtual sport games, gait analysis, aviation etc. There are a number of papers reporting different techniques of accelerometer static calibration [5-10] such in-field calibration and conventional rotary table. No researchers have reported specifically the dynamic calibration of a gyroscope except expensive laboratory gimbal [1, 11]. Two important parameters are the scale factor and zero bias. In normal practice, since gyroscope is non-ratiometric, manufacturer scale factor is used without further scrutinizing the accuracy of the specification while zero bias is the average voltage during static. In this paper, two gyroscopes are compared to a reference angular speed in a test rig built of a pendulum, a potentiometer as an electronic protractor as well as tachometer and a customized data logger sampling at 200Hz.

2. Methodology

2.1. *Test Rig*

The test rig as shown in Figure 1 consists of a compound pendulum installed with a potentiometer as angular and angular speed transducer, a customized data logger, an IMU-5DOF and a stopper to initiate consistent release angle. A electronic spirit level is used to align the test rig platform horizontally.

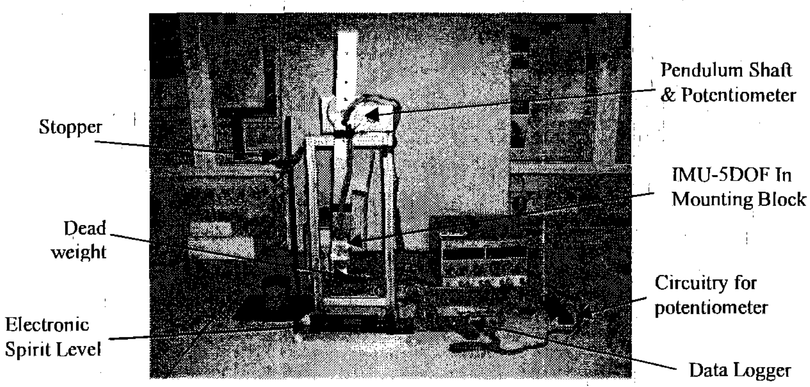
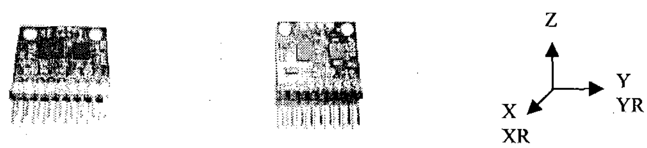


Figure 1: System Test Rig

2.2. *Gyroscopes*

Two types of IMU-5DOF (SparkFun, Inc.) in the form of PCB-breakouts were used as shown in Figure 2. In this paper, gyroscopes (XR-axis, YR-axis), i.e. IDG300[12] and IDG500[13] (InvenSense, Inc.) were studied and compared.



(a) (b) (c)

Figure 2: (a). ADXL330 & IDG300, (a). ADXL335 & IDG500, (c). Axes Assignment

2.3. *Simulation of A Second Order Damped System*

The pendulum can be approximately modeled as a 2^{nd} order damped system, $\ddot{\theta} + 2\omega_n\xi\dot{\theta} + \omega_n^2\theta = 0$, with the initial condition $\dot{\theta}(0) = 0,\ \theta(0) = -40^0$.

Damping ratio, ξ and the natural frequency, ω_n, can be identified according to the method recommended by Ogata[14]. By using Laplace Transform, angular displacement, $\theta(t)$ can be solved as a function of time. The 1st and 2nd derivation would produce angular speed, $\dot{\theta}(t)$ and angular acceleration,$\ddot{\theta}(t)$. Simulation results would provide an approximation to the actual outputs in the potentiometer and the gyroscope.

2.4. *Experiment Protocol*

A differential op-amp was used to build the main circuitry for the potentiometer. Its output was fed into the data logger. Firstly, the potentiometer is calibrated as an electronic protractor over the angle range -40^0 to +40^0. A regression equation of voltage versus angles was modeled. For each trials, the gyroscope was aligned in a specific plane such as Y-Z plane for XR axis or Z-X plane for YR axis. For convenient purpose, Z-X plane (YR axis) is explained throughout the paper. The pendulum was released at -40^0 specified by the stopper. Data logging starts from the release angle until the pendulum stops gradually. The same procedures were repeated for both gyroscopes in two planes.

3. Results

The potentiometer was statically calibrated and the average result of five trials were plotted as shown in Figure 3. Maximum standard deviation, 0.011178 was observed throughout the trials, indicating highly repeatability in the device.

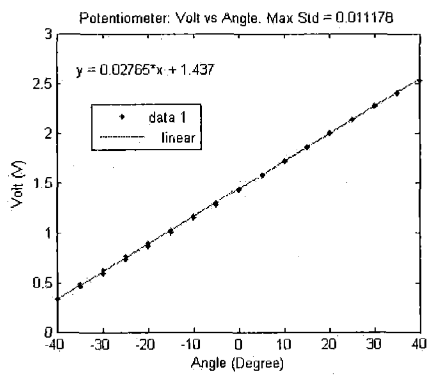
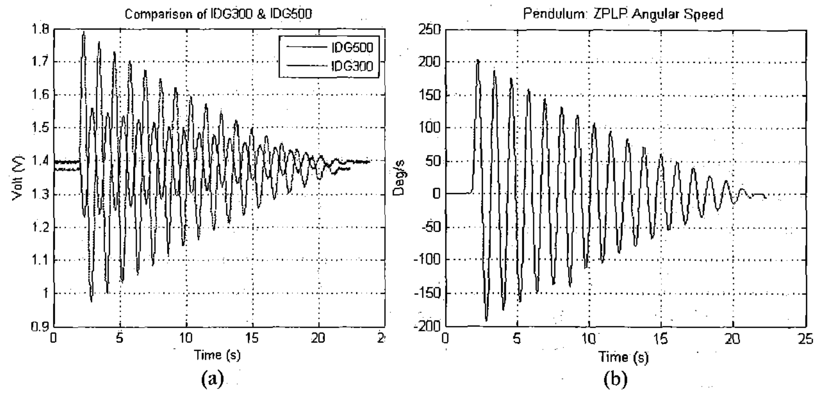


Figure 3: Static Calibration of Potentiometer

The gyroscope output of IDG300 and IDG500 in volt and its corresponding pendulum angular speed in deg/s are shown in Figure 4. For comparison purpose, zero phase delay FIR low pass filter (ZPLP) was applied to pendulum angular speed. For the same release angle, IDG500 exhibits inverse output and nearly half the amplitude as compared to IDG300.



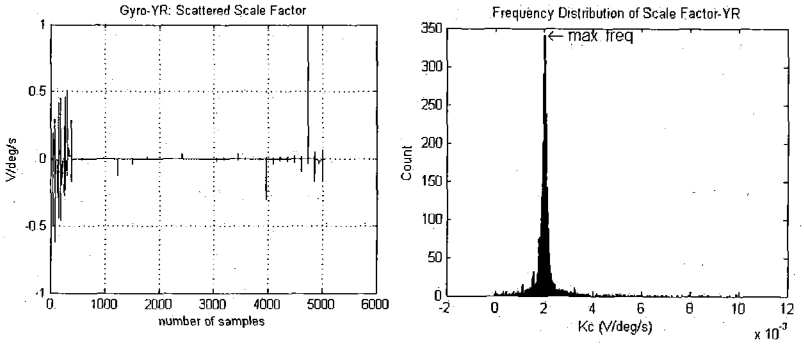
(a) (b)

Figure 4: (a) Angular Speed – YR, (b) Angular Speed - Pendulum

The gyroscope in any axis is formulated as Eq. (1).

$$V = K_c \omega_p + ZB_{av} \tag{1}$$

where V is gyroscope output in volt, K_c is scale factor (mV/^{0}/s) to be determined, ω_p is pendulum angular speed in unit of ^{0}/s and ZB_{av} is average voltage of the gyroscope output.



(a) (b)

Figure 5: (a). Gyro-YR scale factor in a trial, (b) Frequency Distribution

As shown Figure 5(a), scale factor, K_c was calculated and plotted. However, K_c is not symmetrically distributed due to vibration at the start and the end. A frequency distribution method is proposed. The scale factor, K_c is located at the maximum frequency.

Table 1: Comparison of Scale Factor of Two Gyroscopes

Specification	Calibrated IDG300	Calibrated IDG500
0.002	0.0019	0.0.00083

Calibrated scale factor, K_c of IDG300 and IDG500 were compared to the manufacturer specification. IDG300 performs near to the given specification while IDG500 is less than half of the specification.

4. Results

A 2nd order damped system provides an approximation view of the angle, angular speed and angular acceleration of the pendulum, enhancing the confidence of the following analysis. Noises are generated due to 1st derivative and 2nd derivative of the original signal. Improper design of a low-pass filter might attenuate or amplify the signal. It is a subjective procedure to adjust the cut-off frequency and stop frequency of a zero phase FIR low pass filter (ZPLP). Simulation results provide a guide so that no underestimation nor overestimation of the signal. The range of the pendulum angular speed can be slightly increased by releasing at a bigger angle. Adding dead weights at the end of the pendulum would reduce the damping ratio, meaning that the pendulum will swing longer at slower damping rate. The pendulum is working on the gravity and it is not easy to acquire higher speed range without major mechanical design changes. It is most convenient and cheap for calibration of low range of angular speed such as for the application of gait analysis.

5. Conclusion

MEMS type gyroscope is popular in many applications. A simple dynamic calibration was proposed using a compound pendulum to identify its scale factor and zero bias. A 2nd order damped system was simulated and was providing the guide in the analysis. Two gyroscopes are calibrated and their difference with respect to the manufacturer specification were compared. It was found that IDG500 did not match the specification and a new scale factor was proposed.

Acknowledgments

This is where one acknowledge funding bodies etc. Note that section numbers are not required for Acknowledgments, Appendix and References.

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