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Effectiveness of Smartphone Accelerometers for Inspection

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ABSTRACT: Accelerometers are often used for inspection. With the rise of cheap accelerometers and their extensive use in smartphones there are opportunities to utilise such sensors for inspection and monitoring of our built infrastructure. However, there is often a debate around the effectiveness and accuracy of the cheaper smartphone accelerometers as compared to the more sophisticated ones. Additionally, this is also related to the question of whether several lower fidelity sensors can be better than a small number of higher fidelity sensors. To address some of these questions, this paper carries out several tests with smartphone accelerometers and statistically compares their performances. These comparisons add to the growing benchmarks of performance of lower fidelity sensors and also provides guidelines on how such sensors can be useful for a variety of applications, including their reasonable boundaries of operations. The results also provide a way of fair comparison of performances of different sensors, along with interpretation of such errors, paving way for guidelines and recommendations of their implementation in different circumstances and demands.

1. INTRODUCTION

Citizen science and crowd data collection is becoming popular and so is the use of smartphones for such purposes. However, there is less emphasis on the benchmarking and accuracy of such results (Atkinson and Wald, 2014) as compared to the use-case demonstrations. There is also a question of whether several low-end sensors, like smartphone accelerometers, can be more beneficial than a small number of very high resolution sensors.

This paper attempts to address this gap by carrying out calibrations for smartphone accelerometers against a high resolution accelerometer with better range. and provide a reference uncertainty for them, The results provide a guidance on where smartphone accelerometer results can be useful and where we can expect their applicability to be unacceptable or limited.

The work is also relevant since many smartphones often have similar accelerometer models. Existing work in this direction include (Feng et al., 2015; Mourcu et al., 2015; Kos et al., 2016) where smartphones were used for Structural Health monitoring vibrations. Another set of benchmark results were carried out by Cahill et al. (2019) demonstrating variability of results and also in the context of measurement of an iconic pedestrian bridge (ref O'Donnell et al., 2017).

In terms of excitation, harmonic. random and impulse loading are used, apart from in-field ambient vibration tests (Ozer et al., 2020). Such tests can also be managed with good control in a laboratory environment (Albarbar et al., 2007). Tests of coherence (Suryam et al., 2006) have also been carried out. The question at this point is not whether smartphones are useful for monitoring, but rather where and how much should it be used (Elhattab et al., 2019, Kos et al., 2016, Giacomo et al., 2014; Matarazzo et al, 2017; Varanis et al., 2018).

2. EXPERIMENTAL DESIGN AND METHODS

Three smartphone accelerometers were subjected to harmonic excitation and their responses (ISO16063-1, 1998) were compared against a high performance reference accelerometer.

2.1 Equipment for Experiments

Analog Discovery 2 was used to measure, visualize and generate excitation for an electrodynamic shaker.

MEMS accelerometers can easily communicate with the device and are treated as an I2C bus. Specification sheets have a register map and each register sends different control signals to the accelerometer including the tap threshold to set the desired acceleration measurement range, power and sampling rate.

A significantly higher specification reference accelerometer (LORD MicroStrain G-Link LXRS) is connected to the electrodynamic shaker.

2.2 Testing Regime

Although the accelerometers are calibrated during fabrication, there is an offset from mounting and software, which were carefully checked. Three accelerometers were considered for testing due to their popularity: MPU6050, ADXL345 and LIS3DH.

Harmonic excitation for different frequencies and acceleration levels were carried out for 50s covering the most sensitive range on all the accelerometers and where the resolution is highest. Excitation in the 5Hz-20Hz stable range were compared and varied for the test accelerometers. One set of very low frequency (2Hz) test was carried out to investigate errors at such low levels, which are often high.

White noise sine sweep between 5Hz-20Hz were also performed for increasing and decreasing scenarios for the same time period. If smartphone accelerometers for different phones perform in an overall similar manner we expect hat between their tests the performance will not be significant. Apart from the tests of significance it is also possible to compare their performance visually by comparing boxplots.

3. RESULTS

3.1 Peak Amplitude Error: Sinusoidal Excitation

Peak amplitude errors for the three accelerometers and their performances are provided next. A 2Hz excitation was checked for MPU6050 alone, and to test the discrepancy from reference accelerometer even when the excitation may not be very stable on each run. An example is provided in Figure 1. Subsequently, Table 1 provides the performances for MPU6050.

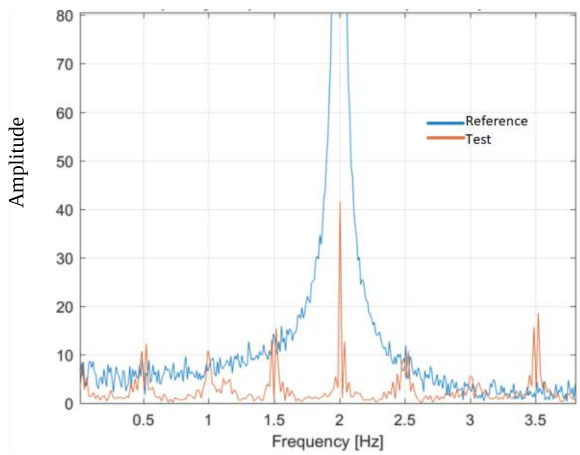


Figure 1: Peak amplitude error for 2Hz sinusoidal excitation for MPU6050

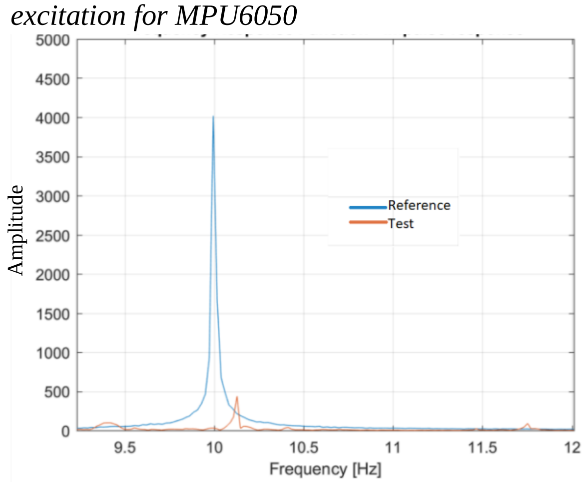


Figure 2: Peak amplitude error for 2Hz sinusoidal excitation for LIS3DH

Peak amplitude error for LIS3DH is presented in Figure 2, while Table 2 provides details of errors. Table 3 presents errors of ADXL345 with a smaller number of experiments since the trends are similar to the other examples.

Overall there is a slight bias towards estimating higher frequencies for the smartphone accelerometers. There are occasional amplification of errors by at least an order (10 times), which cannot be predicted beforehand and filters cannot be used. These are outliers and easy to detect. The errors, discounting the obvious outliers are consistent.

Table 1: Peak amplitude errors of MPU6050: Frequency (Hz)=Frq, Range=R, Computed Sampling Rate(Hz)=SR, Peak: Test Accelerometer (Hz)=PTA, Peak: Reference Accelerometer(Hz)=PRA, error=E%

Frq	*R*	*SR*	*PTA*	*PRA*	*E%*
5	2g	44.4	5.01	4.99	0.42
7	2g	41.4	6.54	7.01	6.64
10	2g	79.84	10.01	10.00	0.11
20	16g	75.84	20.06	20.00	0.3
5	2g	46.54	5.00	5.00	0.00
7	2g	59.9	6.92	7.00	1.16
10	2g	49.28	6.45	10.00	35.46
20	16g	60.46	16.23	20.00	18.85
5	2g	82.36	3.22	5.00	35.64
7	2g	81.78	7.15	7.00	2.10
10	2g	81.83	10.21	10.00	2.10
20	16g	79.91	20.42	20.00	2.10
5	2g	81.72	5.11	4.99	2.24
7	2g	81.85	7.16	7.00	2.33
10	2g	81.91	10.22	10.01	2.10
20	16g	79.89	20.38	19.99	1.95
5	2g	81.77	5.11	5.00	2.3
7	2g	81.8	7.15	7.02	1.9
10	2g	81.69	10.21	9.99	2.2
20	16g	80.2	20.44	19.99	2.3

Table 2: Peak amplitude errors of LIS3DH0

Frq	*R*	*SR*	*PTA*	*PRA*	*E%*
5	2g	69.68	5.01	5.00	1.54
7	2g	69.88	7.12	6.99	1.8
10	2g	69.67	10.15	10.00	1.55
20	16g	69.19	20.30	20.01	1.45
5	2g	68.36	5.06	5.00	1.16
7	2g	68.34	6.96	7.00	0.49
10	2g	32.20	8.01	10.01	19.11
20	16g	67.87	19.91	19.99	0.40
5	2g	69.7	5.07	5.00	1.48
7	2g	68.42	6.98	7.00	0.29
10	2g	69.7	10.16	10.01	1.5
20	16g	68.63	20.26	20.01	1.25
5	2g	69.57	5.01	5.00	1.34
7	2g	68.40	6.97	7.00	0.47
10	2g	69.53	10.21	10.00	2.10
20	16g	68.48	20.24	20.00	1.20
5	2g	69.55	5.06	4.99	1.32
7	2g	68.69	7.01	7.00	0.21
10	2g	69.52	10.12	10.00	1.2
20	16g	68.68	20.25	19.99	1.3

Synchronisation of clocks and sampling rates are less variable and for many applications, will not pose a problem, unless real-time estimates are required for control or similar applications with consequences related to small errors around clock synchronization.

Table 3: Peak amplitude errors of ADXL345

Frq		*R*	*SR*	*PTA*	*PRA*	*E%*
	Specimen 1					
5		2g	89.17	5.10	4.99	2.10
7		2g	89.00	7.12	6.38	11.7
10		2g	91.50	10.21	10.01	2.00
20		16g	96.51	20.46	20.00	2.30
	Specimen 2					
5		2g	89.47	5.12	4.99	2.56
7		2g	89.10	7.13	6.38	11.82
10		2g	91.04	8.01	10.01	2.50

3.2 Distribution of Responses: Boxplots

Boxplots of distributions of responses were created to visualize the performance of smartphone accelerometers with respect to reference accelerometers.

Figure 3 presents these boxplots for 5Hz excitation for the three smartphone accelerometers under consideration, while Figure 4 and Figure 5 present the same for 7Hz and 10Hz, respectively.

The variations of the results are observed from the boxplots presented next.

Figure 3:5Hz acceleration response boxplots of a)MPU6050, b) LIS3DH0 and c)ADXL345

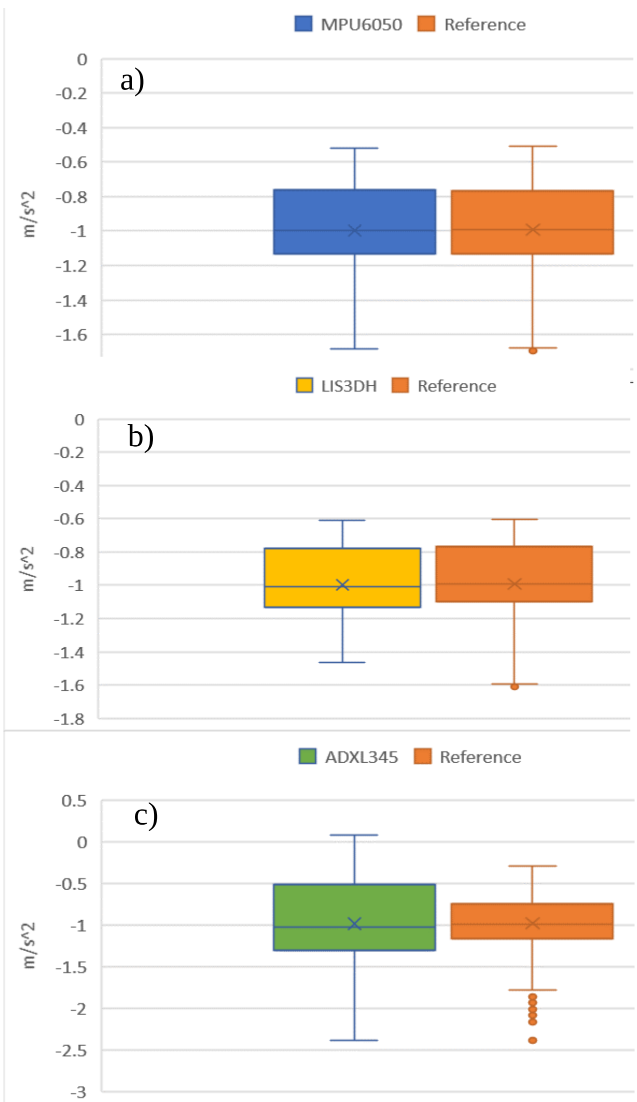


Figure 4:7Hz acceleration response boxplots of a)MPU6050, b) LIS3DH0 and c)ADXL345

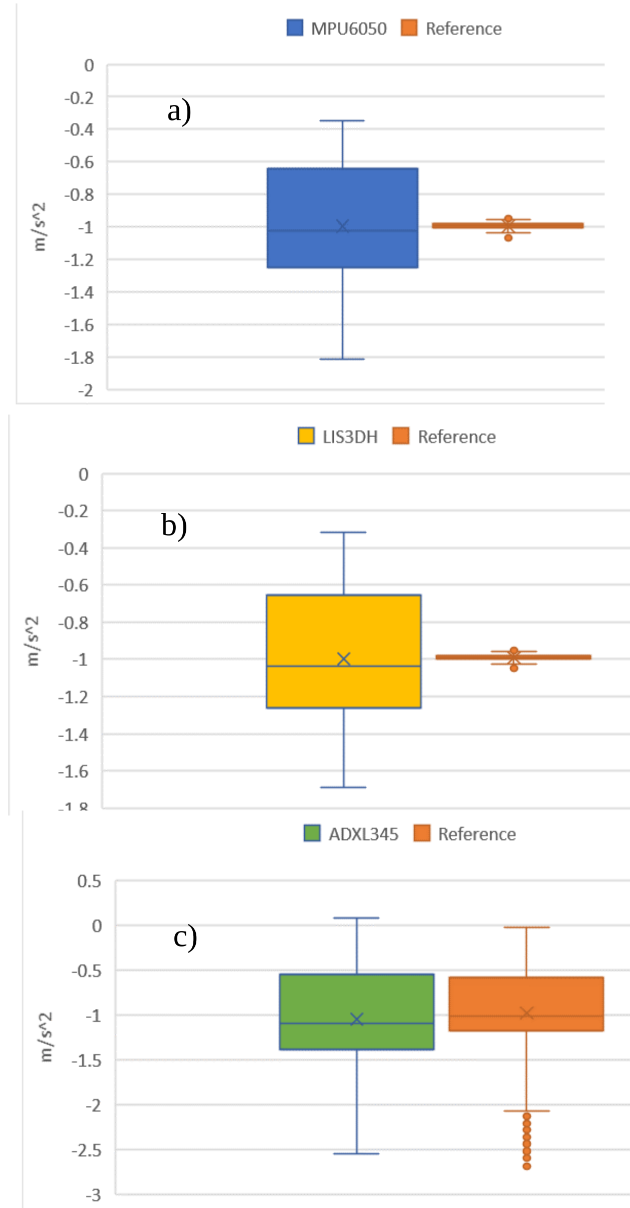
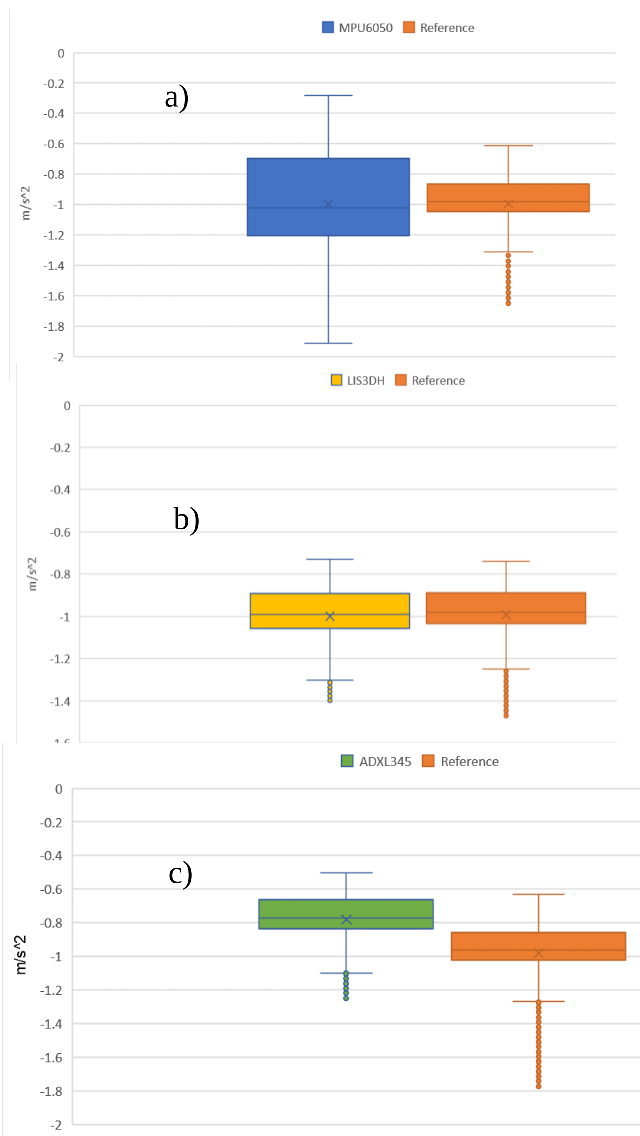


Figure 5:10Hz acceleration response boxplots of a)MPU6050, b) LIS3DH0 and c)ADXL345



4. CONCLUSIONS

This paper compared three smartphone accelerometers (MPU6050, LIS3DH0 and ADXL345) and compared their harmonic responses against a high fidelity accelerometer, as an investigation to establish whether there is a significant difference in performance between smartphone accelerometers and their more sophisticated.the

Investigations suggest that while there is a small variation between peak responses, there exists situations where the smartphone accelerometers are prone to sudden outliers. The accelerometers were compared within a stable range of responses between 5Hz-20Hz, which is often the range within which built infrastructure responses are measured. Here the peak accelerations and the ability to represent the driving frequency was found to be good by the smartphone accelerometers.

Statistical tests were carried out to assess whether there is a significant difference between the smartphone accelerometers and the higher specification reference accelerometers. Boxplots were also used for a visualization of the same. It was observed that there is no significant difference in terms of means considering the smartphone accelerometers tested, in comparison with the reference accelerometer.

While there was not a significant difference between the smartphone accelerometers and the reference accelerometer, the variance of the smartphone accelerometers were found to be statistically significantly different and larger for several of the tests, as compared to the reference accelerometer.

Since the tests were carried out for stable harmonic responses, it is observed that while the frequency representation by the smartphone accelerometers can often be adequate for measurement of features for the built infrastructure sector, the uncertainties of smartphone accelerometers are often qualitatively different and quantitatively higher than higher specification accelerometers. Under such circumstances, whether several smartphone accelerometers can detect a certain feature or not depends on the context of the feature and their thresholds and the use of several accelerometers may or may not guarantee a better result.

There exists a need to develop a comprehensive evidence base around the performance of smartphone accelerometers for as wide a range as possible for detection of features of interest (Dashti et al., 2014) for the built infrastructure (Eriksson et al., 2008) or other sectors (Gao and Zhang, 2004) and extensive testing can lead to such a benchmark, establishing performance, limitations and uncertainties of measurement (Sinha, 2005). Despite this limitation of lack of benchmarks, the usefulness of smartphone accelerometer sensors keep increasing.

5. CONCLUSIONS

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