Introduction

Gulf Coast Data Concepts incorporates a digital 3-axis MEMS accelerometer sensor in the X6-2 and X6-1A USB data loggers. The MEMS (micro electromechanical system) sensor uses a suspended silicon structure that is free to move on the substrate when an acceleration is applied. The position of the silicon structure is monitored as it moves from its nominal position. The change is position is converted to a digital output that changes linearly with acceleration. Factory characteristics of the sensor maintains linearity within +/-2% (Full scale) and the 0-g offset within +/-100mg. The sensor is considerably precise at a very affordable price.

The digital sensor output is converted to g-force using the linear equations 1 and 2. These are idealized equations assuming the is no offset or scaling error. The equations are in the format of y=mx+b, where y is calculated g-force, m is the scaling factor (g/counts), x is the sensor output (counts), and b is the y-intercept (or offset). The blue line in Figure 1 illustrates the ideal output at high gain. The red line represents a typical output, which may have both an offset and slope error. Calibration of the accelerometer determines the correct scale (m) and offset (b) factors and makes the red line equal the blue line in Figure 1.

High Gain $$g-force=\left(\frac{1}{1024}\right)*counts+0$$ Equation 1

Low Gain $$g-force=\left(\frac{1}{324}\right)*counts+0$$ Equation 2

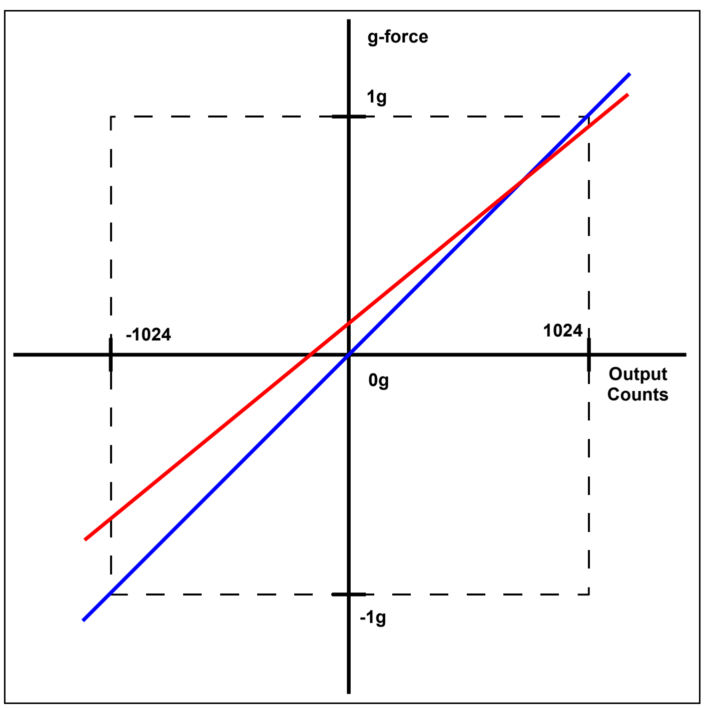

Figure 1: Ideal Versus Typical Sensor Output

Increasing the accuracy of the accelerometer sensor is achieve using a "Tumble" calibration method. This calibration method uses gravity as a reference acceleration. Placing each axis in and out of the gravity vector provides +1g, -1g, and 0 g reference points to establish a scale factor and an offset factor that fine tunes the linear relationship of the sensor. The following instructions outlines the tools and process to perform a 6 point tumble test for a 3-axis accelerometer.

Test Setup

Equipment

A flat level table must be used in order to properly align the accelerometer sensor (see Figure 2). Here, a 12" square piece of marble tile commonly used for flooring is cut into a triangle. Marble tile is typically machined and polished with a very smooth flat surface. Furthermore, the marble is very easy to drill mounting holes through. The triangular shape is used because the three points of the triangle define a stable table plane (no wobbling). At each corner is a thumb screw for leveling the table. A precise circular bubble level is placed on the table to check the table orientation.

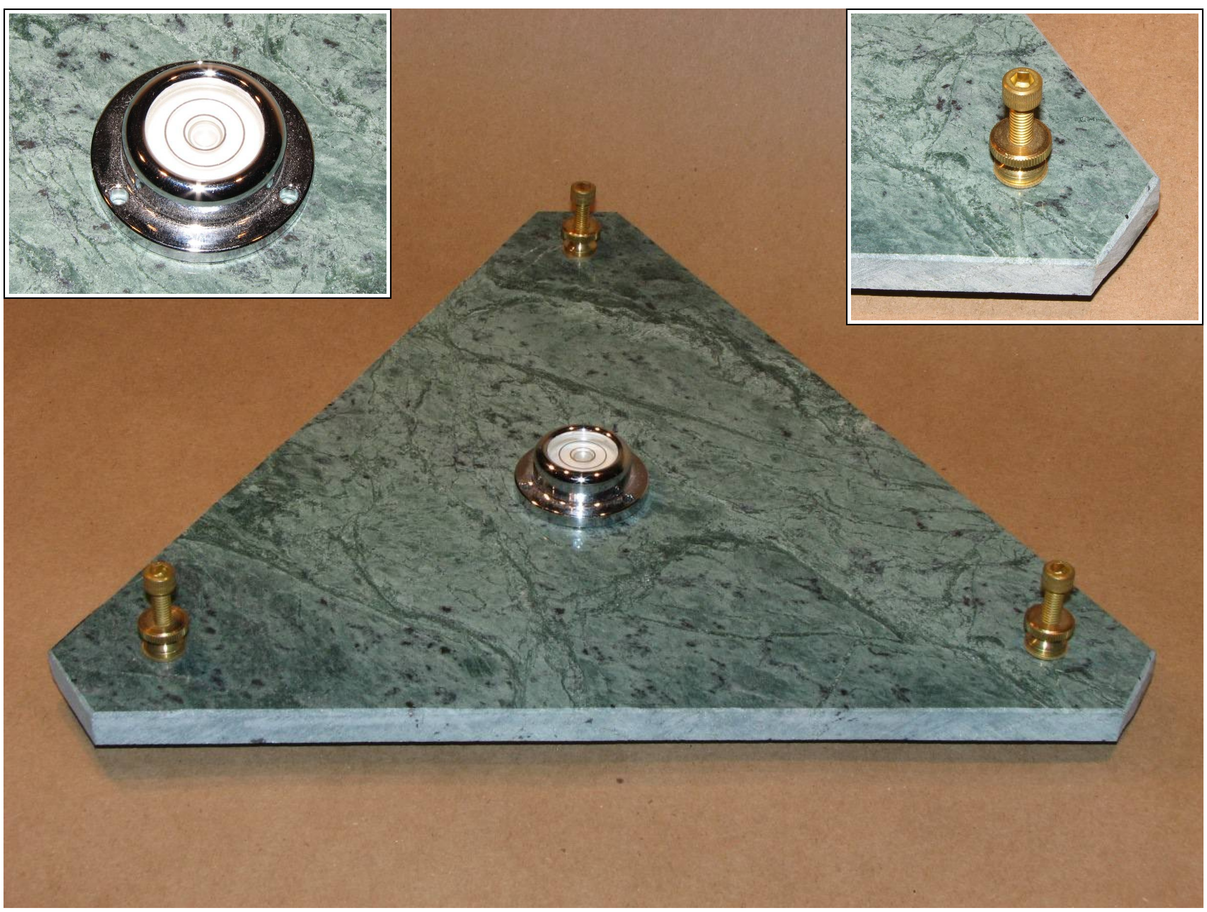

Figure 2: Leveling Table

Table 1: Parts List

Quantity	Description	McMaster-Carr Part Number	Price (ea)
1	Multipurpose Aluminum (Alloy 6061) Rect Tube 1/4" Wall Thickness, 4" X 4", 1' Length	6546K331	$42.71
3	18-8 Stainless Steel Round-Base Weld Nut 10-32 Screw Sz, 3/4" Base Dia, 9/32" Barrell Height, Packs of 10	90860A107	$1.03
3	Brass Socket Head Cap Screw 10-32 Thread, 1-1/2" Length	93465A333	$2.44
1	Glass Surface Mount Bull'S-Eye Level Concentric W/2 Circles, 1-7/16" Base Dia, H 33/64"	2198A86	$16.80
1	Brass Round Knurled Thumb Nut 6-32 Thread Size, 3/8" Head Dia, 1/4" O'all Height	92741A110	$0.31
1	3/8” thick 12”x12” marble tile	-	-

The six positions of the tumble test must be orthogonal to each other. Placing the accelerometer on the inside of the cube allows each side to sit flat on the table without the interference of the accelerometer. A 4” square aluminum tube segment serves as the cube. Aluminum extrusions are very straight and square, especially in the stretched tempers, so final machining is not necessary. A miter saw cut and a belt grinder squares the two cut ends.

For quick placement of the GCDC accelerometer data logger, a bottom portion of the plastic enclosure is glued to the inside of the cube. A small thumb screw allows quick mounting of the printed circuit board into the plastic enclosure.

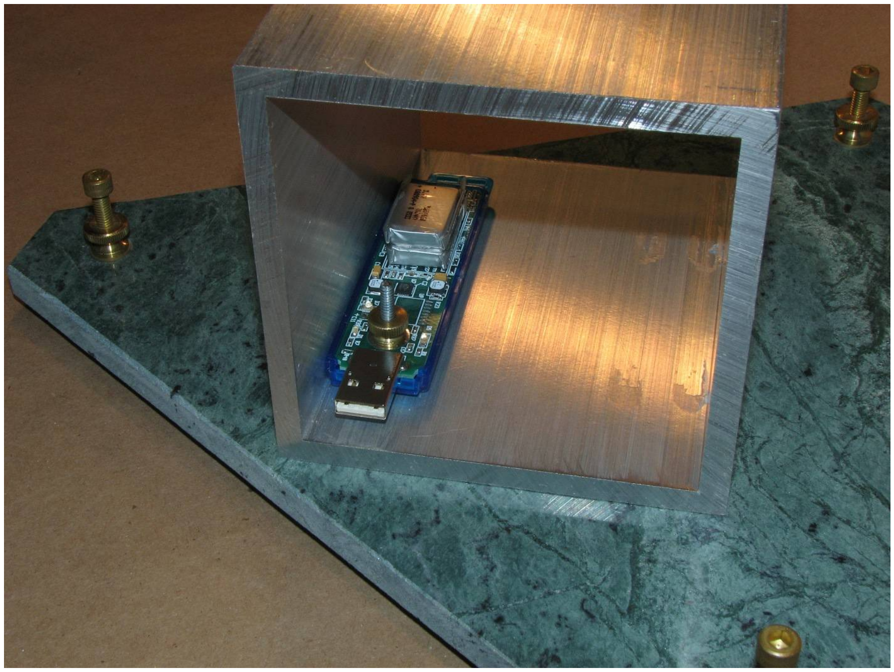

Figure 3: Table and Aluminum Extrusion

Calibration Procedure

An X6-2 accelerometer unit is used for this example. However, this calibration method is applicable to both the X6-2 and X6-1A devices (or any low g-force accelerometer). Separate calibration factors must be determined for high gain and low gain settings of the accelerometer. Therefore, perform the following instructions with the accelerometer set to high gain and again at low gain.

Tumble Test

The X6-2 is configured to sample at 20 Hz, high gain, and no deadband. This calibration method does not need a significant amount of data so a low sample rate is recommended. The following example configuration file works well with the test method:

```
; PRODUCT_ID = X6-2
; config.txt  - x6-2 settings
; example configuration for calibration test
gain = high
deadband = 0
DeadBandTimeout = 3
samplesperfile = 30000
statusindicators = Normal
SampleRate = 20
```

Figure 4: Example Configuration for Calibration Tests

Step 1: Configure the X6-2 according to the parameters listed above (Figure 4).

Step 2: Place the leveling table on a sturdy surface to minimize extraneous motion and vibration.

Step 3: Place the circular bubble level at the center of the table. Use the three adjustment screws to level the table.

Step 4: Mount the X6-2 into the plastic base inside the cube. Begin recording data. It may be easier to start the data logger first and the place it inside the cube.

Step 5: There are six positions of the cube. Place the cube on a face and wait for 10 seconds (do not bump or move the cube). Rotate the cube to another face and again wait for 10 seconds. Rotate through all six positions.

Step 6: Turn off the data recorder and remove the X6-2 from the cube.

Step 7: Download the data from the X6-2.

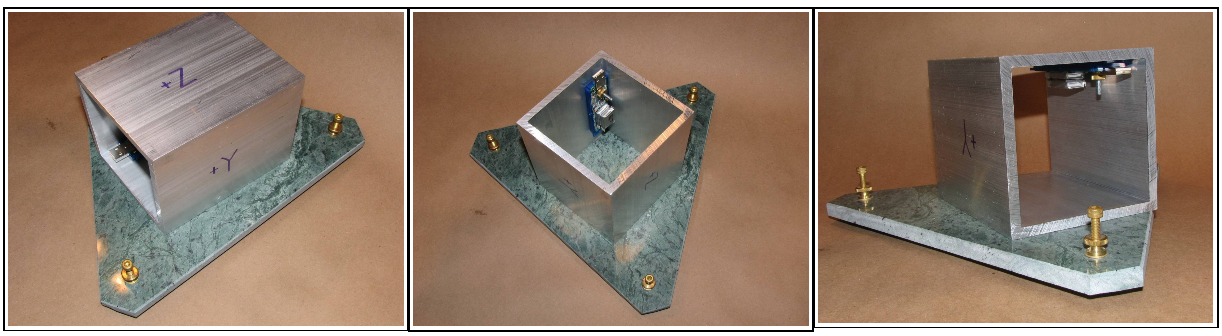

Figure 5: Rotating the Cube Through Different Position

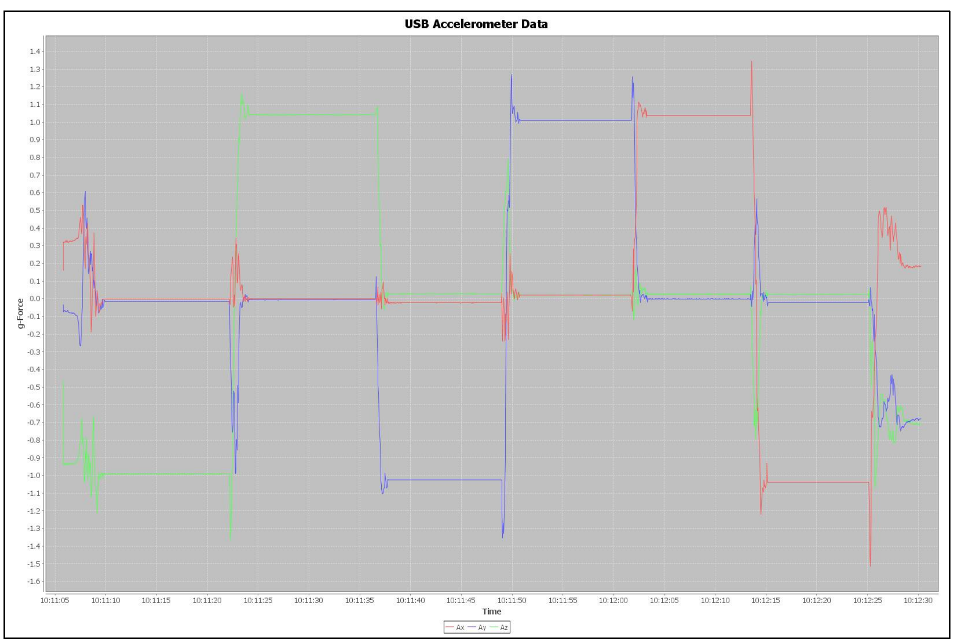

Figure 6: Example Data from Tumble Test

Data Analysis

The six positions of the tumble test place each axis in the line of positive and negative gravity. While one axis is registering gravity, the other two axes are perpendicular to gravity and therefore register 0g. The ideal output relationship of the sensor is a line. The slope of the line is determined by using the measured values for positive and negative gravity. Then, the offset (or intercept value) is calculated using the values measured for 0 g.

The data collected with the tumble test can be imported into a spreadsheet and easily analyzed. The analysis should be performed using the “counts” output of the accelerometer (not converted g-force). The new slope and offset values are substituted into the g-force conversion equation to provide calibrated g-force output.

The example data illustrated in Figure 1 is imported into a spreadsheet to determine the scale and offset factors.

The scale factor or each axis is calculated as follows:

scale factor = ((average counts at +1g) – (average counts at -1g)) / (2 g's)

The offset is calculated using the data registered by the sensor when the axis was perpendicular to gravity. This occurs 4 times for a 6 position tumble test.

Offset = - (average counts when axis is perpendicular to g)

The ideal conversion factors stated in Equation 1 are replaced with the new factors for each axis, which results in Equation 3, 4, and 5.

X-axis $$g-force=\left(\frac{1}{1063}\right)*(counts+1.8)$$ Equation 3

Y-axis $$g-force=\left(\frac{1}{1041.5}\right)*(counts+11.0)$$ Equation 4

Z-axis $$g-force=\left(\frac{1}{1040.2}\right)*(counts-24.7)$$ Equation 5