EE 617 Sensors in Instrumentation

Autumn 2020 - Assignment 01

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1 Problem Statement

1. Let us measure the offset and noise of the Z-axis accelerometer: the axis of sensitivity that is oriented along direction of gravity when the phone is placed with the screen facing up on a flat surface. Identify at least thirty "flat" surfaces at home and measure the Z-axis accelerometer output by placing the phone on these flat surfaces. For each location of the accelerometer, make at least ten measurements and take their average.
   (a) Plot a histogram of the data collected at all locations, and provide a table of all measurements. For each location, use the average value as mentioned above. What are the values of the mean and standard deviation of the histogram?
   (b) What is the offset of the Z-axis accelerometer in units of **g**?
   (c) What is the RMS noise of the Z-axis accelerometer in units of **g**?
2. Find out what accelerometer is present in the phone. Compare the measured offset and RMS noise to the datasheet specification for this accelerometer. Mention and explain the observations.

2 Solution

Part 1: Observations

The *Accelerometer Meter* mobile application has been used for all measurements. Some of the points chosen for measuring the required quantities are the floor (with different textures), the dining table, the microwave oven, a teapoy and the crockery shelf. All thirty points are noted in Appendix B.
According to Wolfram Alpha [1], the value of the acceleration due to gravity at my city (Thiruvananthapuram, Kerala) is 9.78068 ms^{-2} with negligible east and south components. I am not completely certain about this value because it seems to be an average value and my city is one with a huge range of altitudes, being close to sea level at the beaches and much higher than those regions at urban and other suburban regions. Irrespective of this doubt, I will be using the above mentioned value to calculate the offset.

a. Data Logging

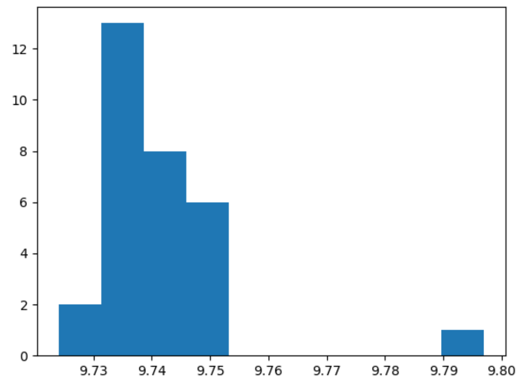
Measurements were taken at first through two days. However, readings taken on the first day showed a slightly higher value, probably due to the conditions of the mobile phone. Measurements were collected a second time, all on 2020 Aug 26 in the afternoon, with the phone at an almost constant battery charge around 40%. 800 data points were considered for each location from which the mean and standard deviation were measured as follows:

Point	μ	σ	Point	μ	σ	Point	μ	σ
01	9.72457	0.00563	11	9.74034	0.00587	21	9.74730	0.00554
02	9.73821	0.00696	12	9.74012	0.00678	22	9.74684	0.00704
03	9.73612	0.00563	13	9.73289	0.00633	23	9.73631	0.00602
04	9.74688	0.00681	14	9.72401	0.00639	24	9.74931	0.00669

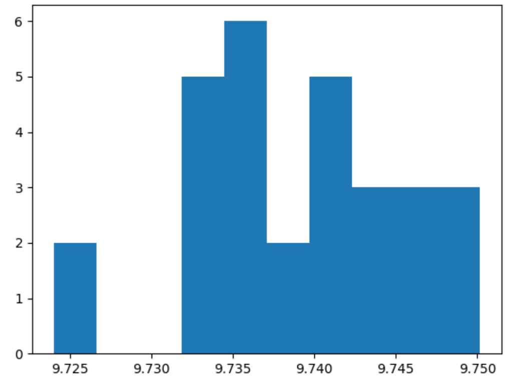
Point	μ	σ	Point	μ	σ	Point	μ	σ
05	9.73591	0.00728	15	9.73224	0.00591	25	9.73754	0.00576
06	9.74047	0.00586	16	9.73190	0.00548	26	9.74809	0.00551
07	9.73481	0.00531	17	9.73988	0.00753	27	9.73517	0.01855
08	9.74027	0.00595	18	9.73398	0.00647	28	9.73540	0.00520
09	9.74275	0.00625	19	9.73398	0.00585	29	9.74235	0.00701
10	9.74323	0.00635	20	9.79700	0.00501	30	9.75018	0.00848

Table 1: Mean and Standard Deviation of Individual Measurements

From this data we can plot a histogram of all the means as:



The outlier in the above histogram is from datapoint num. 20 which was measured on a (slightly shaky) stool. We may exclude this value to obtain the 'Corrected Means' readings as:



b. Z-axis Offset

Based on the histogram, the mean of all locations is obtained as $\mu_h = 9.74060\ ms^{-2}$. The z-axis offset (o_z) is the difference of this value from the actual acceleration due to gravity at my location, giving:

$$o_z = \mu_h - g = 9.74060 - 9.78068 = -0.04008\ ms^{-2}$$

Considering the corrected means, we get $\mu_{h,c} = 9.74060\ ms^{-2}$, giving:

$$o_{z,c} = \mu_{h,c} - g = 9.73866 - 9.78068 = -0.04202\ ms^{-2}$$

c. Z-axis RMS Noise

The z-axis rms noise for all values is given as the standard deviation of the histogram,

$$N_{rms} = \sigma_h = 0.012293\ ms^{-2}$$

Considering the corrected means, we get

$$N_{rms,c} = \sigma_{h,c} = 0.00655\ ms^{-2}$$

Part 2: Comparison

The sensors used in my mobile phone according to the app are based on the 6-axis inertial measurement unit K6DS3TR by ST Microelectronics. This does not have a public datasheet, however, according to phyphox.org from the RWTH Aachen University [2], the accelerometer has a range of 39 ms^{-2} with a resolution of 0.0012 ms^{-2} measured at 99.0 Hz, and provides a mean value of 9.693 ms^{-2} (depends on location) and a standard deviation of 0.032 ms^{-2}. An article on 'UniMiB AAL: An Android Sensor Data Acquisition and Labeling Suite' [3] developed at the Dept. of Informatics, Systems and Comm., Univ. of Milano-Bicocca, mentions that the sensor has a minimum delay of 2000 μs, a maximum range of 784.532, a resolution of 0.0023942017, and consumes 0.25 mW. Finally, the app mentions that the sensor has a maximum range of 39.2266 ms^{-2} and a resolution of 0.0011971008 ms^{-2}, consuming a power of 0.13 mW.
Based on consensus, the first and the third values seem more correct. Hence we may assume the values from the first source to be the values of the mentioned quantities. As per [4], we may consider resolution to be a result of the total noise from the sensor. Assuming that the noise density remains constant from 0 Hz to 100 Hz (approximated from 99 Hz), we may consider resolution to be the integral of the square of the noise density giving an average value for noise density as $N = R/100 = 12\ \mu ms^{-2}/\sqrt{Hz} = 1.227 \mu g/\sqrt{Hz}$. The RMS noise obtained in the experiment is about 5.45 times the supposed resolution according to the datasheet.
The observed offset may be from a possibly slanted posture for the phone or for the accelerometer itself. On the other hand, noise can also be due to external factors such as a running fan or someone stomping on the floor. The effect of a running fan can be visualized from readings 29 and 30. The former reading was taken from a drum piece when the fan was switched off, giving a standard deviation of 0.00701 ms^{-2}, whereas the latter was taken from the same piece with the fan running, increasing the standard deviation by about 21% to 0.00848 ms^{-2}.
Human error is also a source of noise in such readings. In order to reduce human influence in data measurement by starting the measurement, the first 200 readings (out of 1000 to 2000 readings) have been discarded, and only 800 readings have been taken for analysis considering the fact that the last few values will be disturbed due to the operator stopping the process.

A References

1. Gravitational force at Thiruvananthapuram, Kerala, India
2. Sensors of SM-G615F
3. UniMiB AAL: An Android Sensor Data Acquisition and Labeling Suite
4. Acceleration Noise Density - Technical Note

B Points of Interest

The first 26 measurements were taken at ground level and the rest at a floor above (~3.25 m)

- Dining Table
- Arch Sill
- Sofa Hand-rest
- Study Table
- Crockery Shelf
- Pressing Board
- Teapoy
- Stair
- Computer Table
- Granite-tiled Floor
- Cooking Range
- Microwave Oven
- Telephone Stand
- Bookshelf
- Side Table
- Refrigerator
- Window Sill
- Washing Machine
- Electric Oven
- Stool
- Dishwasher
- Kitchen Cabinet
- Cooktop
- Dressing Table
- Kitchen Shelf
- Vitrified-tiled Floor
- Granite-tiled Floor
- Drumkit Chair
- Silent Floor Tom
- Floor Tom with switched-on fan