Research Article

Evaluation of Smartphone's Embedded Sensors Through Applications: A Case Study of Gyroscope and Accelerometer

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Abstract

Smartphones are used for many daily activities like tele-communication, gaming, web browsing, fitness and health monitoring and traditional office working. Smartphones are equipped with built-in sensors to be able to perform these activities. It is well known that the sensors affect the resolution of the smartphone applications which is very vital in life critical applications (LCA). In this paper, two main sensors, the gyroscope and accelerometer have been studied. All commercial smartphones contain these two sensors and support functions related to them. These two sensors have direct link with the physical measurements which feed the fitness and health applications. A fitness application has been selected and ran under Android and iOS operating systems in two different popular smartphones: Samsung Note5 and iPhone7s smartphones. Statistical methodology has been applied to analysis the data and evaluate the performance of the sensors. The results show that commercial smartphones are not reliable devices for motion-related measurements and they can only be used for general purpose monitoring but not in life critical applications.

Keywords: Smartphone, Gyroscope, Accelerometer,IMU, Sensors

1. Introduction

Smartphones are the most widely electronic device used by individuals in the history of mankind. According to the Statista website the number is 3.5 billion devices worldwide in 2020 (Statista, 2020). Smartphones are multi-purposes devises their main function is in telecommunication, while its utility factor is mainly covered by computer gaming, entertainment, Internet browsing and service applications (Hasan & Hamarash, 2017) (Gao *et al.*, 2017) (Banskota, Healy & Goldberg, 2020).

Smartphones are indispensable in everyday life, the numerous application features and flexibility make smartphones an excellent choice for many applications in many different sectors. Every day, new applications are presented in app stores offering new opportunities. Programmers and developers exploit hardware and software features to build their own applications too. Most of these applications use smartphone built-in sensors to add environmental interactions (Belkhamza & Niasin, 2017)(Iyengar *et al.*, 2020)(Nasution *et al.*, 2020). The built-in sensors measure physical quantities to be fed as inputs directly and indirectly providing powerful tools and data for programmers to build their programs and applications.

Gyroscope and accelerometers are among the most used sensors in modern smartphones (Dzeng, Fang & Chen, 2014) (Jain & Kanhangad, 2018).

Gyroscope measures the angular velocity, i.e. the rate of change of the sensor's orientation (Passaro *et al.*, 2017), while accelerometer measures the external force acting on it. The acceleration creates a force that is captured by the force-detection part of the accelerometer. It measures acceleration indirectly through an applied force to the accelerometer's axes. The applied force consists of two components: the sensor's acceleration and the earth's gravity (Dadafshar, 2014).

The mathematical models for gyroscopes and accelerometers are well established in the literature of dynamics, for detail diagrams and formula see (Passaro *et al.*, 2017) and (Dadafshar, 2014). The orientation and force effects of gyroscopes and accelerometers are fused together to determine the motion activities of the smartphone or any touched object (Kok, Hol & Schön, 2017).

Currently, microelectron-mechanical system (MEMS) technology is used in gyroscopes and accelerometers manufacturing. MEMS elements characterized with light, low energy consume, short start-up time and high accuracy (Edinger *et al.*, 2020). These specifications led to raisin the accuracy and resolution of built-in accelerometers and gyroscopes in smartphones. The equipping of smartphones these two sensors have generated opportunities to incorporate motion activity measurements and healthcare systems in smartphone applications (Ogbuabor & La, 2018). In the electronic industry, gyroscopes and accelerometers are packaged together which is then referred to as Inertial Measurement Unit (IMU). All nowadays smartphones are equipped with at least one IMU. Most smartphone built-in IMUs are commercial general purpose without special consideration of accuracy which is required for serious healthcare and fitness applications. This paper studies the accuracy and performance of these two sensors in two popular smartphones to evaluate their adequacy for healthcare applications.

2. Related Works

The embedment of IMU sensors in smartphones brought up opportunities in the industry of mobile applications, especially in Life Critical Systems (LCS), navigation and physical activities. Ma. *et al.* presented a comparison of different types of IMU in (Zhizhong Ma *et al.*, 2013).The comparison shows the relatively high errors in the commercial IMUs in comparison to special designed counterparts.

Built-in IMU sensors in Google Nexus4 smartphone have been evaluated in (Zhizhong Ma *et al.*, 2013). They researchers curried out a test for the characteristics; accuracy, precision, maximum sampling frequency, sampling period jitter, and energy consumption. They found that the gyroscope and accelerometer have small deviations while the compass has a large notable deviation from the real values.

Francisco et. al. (Duarte, Lourenço & Abrantes, 2014) used Artificial Intelligence (AI) to classify physical activities measured by smartphone's accelerometers. The study presented the combination of Android OS with the built-in sensors to found motion features in both frequency and time domains.

Wang et. al. evaluated the best position for the smartphone sensors to be put for motion recognition (Wang *et al.*, 2016). The study concluded that the gyroscopes and accelerometers are able to take the lead roles individually, depending on the type of activity being categorized, the body position, the used data features and the recognition algorithm employed.

Gikas and Perakis presented a study about the accuracy of iPhone5 and HTC One C smartphones to navigation problems. They showed that there is a good consistency between the two devices while there have been differences in the responding to environment conditions (Gikas & Perakis, 2016).

Sunaryono, et. al. studies Android OS-based smartphones from video and image processing perspectives. They determined that phones have advantage over the others, they found that for capturing images Android phones could be used as a tool(Sunaryono, Siswantoro & Anggoro, 2019).

The aforementioned literature shows that there is relatively little systematic research for finding the accuracy of smartphones when they use their built-in gyroscopes and accelerometers in measuring motion activities. The few existence studies show that the measurements accuracy is still an issue point when smartphones are used in life critical systems and serious applications.

In this paper, two very popular smartphones; Samsung Note 5 (Android OS) and iPhone 7 (iOS) have been used to evaluate the accuracy built-in gyroscopes and accelerometers through an application. A simple and straightforward statistical procedure is proposed to evaluate smartphones before using them in serious motion activities. This study uses quality control approach to evaluates the accuracy performance by looking to the device as a black-box; which is the real case from the end-user's perspective.

3. Methodology and Test Setup

Judging the quality of an entity to perform its function adequately according to standards is called evaluation. There are different approaches for evaluation of equipment ranges from complete device testing to comparing manufacturer's datasheets and specifications. The selection of the method depends on the equipment, function and the work conditions. Most evaluation process use statistical quantitative and qualitative measurements to find the final conclusion. In this study, the testing and comparison evaluation method has been selected. The accuracy of the devices under test are evaluated via comparing the results of many tests to individual device itself and to other devices.

Commercially, there are different smartphone brands in the market. Most of them equipped with built-in gyroscopes and accelerometers. They run different operating systems, mostly iOS and Android systems. In this study two popular smartphones from two different manufacturers have been selected. They are: Samsung Note5 and iPhone 7, they run Android 4.3 and iOS 7 operating systems respectively. Both of them are equipped with a separate built-in gyroscope and accelerometer (Jain & Kanhangad, 2018).

The test is carried out by using the two devices in three motion activities; they are: number of steps, distance and speed. The dataset is the output of the devices and the three activities. To maintain constant speed and motion settings, the two smartphones were held by a person walking on a treadmill machine. The two devices are back glued together and put inside the right pocket of the trouser of a person, this arrangement makes the sensors triggering normally, simulate the condition as naturally as possible and finally creates the same exact testing environment for the two devises at the same time.

During the test, three motion activity attributes have been recorded, they are: (1) number of steps, (2) distance, and (3) speed. These activities are measured by the smartphones using three-layer process, starting with reading data from their built-in accelerometer and the gyroscope, then data is captured by the smartphone's operating system and finally the data is converted to the physical quantity values through a an application.

In smartphone industry, the operating system is responsible for data pre-processing and data cleaning. This research does not consider the data pre-processing layer. It uses the final output of the motion activities using Accupedo 3.1. software application for the evaluation process. Accupedo has been selected because it is run in both Samsung Note 5 and iPhone 7. The application has been downloaded from the manufacturer's online store then locally installed before the test is conducted.

Before the recording process, the person's data was recorded as : age = 50, height = 165 cm, weight = 72 kg, and step span = 45 cm. Accupedo has goal variables to be st, they have been set to: speed = 2 km/h, distance = 1 km, and number of steps = 2000 in both smartphones. Each test practiced for 10 minutes and repeated ten times in five separate days, two tests per day. The model of the Treadmill walking machine was YORK Fitness T500. The test settings and configuration are detailed in Table 1, and the test arrangement is shown in Figure 1.

Table 1. Configuration of the Study Case.

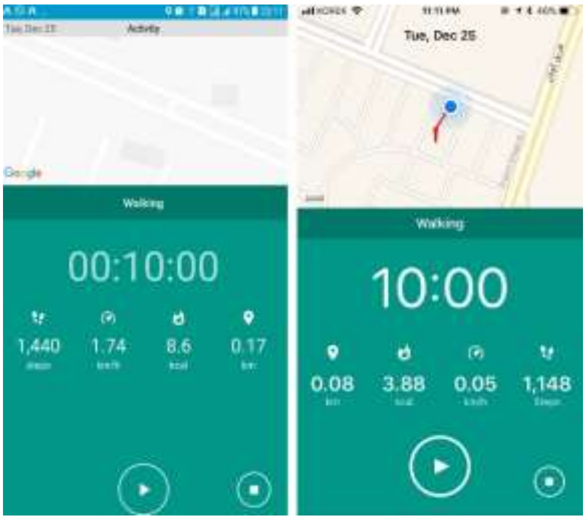
Settings	Participant Gendre, age(years), Height (cm), Weight (kg)	Activity	No. of Times Repeated
Study Case	Man, 50,165,72	Walking on Treadmill machine, Model: York T500	10

Figure 1. Test on Treadmill Machine.

4. Analysis of Results

Once the treadmill walking machine starts running and the person starts walking on it, the smartphone built-in sensors trigger, as a result the measurements of the three motion activities begin, the Accupedo visualizes the readings on the screen both online and record them automatically and simultaneously. Figure 2 shows two screenshots during a test. The screenshots include the three motion activities, calories, and the time / date of the test. Table 2 shows the results of walking on a treadmill machine tests for ten repeating times each for 10 minutes.

The software SPSS - Ver. 20 has been used for the analysis of the results. In the analysis, the best suitable statistical method the test sampling, dependency between the variables, and the variable values have been considered. In the experiment, we have two different devices, the tests are curried out for both devices simultaneously and for the same person, this test configuration means that the datasets are strongly tie to each other. Also, the distribution of the readings is not known initially, the true values of the motion activities for any of the smartphones are not known too which means that none of the test results could be selected as control datasets for statistical analysis. Finally, the data is continuous in manner. According to all the above facts regarding the test and the dataset, the best statistical approach for the evaluation is the paired comparison of the two sample data sets to each other.



(a) (b)

Figure 2. Screenshots for a) Samsung Note 5, b) iPhone 7.

Table 2. Experimental Results.

Test Number	No. of steps		Distance (m)		Speed (km/h)	
	Note5	***iPhone7***	***Note5***	***iPhone7***	***Note5***	***iPhone7***

1	1492	1177	440	200	2.26	0.28
2	1440	1177	170	800	1.74	0.05
3	1500	1141	900	800	1.44	0.98
4	1551	1141	300	800	0.65	0.98
5	1391	1144	220	750	1.30	0.97
6	1450	1147	400	760	1.60	0.70
7	1436	1141	270	802	1.70	0.88
8	1462	1144	330	790	1.54	0.96
9	1490	1149	450	762	1.45	0.98
10	1462	1141	335	800	1.60	0.89

Continuous data are often summarized by determining their average, minimum, maximum and standard deviation (SD). In the other hand, the paired t-tests are used to compare the means of the two samples of related data. The paired t-test compares the mean difference of the values to zero. It depends on the mean difference, the variability of the differences and the number of data (Seltman, 2018). Two hypotheses have been selected: the null hypothesis and the alternative hypothesis. The null hypothesis has been selected to describe the case that there is no difference between the outputs of the two devices for the same test, while an alternative hypothesis has been selected as the existence of the difference. At the beginning each smartphone has been evaluated individually. The descriptive statistics for each device for the three motion activities (Attributes) have been found. The results are listed in Table 3. The histograms for the three motion activities are given in Figure 3 and 4 for Samsung Note5 and iPhone 7 respectively.

The histograms of Figure 3 and 4 show the data for all motion activities (number of steps, distance and speed) are clustered around a centre however they are not distributed normally. The histogram also shows that there are outliers in the datasets. The descriptive statistics and the histogram show that the two smartphones give different measurement values for the same condition and test.

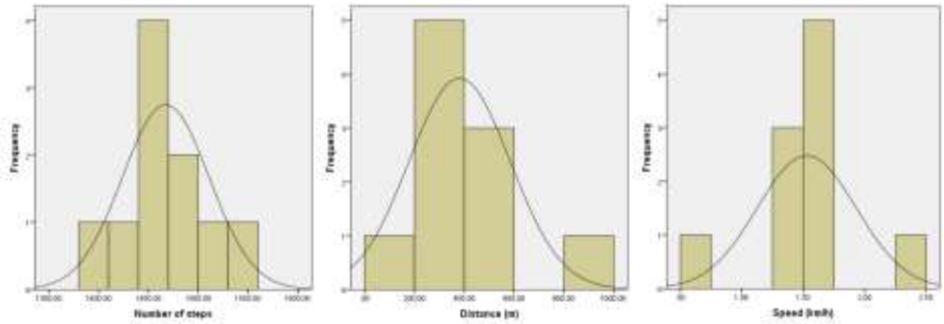


Figure 3. Histogram for Samsung Note 5 Motion Activities.

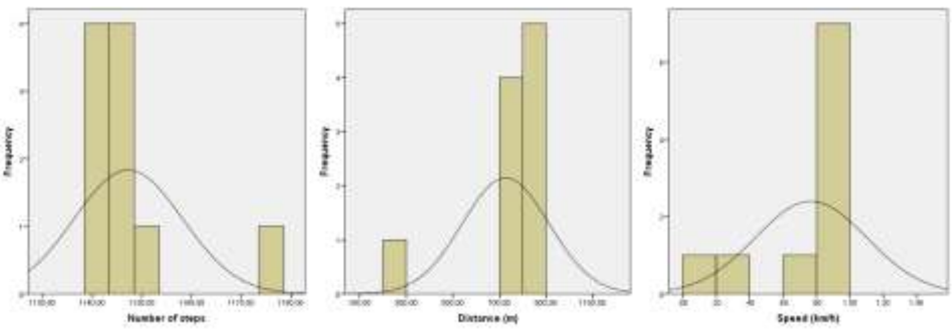


Figure 4. Histogram for iPhone 7 Motion Activities.

Table 3 shows that there are differences between maximum and minimum values for both devices. The ratio between standard deviation to mean is < 0.3 for the number of steps, < 0.5 for the speed and >0.5 for the distance in Samsung

Note 5. The same ratios for the iPhone 7 is <0.01 for the number of steps, < 0.5 for the speed and < 0.3 for the distance. It is clear that the differences are higher in Samsung Note5 than its counterpart in iPhone 7.

Table 3. Descriptive Statistical Analysis.

Parameter	N	Minimum	Maximum	Mean	Std. Dev.
No. of steps (Note5)	10	1391	1551	1467.4	43.59
No. of steps (iPhone7)	10	1141	1177	1147.3	10.88
Distance (m) (Note5)	10	170	900	381.50	203.30
Distance (m) (iPhone7)	10	200	802	726.40	186.03
Speed (km/h) (Note5)	10	.65	2.26	1.5280	.40243
Speed (km/h) (iPhone7)	10	.05	.98	.7670	.33303

The paired t-test is used to compare the means of the readings for the two devices, the t-test determinations are listed in Table 4. Table 4 shows that there are strong evidences (t= 21.401 for number of steps, -5.051 for the distance, 3.524 for the speed) that there are significant differences between the two devices for all motion activities during the same test and condition. The lower and upper limits of the confidence interval 95% shows that we can be 95% confident that the mean difference between the two devices is between 286.26421 and 353.93579 for the number of steps, between 499.36720 and 190.43280 for the distance and between .27245 and 1.24955 for the speed. The p-value (Sig. (2-tailer)) is less than 0.01 for all three motion activities used in the evaluation (see table 4). Therefore, the null hypothesis is rejected with 99% confident and the existence of significant difference between the results of the same test for the same condition is confirmed.

Table 4. SPSS Paired Samples Test.

#	Parameter	Paired Differences					t	df	Sig. (2-tailed)
		Mean	*Std. Deviation*	*Std. Error Mean*	*95% Confidence Interval of the Difference*				
					Lower	*Upper*			
Pair 1	Number of steps (Note5) - Number of steps(iPhone7)	320.10000	47.29917	14.95731	286.26421	353.93579	21.401	9	0.000
Pair 2	Distance (m)(Note5) - Distance (m)(iPhone7)	-344.90000	215.93026	68.28314	-499.36720	-190.43280	-5.051	9	0.001
Pair 3	Speed (km/h)(Note5) - Speed (km/h)(iPhone7)	.76100	.68294	.21597	.27245	1.24955	3.524	9	0.006

5. Conclusions

In this paper, a hypothesis has been set that the smartphones iPhone7 and Samsung Note 5 read accurate motion activities through their built-in gyroscope and accelerometers. To proof the hypothesis, three motion activities have been selected for evaluating the two devices. An application has been used to measure the activities using the data provided by their built-in gyroscopes and accelerometers. The sensor outputs are pre-processed before it is being used by a third party Accupedo software. In our study the two smartphones have been subjected to the exact same test and operating condition. The tests revealed that different smartphones read different results for the same test and the hypothesis is rejected. Results show that there is strong evidence from all activities that the distance, speed and number of steps are changed with the smartphone type and model. Every smartphone gives different reads. Also, there are significant differences between measurements within the same smartphone too. Based on the statistical analysis, we conclude that smartphone motion measurements might be used as guidance only but not in applications which require true measurements like Life Critical Systems (LCS). Smartphones with traditional commercial sensors are not reliable measurement devices for motion activities. The suggestion is that for special measurements, special designed sensors and applications with calibration facilities are required.

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