The interaction of smartphone's accelerometer and gyroscope in microgravity condition

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Abstract

Since 2007, smartphones have been developed rapidly and faster than ever. A lot of technologies have been packed in this such small devices, for example, Accelerometer and Gyroscope. We always wonder: what if autronauts bring their smartphones to the space, will it work normally as they do under the earth gravity. Can they play games, like Need for speed, Temple run, Riptide,… on their leisure time? Since there is no gravity anymore, if they tilt the smartphone, can the game recognize it? To answer these questions, we designed an experiment on Accelerometer and Gyroscope, the main factors the detect the movement of the the device, to check if they work correctly in zero-gravity condition. The experiment contains two parts physic test and psychology test. The first part would determine the acuracy of sensors in different conditions while the second one is to check the players' experience during microgravity. As the result showed the differences, we would based on the data to find a solution reducing the application errors and make it more flexible when using on both ground and in microgravity environment.

Keyword(s): Motion sensor, Gyroscope, Accelerometer, Smartphone, Microgravity

1. Problem statement

Taking advantage of the rapid development of mobile's hardware, the mobile game market has been more and more popular, due to its improvement in graphic (which is closer and closer to the PC gaming experience, but installed in such a small device like smartphone) and new gameplay which takes advantages of mobile's technologies such as Accelerometer and Gyroscope. One day, in a class break, when my friends and I were having a race in Temple Run on our phones, suddenly, a question occur in my mind: "Can astronauts in International Space Station play Temple Run like us play it on earth?"

Astronauts do have spare time when they were working on space, but playing game on smartphones has never been an option! Regardless of the vivid graphic and interesting gameplay like Need for speed, Temple run or Riptile (see figure 1.1). An assumption has been raised among us students that the some motion sensors to control game may not work properly in zero-gravity condition; since all of the game on smartphone just have been tested on normal condition, under the earth's gravity, which is 1G (or 9.8 m/s^2), it is not sure whether or not these games might work properly in space condition (~0 m/s^2). Therefore, in this research, we design an experiment in order to determine if astronauts can play

Figure 1.1. Numerous game on store nowadays often use motion sensors as game-control

If a motion-based game cannot be played in space condition, there can be because of at least two reasons: the device factor (in particular, the accelerometer and the gyroscope, which recognize motions and send corresponding signal to applications, the recognition may not work properly in space condition) or because of the human factor. Our experiment access these two factors to determine which one may take more effect if the game does not work in zero gravity condition. The smartphone's operation was tested on normal gravity condition and zero gravity condition, and two healthy normal gamers played some games in both condition

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as well. The data of smartphone operation and the accuracy when playing game were recorded and then analyzed. In the early analysis result, it is more likely the reason causing the improper controlling game issue in space is the smartphone hardware.

2. Background knowledge and problem approaching method.

2.1. Experiment condition: microgravity environment

To answer the question if astronauts can play games like Temple Run on space, apparently, the experiment must be performed in zero gravity condition. However, it is almost impossible to do it in space, due to the limited of fund. To send something to space, it may cost up to millions of dollars, which is way out of our reach. While it is not possible on Earth to be brought to realization a zero-gravity environment for a long period of time, it can be simulated for short periods of time (from several seconds to tens of seconds) by using a free-fall phenomenon.

Some replaced options have been raised. An object inside an elevator will apparently lose its weight (microgravity) if the elevator cable breaks and the elevator starts a free fall. The weight is lost because the gravitational acceleration acting on the object and the acceleration of the free-falling elevator are virtually the same. However, when the elevator landing, it cause catastrophic damage to the experiment's equipment as well as the experimenter.

The damage problem can be eliminated by using Drop shaft experiment, where a Capsule is dropped in a 150-meter vacuum drop tube, obtaining microgravity environment as high as 10^{-5} G that lasts for 4.5 seconds. The braking system can stop the capsule safely with rubber friction dampers. But this option still has some disadvantage, the size of the experiment equipment is restricted. Therefore, it cannot satisfied the purpose of our experiment.

The last option is using parabolic motion. An object thrown diagonally from the ground falls in a parabolic curve. The falling object keeps the weightless (microgravity) state inside because the acting force are balanced at each momentary position. By using this phenomenon, an aircraft or rocket produces a weightless environment, regardless of its orientation. This parabolic motion is called parabolic flight (see figure 2.2). An aircraft flies at a lower altitude than a rocket and receives greater aerodynamic force. To achieve a parabolic flight, an aircraft adds offsets force by greater engine thrust. For this reason, an aircraft produces microgravity of about 1 to 3 x 10^{-2} G. However, it is able to obtain microgravity environment of longer duration, up to 20 seconds, in compare with 4.5 seconds of drop shaft experiment. In addition, in a parabolic flight, we can be able to perform experiment on people (the participants can fly on board on the parabolic flight) as well as change parameters manually while observing the results of experiment, which are totally suit for our experiment's purpose.

The chance of doing our experiment on the parabolic flight was offered by the Student Zero-gravity Flight Experiment Contest. The Student Zero-gravity Flight Experiment Contest is a educational program, in association with the International Space Station (ISS) project, in which Japan is a contributing partner, aims to provide students from a diverse range of research fields, including science and engineering fields, with an opportunity to participate in conducting microgravity experiments, to promote a greater awareness for the utilization of the space environment, and to develop human resources for future space related development activities.

In this program, the parabolic flight was operated by Diamond air Service (DAS) with the GII aircraft in Nagoya Airport. The aircraft flew on 2 days, took 2 hours each day with the number of experiment tries of 8 to 12 per flight. In each tries (parabola), the microgravity duration is about 20 seconds, in which the experiment will be performed (see figure 2.3). The table below (table 2.1) gives further specifications of the experiment condition.

Table 2.1. Specifications of experiment's condition

Aircraft operator	Diamond Air Service
Aircraft	G-II
Base airport	Nagoya Airport
Airspace used for experiments	Enshunada Sea airspace K and Noto Peninsula airspace G
Parabolic flight	Takeoff to landing: About 2 hours/ flight Experiment time: About 1 hour/ flight Number of experiment tries: 8 to 15/ flight
Microgravity duration	About 20 seconds
Standard microgravity levels	X-axis (longitudinal direction of aircraft): 1 x 10^{-2} G Y-axis (horizontal (left/right) direction of aircraft): 1 x 10^{-2} G Z-axis (vertical (up/down) direction of aircraft): 1 to 3 x 10^{-2} G Flights can be arranged providing specific gravity other than these (such as 0.1, 0.5, and 2 G)
Maximum acceleration during parabolic flight (typical)	1.8 G
Power supplies	28 VDC/160A 100 VAC, 60 Hz, 3kVA
Experiment space	1900H * 6500L * 2200W mm
Rack size	550H * 650L * 550W mm
Temperature inside aircraft	15 to 30 ^{0}C
Humidity inside aircraft	10 to 40%

Pressure inside aircraft	About 0.8 to 0.9 bar
Vibration during parabolic flight	X and Y axis: 1,130 Hz; Z axis: 610 Hz;
Mass of experiment equipment	50 kg/rack
Number of experiment on board	1 to 3/ experiment
Safety standards	Same as those for normal cargo aircraft

2.2. Experiment objectives

To answer the question “If astronauts can play games like Temple Run in space”, we need to understand how these kind of games work on the devices – smartphones. In the Temple Run case, you play a character who have stolen the cursed idol from the temple, and now you have to run for your life to escape the Evil Demon Monkeys nipping at your heels. Swipe to turn, jump and slide to avoid obstacles, tilt their devices to the left or to the right in order to change the running lane, collect coins and power ups, and see how far the character can run!

Many other games on the market have enhanced the user experience by improving the game controller. They can tilt their phone back and forth in order to make the in-game character run backward and forward respectively in first person shooter titles, or you can hold your smartphone like a steering wheel and control the car in racing games like in Need for speed for example. So how can your phone recognize that kind of movement: tilting the phone back and forth, left and right, and so on. The answer is smartphone’s motion sensors, or to be more particular, Gyroscope and Accelerometer.

2.2.1. Accelerometer overview

Accelerometers are used to sense linear acceleration and tilt angle. Acceleration can take one of two forms: Acceleration due to gravity and Acceleration due to translation (movement). Figure 2.4 shows the fundamentals of an accelerometer. In a typical implementation, a suspended proof mass reacts to acceleration in its axis of orientation by moving. This movement changes the capacitance between the mass and its sense electronics, and this capacitance is converted to an output voltage. An analog-to-digital converter then digitizes this voltage for further use by a microcontroller.

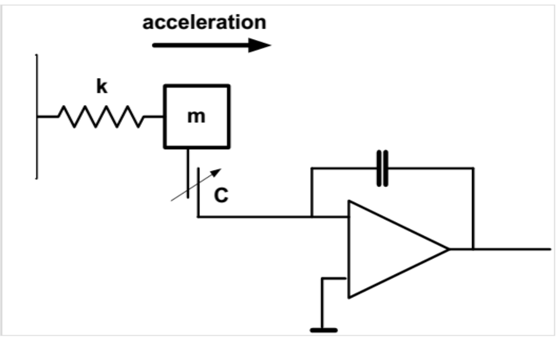


Figure 2.4. Accelerometer basics

Current accelerometers typically incorporate three axes for sensing motion on the X, Y, and Z axes (see figure 2.5). For consumer devices, full-scale ranges are typically from ±1g to ±8g. Accelerometers commonly find usage as tilt and motion sensors for gaming and portrait or landscape display orientation recognition in cell phones and other portable computing devices, and as step detectors in pedometers.

Figure 2.5. The acceleration data collected in 3 direction (along 3 axis)

Since accelerometers cannot distinguish between acceleration due to movement or due to gravity, their outputs are filtered when being used as a tilt sensor. However, filtering makes for sluggish response and may cause inaccuracy when using in abnormal gravity condition (like in space).

2.2.2. Gyroscope overview

Gyroscopes are used to sense the angular rate of velocity (rotation). Figure 2.6 shows the fundamentals of a gyroscope, which operates on the principle of the Coriolis effect where a moving mass with velocity v, rotating at a rate Ω, will be subject to an acceleration a_{cor} that is proportional to the rate of acceleration. This Coriolis acceleration causes the plates of a sense capacitor to move, varying its capacitance. This capacitance is converted into a voltage and is digitized with an analog-to-digital converter for use by a system microprocessor.

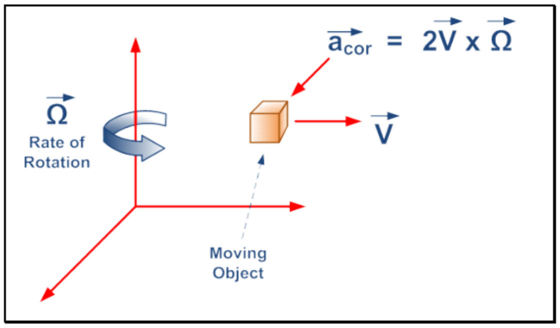


Figure 2.6. Rate Gyroscope Basics.

The output of gyroscopes is rotational rate, and to obtain a relative change in angle, on performs a single integration on the gyro outputs. Thus error in gyro bias (the output of the gyro when rotation is zero) leads to an error that increases in integration time. Consequently, methods must be taken to compensate for these bias errors, which are caused by drift due to time and temperature, and by noise.

2.3. Data and methods

It have been determined that, if games like Temple Run cannot be played on space, there must be at least two reasons, because of the device factor or because of the human factor and our experiment accessed these two factors to determine which one may take the responsibility if the game does not work in zero gravity condition. Now that the specific objectives have been determined and clear that which parts of the smartphone hardware that take responsibility for the game control mechanism. The experiment would be designed to focus on these ones. In general, the smartphone's operation must tested on normal gravity condition and zero gravity condition, and two healthy normal gamers played some games in both condition as well. The data of smartphone operation and the accuracy when playing game were recorded and then analyzed. The experiment would be divided into 3 specific part. Below is the 3 tasks required to be accomplished in order to find the answer for our problem.

First of all, the accelerometer and gyroscope data must be recorded, in both normal gravity condition and in microgravity condition so as to determine its operation

Secondly, a special game, for experiment purpose only, must be played, in normal gravity condition as well as in microgravity condition. Furthermore, the game must have 2 separate mode, one runs on accelerometer sensor and the other runs on gyroscope sensor. This will help us figure out which sensor works better in both 2 conditions.

Finally, after all the data was recorded, it need to be analyzed in order to understand it and find the answer for our wondering.

To accomplish task one, we needed to build a software that runs on Windows Phone OS of Nokia Lumia 920, iOs of ipod gen 4 and Android of the Samsung galaxy s2 (3 operation software of 3 devices that is chosen for the experiment, further detail about this choices will be explained later in this document). The requirement for this software is collecting the raw data of smartphone's accelerometer and gyroscope, so that, bases on this data, we can analyze and determine if those sensors work properly.

To accomplish task two, we designed a game in order to play and test motion sensor's operation in microgravity environment, as a straight approach way to the question "Can astronauts play motion-based games like Temple Run in zero gravity condition".

Last but not least, to accomplish the final task, an analysis software was designed to be able to represent data in charts, have the option for users to choose the data sources from different devices and different time segment so as to compare the data on ground and that onboard.

2.3.1. Task one: data-collecting software

The target operating system of this Collecting data software is Windows Phones OS, iOS and Android. All these three OS support multiple sensors that allow apps to determine the orientation and motion of the device. In our case, we want to access the data recorded by the Accelerometer and Gyroscope. In general, each of those sensor APIs is built on the base class Sensor Reading and follow a similar pattern of starting the sensor and acquiring data.

The accelerometer measures the forces applied to the device at a moment in time. These forces can be used to determine in which direction the user is moving the device. The acceleration value is expressed as a 3-dimensional vector representing the acceleration components in the X, Y, and Z axes in gravitational units. The orientation of the acceleration is relative to the device such that -1g is applied in the Z-axis when the device is face up on a level table and -1g is applied to the Y-axis when the device is placed perpendicular to the table top.

The Accelerometer sensor detects the force of gravity along with any forces resulting from the movement of the phone. The unit of this accelerometer data is G (1G is equal to 9.8 m/s^2)

First of all, after creating the project and the accelerometer object, check to see whether the accelerometer object is null, which it will be until it is initialized. If the accelerometer is null, initialize it using the constructor. Next, set how fast the experiment requires to receive data from the accelerometer by setting the Time Between Updates property (in our case, we set it to 20 milliseconds)

The accelerometer_CurrentValueChanged method will be called by the system with new accelerometer data at the frequency specified with TimeBetweenUpdates. The handler receives an AccelerometerReading object containing the accelerometer data.

Implement the UpdateUI method that will show the accelerometer data to the user. The three TextBlock objects are updated to display the numeric values of the acceleration on each of the sensor's axes. The data is written into a file in order to be analyzed later as well.

The second type of data is Gyroscope. The gyroscope sensor measures the rotational velocity of the device along its three primary axes. When the device is still, the readings from the gyroscope are zero for all axes. If you rotate the device around its center point as it faces you, like an airplane propeller, the rotational velocity on the Z axis will elevate above zero, growing larger as you rotate the device faster. The rotational velocity is measured in units of radians per second, where 2 * Pi radians is a full rotation. The unit of this accelerometer data is rad/s.

The process is similar to that of accelerometer. Make a Gyroscope object and initialize it using the constructor then set the time interval to update the Gyroscope value. Finally, set a handler for the CurrentValueChanged so as to update the UI as well as record the data into a file.

The last data type that will be recorded is Gravity values. In Windows Phone, the Motion API handles the complex math necessary to combine the raw sensor data from device's Compass, Gyroscope, Accelerometer sensors and produce easy-to-use value for the device's attitude and motion.

Each of the data type above will be recorded into a file with a mutual format. Figure 2.10 below shows the format.

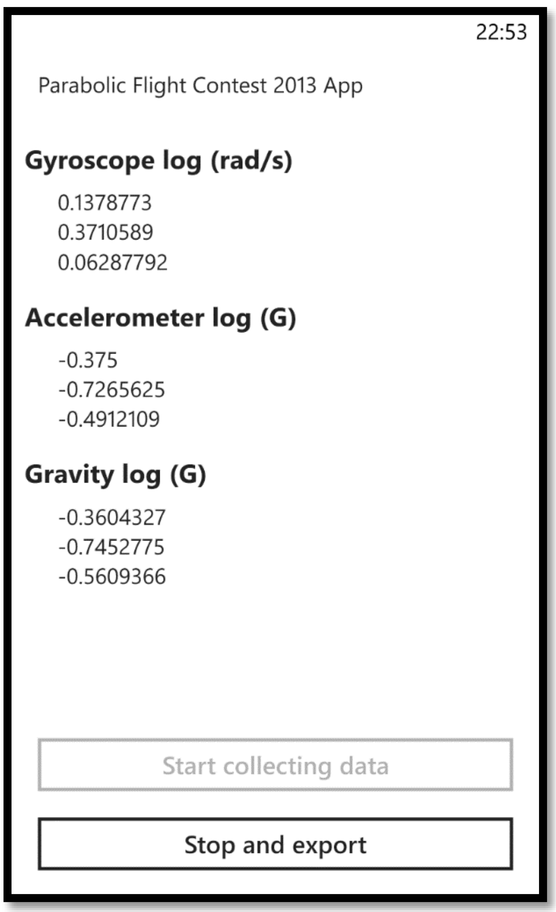
TheMillisecond ValueAlongXAxis ValueAlongYAxis ValueAlongZAxis

Figure 2.10 The output format

TheMillisecondOfDay: the millisecond that a line of data is recorded in order to synchronize between different sources from different devices.

ValueAlongXAxis, ValueAlongYAxis, ValueAlongZAxis: The value expressed as a 3-dimensional vector representing the sensor components in the X, Y, and Z axes

Figure 2.11 show user interface of the application and a sample data collected



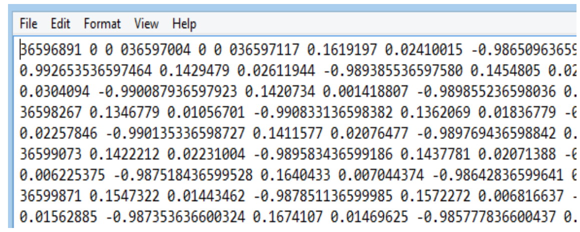


Figure 2.11 Application user interface and sample data

2.3.2. Task two: motion-based game

A game is needed to design in order to determine the psychology aspect and the performance of human when playing motion-based games in such special condition like microgravity.

The game was developed on Unity game Engine, for Android devices. Unity is a game development ecosystem: a powerful rendering engine fully integrated with a complete set of intuitive tools and rapid workflows to create interactive 3D and 2D content; easy multiplatform publishing; thousands of quality, ready-made assets in the Asset Store and a knowledge-sharing community.

FLOW is the title of the game we designed. Here is the basic gameplay, players have to tilt their device so that the bar on the screen rotate and look forward the arrow. The bar rotates based on acceleration, it keep its upward direction opposite to the gravity detected by acceleration. Acceleration along each axis is reported directly by the hardware as G-force values. A value of 1.0 represents a load of about +1g along a given axis while a value of -1.0 represents -1g. If you hold the device upright (with the home button at the bottom) in front of you, the X axis is positive along the right, the Y axis is positive directly up, and the Z axis is positive pointing toward you.

On the right side is the game UI, the upper of the screen indicate the location path in which the accuracy of the player is recorded. At the middle, the bar is the object that we must control and make it match the color with the ring outside as well as keep it close to the pointer/ arrow as close as possible. At the bottom, this part shows the accuracy of the player, in the demonstration, the accuracy is 51%, and the bar is 88 degree away from the perfect point.

2.3.3. Task three: data-analysis software

The data-analysis software is design on Matlab and able to represent data in charts as well as have the option for users to choose the data sources from different devices and different time segment so as to compare the data on ground and that onboard.

The software can work with 3 types of data. Firstly, it can display the acceleration on 3 axis of the devices in G unit (1G is equal to $9.8m/s^2$) as well as the acceleration in summary affecting the whole devices. Second is the Gyroscope's data, which is in rad/s. And finally the accuracy and Signal to noise ratio when playing the game FLOW can also be analyzed on this software.

Matlab is a high-level language and interactive environment for numerical computation, visualization, and programming.

Using MATLAB, you can analyze data, develop algorithms, and create models and applications. For this reason, it is used to develop this Data-Analysis software.

3. Experiment setup

3.1. Experiment purpose

In order to answer the question: if astronauts can play motion-sensor-based game on space, we designed and tested our experiment on ground and on board. As mentioned above, we used devices installed Accelerometer and Gyroscope sensors for test and record its own parameters in two environments. For further details, Accelerometer and Gyroscope sensors were used to measure device's angular acceleration and angular velocity in each periods, respectively. The data of sensors had been collected since the experiments started until it completed.

Since, we have compared to show differences between parameters when testing on ground and on microgravity.

3.1.1. Device operation on ground and on microgravity condition

We used three devices because they had both gyroscope and accelerometer sensor in set. On the other hand, that each types of equipment were produced by different hardware suppliers and installed in different devices leads to some little differences in specification. Using these devices in 3 experiments was to answer the question whether these devices were used well in different environmental conditions (in this micro gravity). Then, it gave logical conclusions to not only manufacturers but also the software companies, which helped them develop better uses of the Gyroscope and Accelerometer sensor for hardware and software. This is motion sensor's specification of devices table 3.1below.

Table 3.1 Devices used in the experiment

	Ipod 4	Galaxy SII	Lumia 920	Nexus 7
				
Weight	140g	116g	185g	340g
Number	1	1	2	1
Size	Height : 115.2mm Width: 58.6mm Thickness: 9.3mm	Height : 125.3 mm Width: 66.1mm Thickness : 8.5mm	Height : 130mm Width : 70.8mm Thickness: 10.7mm	Height: 198.5mm Width: 120mm Thickness: 10.5mm
Accelerometer chip	STMicro 8134 33DH 00D35 three-axis accelerometer	LIS3DH three-axis accelerometer	Snapdragon S4 built-in Accelerometer, gyroscope	InvenSense MPU-6050 – Six-Axis (Gyro + Accelerometer) MEMS Device
Gyroscope chip	STMicro AGD8 2135 LUSDI gyroscope	OMAP4430 SoC built-in Gyro		

We have used threes smartphones as above (named Samsung Galaxy SII, Ipod Gen 4, Lumia 920), each was given a particular acceleration. Using a special application developed by us such as named **Parabolic Flight Contest 2013 App**, the data accelerometer and gyroscope was collected during the parabolic flight was recorded.

Parabolic Flight Contest 2013 App (PFCA):

Interface User's Parabolic Flight Contest 2013 App was designed as above with threes parameters about Gyroscope, Accelerometer and Gravity (figure 3.2). The data of accelerometer and gyroscope sensors will be collected during the parabolic flight. The parameters will be recored every 100 milliseconds, since the 'Start' button is tapped, until the user tap 'Stop' button. Furthermore, The record will only start when the value of the millisecond is 0, so all of the devices can be synchronized.

Comparison method:

The data recorded during the parabolic flight would be compared with the data collected in the same condition but on ground. We used our data analysis program in order to examine that the changes of Gyroscope, Accelerometer and Gravity's parameters between on ground and on board. In addition, we could also observe the noise signals from the surrounding environment affecting how the results obtained and how much the rate was. Overall, from the data collected in two different environments, we could have an objective assessment in the identification of mobile using Gyroscope and Accelerometer sensors how active on ground and on microgravity.

3.1.2.Gaming experiment on ground and on microgravity condition.

In order to test experience of player when playing games in microgravity condition as same as astronauts can play game, a game designed by us, named FLOW (figure 3.3), would determine the performance of player. The game had two mode, Accelerometer mode and Gyroscope mode and it was installed on Nexus 7 device (Android OS), to find out which sensor was more suitable for playing game on various conditions. Besides, some popular games on the market would also be tested.

Figure 3.3 The FLOW's interface, players have to tilt their devices so that the stick match color which the outside ring

Comparison method:

The accuracy of the player was recorded continuously during the game, so we could calculate the overall accuracy of any interval of time for analysis.

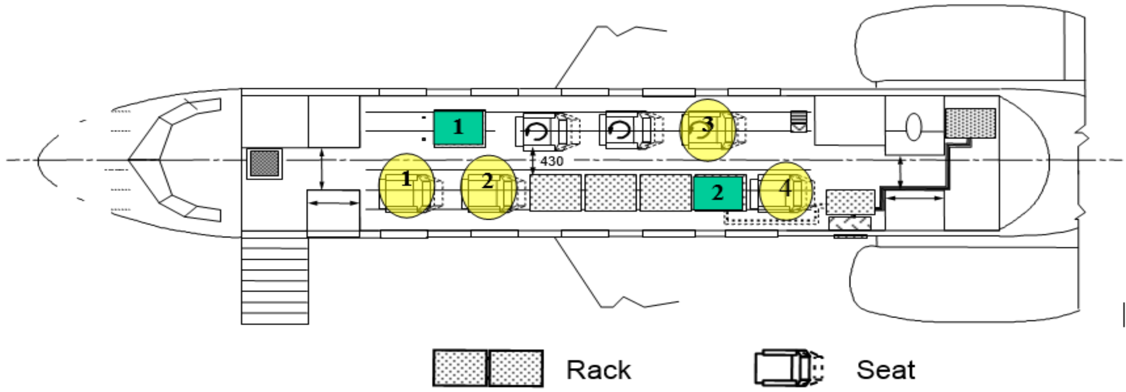
Example of performance log (format: ***Hour:minute:second millisecond accuracy***
10:49:15 100 78%
10:49:15 200 79%
10:49:15 300 80%
10:49:15 400 80%
…

The data obtained would be analysed via our special program. From the overall accuracy of flow game's mark when playing on ground and on board, we could see that performance of player. Therefore, we could answer the question: Can astronauts play motion-sensor-based game on space?

3.2. Experiment setup for camperison of device operarion on ground and on microgravity condition.

3.2.1.Expriment equipment

There were 6 teams from various Asia countries doing experiment inside a G-II aircraft, each team was given a rack with the size of 650mm high x 650mm long x 550 mm deep.



Flight #3 & #4

	Rack 1	Seat	Rack 2	Seat
upper	Thailand	2	Univ. of Tokyo	(4)
lower	Vietnam	1	Malaysia	3

Figure 3.4 Experiment place and experimenter's seat arrangement

In order that our equipment could work on board, we used a power supply available containing two options: **AC 100V(+-max.10%), 60Hz, 3Amp(300W)** or **DC28V(26~30V), 5Amp**. On the other hand, in order to maintain safety for all crew, experiment equipment's weight restrictions were at maximum of 50kg or less and we used some measure instruments like that video camera to observe experiment equipment's action on board.

Experiment equiment setup:

Inside out rack (figure 3.5), the rotating fan, controlled by a Circuit board, has three slots that can put smartphones in (namely, a Samsung Galaxy SII, an ipod gen 4, and a Nokia Lumia 920). Another phone is placed in front of the rack in order to record the whole experiment, and gathering the data from the Control circuit board via Bluetooth. The figure below shows the set up.

1 – Analysis data application
2 – Control circuit board + Bluetooth module + RF module
3, 4, 5 – smartphone-holding box
6 – Camera
7 – Power supply
8 – Psychology and performance test device

Figure 3.5 Expriment setup

The fan is made of stainless steel and has 3 "hands" to hold phones. Each hand is 200 mm long. The size of this whole rotating device is 490*490*300 (mm) (length * width * height) (see figure 3.6).

The spinning fan gives smartphones some certain acceleration, the data those mobiles collected will determine if they work and measure properly. The fan can run at 3 different speed, 20-40-60 rpm, represent regular user's behavior when playing motion-based game like Temple Run. On average, in 1 second, a person can wave his hand 90^0 three times, which means the angular speed is about 90^0 * 3 per second ~ 0.75 circles per second ~ 45 circles per minute.

A tablet outside the rack will be played by an experimenter to determine the effect of microgravity condition on psychology aspect and the performance of human when playing motion-based game on such special condition.

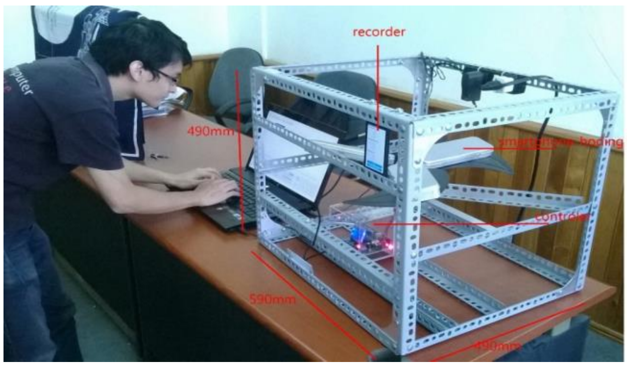


Figure 3.6 Experiment's size and setup inside

About PID algorithm:

During the trasition between the speeds, the instantaneous velocity of the engine would fluctuate sharply and we could not maintain exactly the desired speed, which would effect the performance of devices as well as accuracy of the parameters obtained on smartphones device. Therefore, maintaining the level of speeds preinstalled (20-40-60 rpm) is very important. Hence, PID algolrithm was applied in order to maintain and control motor's speeds.

A **proportional-integral-derivative controller** (**PID controller**) is a control loop feedback mechanism (controller) widely used industrial control systems. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control outputs.

The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called **three-term control**: the proportional, the integral and derivative values, denoted *P, I,* and *D.* Simply put, these values can be interpreted in terms of time: *P* depends on the *present* error, *I* on the accumulation of *past* errors, and *D* is a prediction of *future* errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element.

The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Definingu^t as the controller output, the final form of the PID algorithm is:

$$u(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t) \quad (1)$$

Where:K_p is proportional gain, a tuning parameter; K_i is integral gain, a tuning parameter; K_d is derivative gain, a tuning parameter; e is Error = SP – PV; t is time or instantaneous time (the present); τ is variable of integration; takes on values from time 0 to the present t.

Derivative action predicts system behavior and thus improves settling time and stability of the system. Derivative action is seldom used in practice though - by one estimate in only 20% of deployed controllers- because of its variable impact on system stability in real-world applications. For example, in the presence of severe measurement noise the derivative action will be erratic and can actually degrade control performance or stability. Large, sudden changes in the measured error (which typically occur when the set point is changed) cause a sudden, large control action stemming from the derivative term, which goes under the name of derivative kick. This problem can be ameliorated to a degree if the measured error is passed through a linear low-pass filter or a nonlinear but simple median filter.

About control circuit board:

An important part of equipment system is the control circuit board controlling motor's speed. The size of circuit board is 90 mm x 90 mm(width x length). Circuit board plays an important role in connecting RF signal remote with devices in order to change motor's speed when a passenger go far away from circuit board. RF signal remote incudes two part. The first part is transmitter module. Transmitter module transmit signal to control's set which is also receiver module. There are four control buttons for controlling speed of motor on receiver module (20-40-60 rpm). In addition, we also used Bluetooth module for gathering gravity parameters in two conditions. That information would be collected during the parabolic flight and tested on ground via smartphone device installed a software by us. The collected information will show gravity parameter's differences and changes in two environments.

4. Analysis

When the phone moving in space, its motion sensor will track the changing on three dimensions that is axis x, y and z that was illustrated in figure 4.1. In our experiment, each phone has installed a software which collected the data from motion sensors: Accelerometer and Gyroscope. In each second, our software samples data of sensor 10 times. Accelerometer data includes 4 values which is value of sensor on axis x, y, z and the magnitude value. Gyroscope data also includes 4 values which is value sensor on axis x, axis y and axis z and the magnitude value.

$$A = \sqrt{x^2 + y^2 + z^2} \quad (1)$$

Where A is magnitude and x, y and z is respectively value on three dimension: x axis, y axis and z axis.

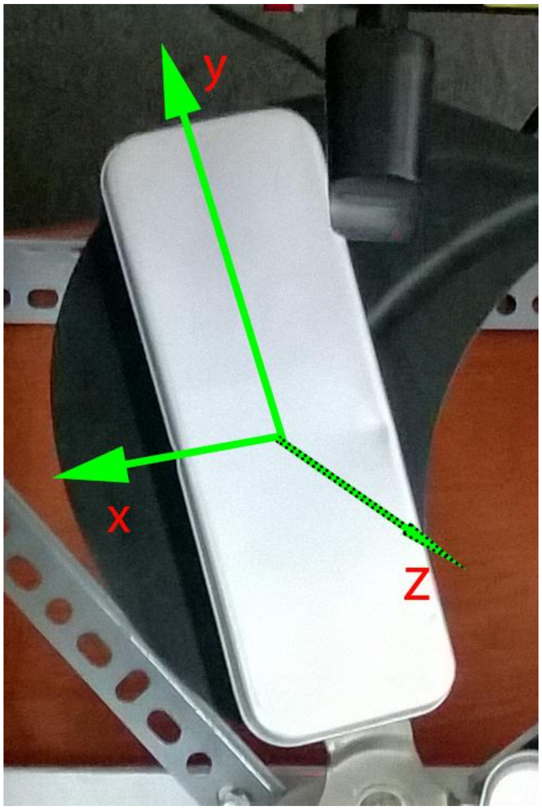


Figure 4.2: Three directions of phone when fixed on the box

On figure 4.2 shows the way each phone will be fixed in a box with three dimensions x, y and z direct respectively similar beside picture. Axis x line is parallel with width; axis y line is along with the longs of box and the axis z line directs to the ground. The blades will be counter- clockwise rotation. In fact, phones do not place completely horizontal in box. They are inclined about 20 degree.

Besides, we have collected the data on ground that will be used to compare with data on parabolic flight. After parabolic flight, we have got 3 sets of data, each was data set for each rounding speed of blades: 20cycles/minute, 40 cycles/minute, and 60 cycles/minute. And each set data includes both of on ground (the data is collected on ground) and on board data (data that is collected on flight).

4.1. Interaction of accelerometer on ground and on board conditions.

This session will give more analyzing and comparison of data that was collected on ground and on board.

4.1.1. Interaction of acceleration with 20 cycles per minute blades velocity

Galaxy S2:

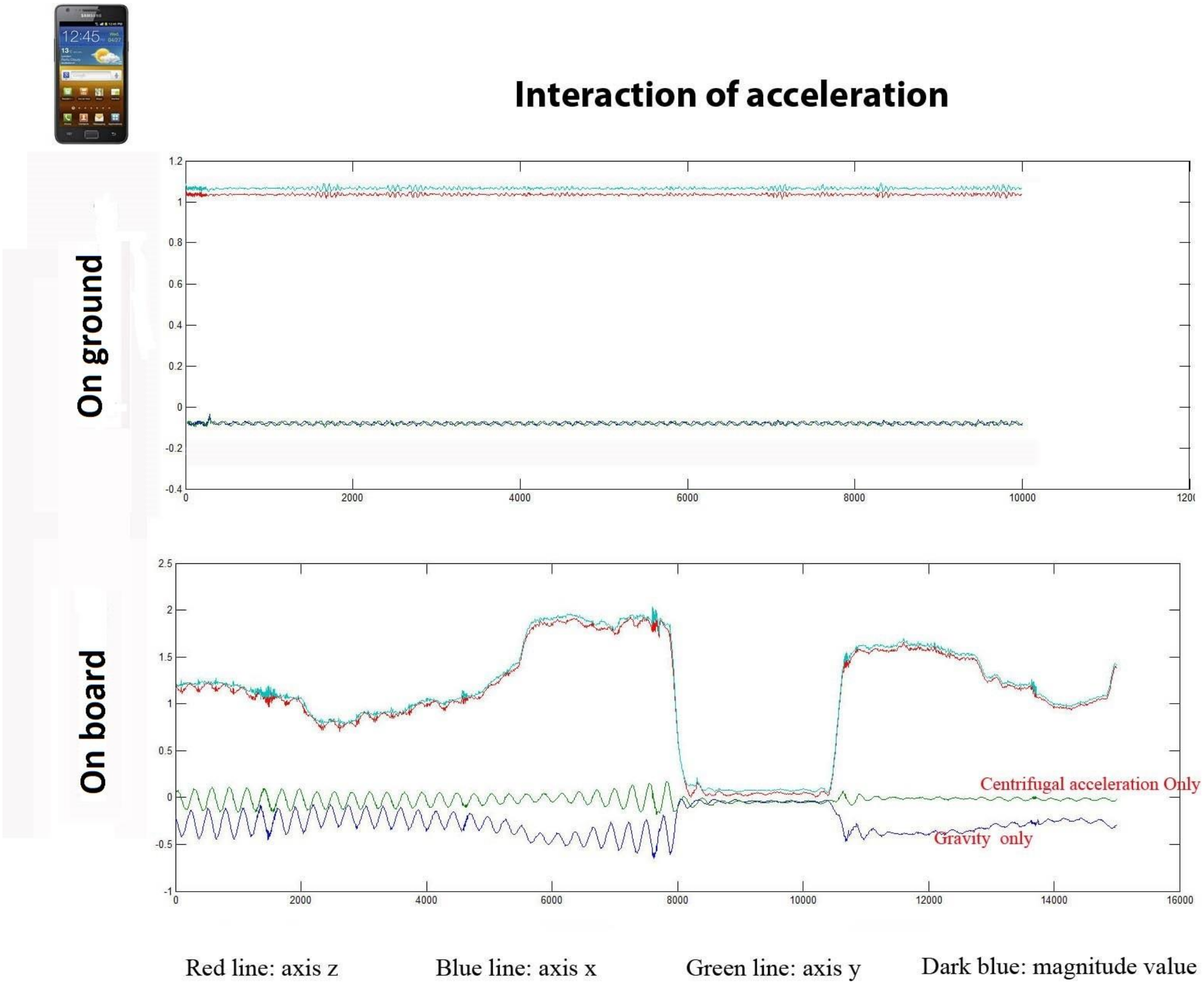


Figure 4.3: the interaction of Samsung galaxy S2 accelerometer on ground and on board with velocity is 20 cycles per minute.

On ground: the first part of figure 4.3 shows the interaction of accelerometer On ground. It represents the changing of value on three dimensions and magnitude value. On theory, the blue line (represents x axis) is close zero, and the green line (represent y axis) is just above zero line with small distance. But the experiments gives some different result. On the real experiments, the changing of all value dose not much, each line represents each axis is just fluctuates around a value and its fluctuation is with very small amplitude .The value on the axis x (blue line) and axis y (green line) are almost close each other. Two lines go around the value 0.1G, the blue line is above zero line, it not true on theory. The reason for this deference is galaxy S2 does not place completely horizontal, it is incline about 20 degree, so there is a small part of gravity is projected to the axis x, that make its value above zero. The value of sensor in the axis y is completely projection of centrifugal acceleration that is made when the fan rounding. With speed level is 20 cycles per minute, it makes an acceleration on axis y, and it is about 0.1G. Besides, the last part of gravity projected to z axis, that why red line is near 1G. In this situation, we can see that the magnitude value is completely close z axis value, it is near 1G. Of course, because using an expression (1) to get magnitude value the value on x axis and y axis are too small.

On board: The second part of figure 4.3 is the interaction of accelerometer on board, it includes three conditions: unknown gravity, hyper gravity and micro gravity. Unknown gravity is time between normal gravity and hyper gravity, in this time gravity increases very fast from 1G to 2G.Look at figure, there are two reaches that describes 2 times of hyper gravity. Between two reaches, there is a bottom, which is corresponded micro gravity time. And another is repented unknown gravity condition. On board, there is a large change of acceleration sensor with its interaction On ground. Firstly, we see that sensor did not work stability, and it depend on the gravity very much. The value of sensor in axis x and axis z are the projection of gravity vector, that why their value fluctuate dramatically. Because the phone is not placed in flat, it is inclined 20 degree. That why the projection of gravity in axis x is not zero, its value is fluctuated from 0g to 0.5G. The value of sensor in axis y is just projection of centrifugal acceleration which was created when blade rounding, although the gravity affected directly to y axis value, but it affected to the speed of. Then the fan did not rotate stability that make its centrifugal change with large intensity. The value of sensor in axis y is very small and depend on the length of centrifugal acceleration vector, its value go around between 0G and 0.1G. Value of axis z changed following the gravity of environments, it fluctuated between 0g to 2g. Secondly, the magnitude value is depend on the gravity on all the time includes micro gravity time. In normal gravity and hyper gravity, magnitude value is depend much more on the gravity, of course, in those situations the z axis value larger than x axis and y axis value very much. But in micro gravity condition, magnitude vector still be affected by z axis value, because although z axis and x axis value are very small but y axis value is small too. With speed is 20 cycles per minute, it just make a small centrifugal acceleration and that value does not affect to magnitude value. Thirdly, the interaction of sensor is stable when the gravity stable. In the graph, at hyper gravity there is a small time that red line is very stable (small amplitude), in the same time green and blue line are stable, all lines is very close 0G.

So, the sensor works pretty well On ground. The gotten value of Galaxy S2 motion sensor is very close to the calculated value in both situations. In the charging gravity condition, the working of sensor depends much more on real gravity, more changing gravity, more different result. Both in unknown and hyper gravity condition, its values fluctuates very much. In micro gravity, its value is quite stable, but it is too small, it is not good ideal when using this value. Finally, gravity affect is very much to the action of sensor in all time except micro gravity condition.

IPod Gen4

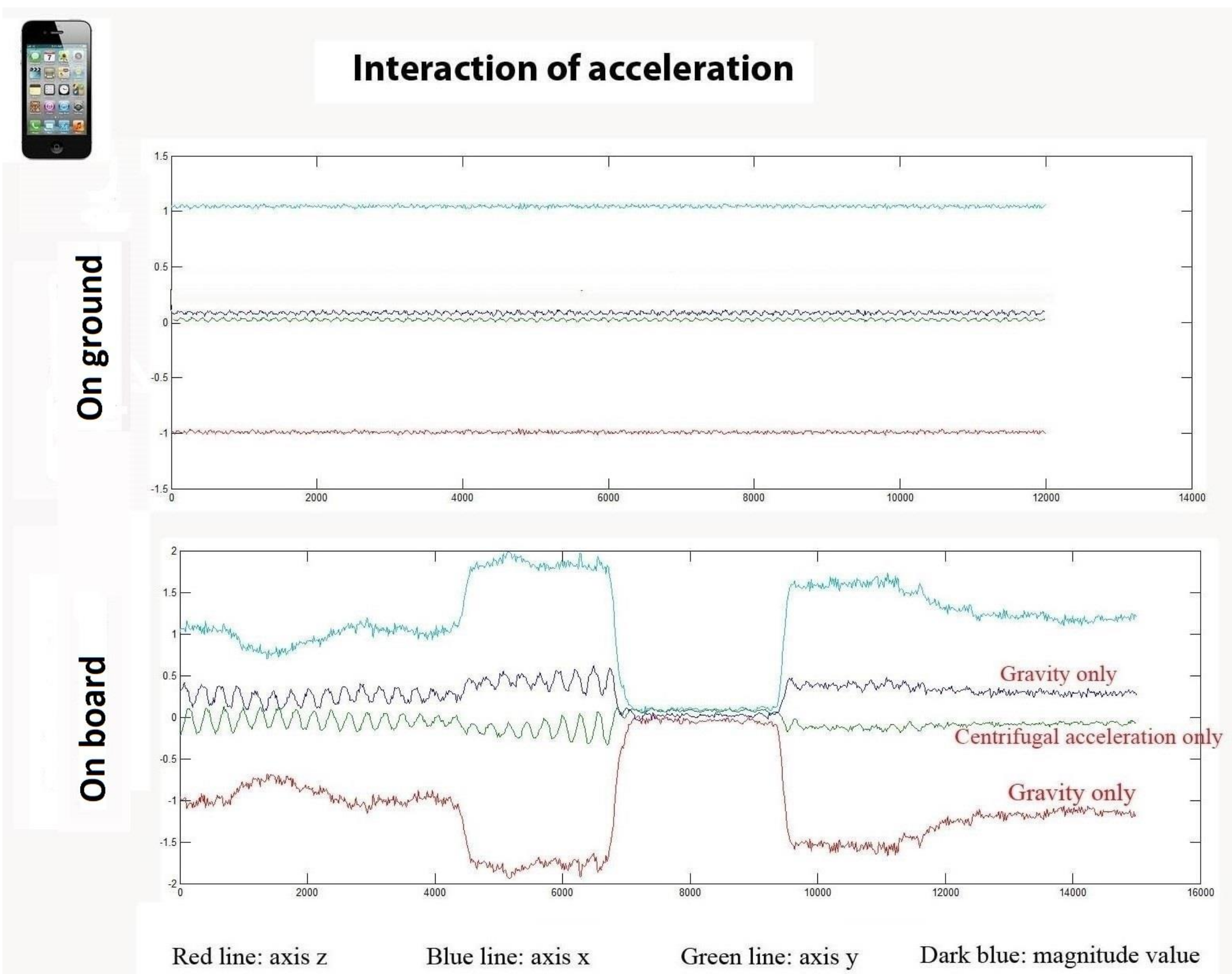


Figure 4.4: interaction of IPod Gen 4 accelerometer On ground and on board with velocity is 20 cycles per minute.

On ground: The first part of figure 4.4 shows the interaction of sensor On ground condition: stable gravity 1G and angular velocity is 20 cycles per minute. Look the figure, value of sensor in three dimensions x, y, and z is very stable, it is same with Samsung galaxy S2 interactions. The value on the axis x (blue line) and axis y (green line) are almost close each other. Two lines go around the value 0.1G .In theory, value in axis x is zero and the value in the axis y very close zero. Like galaxy S2, IPod did not place completely horizontal, it was incline about 20 degree, so there was a small part of gravity projects to the axis x, that make its value above zero. The value of sensor in the axis y is completely is value of centrifugal acceleration that was made when the fan rounding, but its value is too small, it is very close zero. With speed level is 20 cycles per minute, it make an acceleration on axis y, and it is about 0.1G. Another part of gravity that projects on z axis, that why z axis value is very close 1G. In this situation, we can see that the magnitude value is completely close z axis value, it is near 1G. Of course, with expression (1) magnitude value is close z axis, because x axis and y axis are too small they are not affected to magnitude value.

On board: The rest part of figure describes the action of sensor on board. There are three conditions that are illustrated on the figure, they include unknown gravity, hyper gravity and micro gravity. Unknown gravity is time that charging from normal gravity to hyper gravity, in this time gravity charges so quickly. Look at the figure, On board, there is a large change of acceleration sensor with its interaction On ground. Firstly, we see that sensor did not work stability, and it depend on the gravity very much. The value of sensor in axis x and axis z are the projection of gravity vector, that why their value fluctuate dramatically. The reason that the sensor got value in axis x is the phone was not placed in flat, it is inclined 20 degree. That why the projection of gravity in axis x is not zero, its value is fluctuated from 0g to 0.5G. The value of sensor in axis y is just projection of centrifugal acceleration which was created when blade rounding, although the gravity affected directly to y axis value, but it affected to the speed of. Then the fan did not rotate stability that make its centrifugal change with large intensity. The value of sensor in axis y is very small and depend on the length of centrifugal acceleration vector, its value go around between 0g and 0.1G. Value of axis z changed following the gravity of environments, it fluctuated between 0G to 2G. Secondly, we get that the magnitude value is depend on the gravity on all the time except micro gravity time. In sub hyper gravity and hyper gravity time, magnitude value is depend much more on the gravity, of course, in those situations the z axis value larger than x axis and y axis value very much. But in micro gravity condition, magnitude vector be affected more by y axis value, this is difference to Galaxy S2 sensor. In this time, the magnitude value is very close y axis value. It is same to the expected result that there is no gravity, so x axis, z axis value near zero and magnitude value is just y axis value. Thirdly, we see that, the interaction of sensor is stable when the gravity stable. In micro gravity all of three lines fluctuate with very small amplitude when gravity does not have more change.

All above shows that sensor works pretty well On ground with stable gravity and small velocity. In the charging gravity condition, there are some deferens. The working of sensor depends much more on read gravity. In unknown gravity and hyper gravity, its values is not stable. And in micro gravity, the sensor works very well, all line fluctuates with small amplitude, but its value is too small, it is not ideal to use this value. Finally, gravity affect very much to the action of sensor in all the time except microgravity.

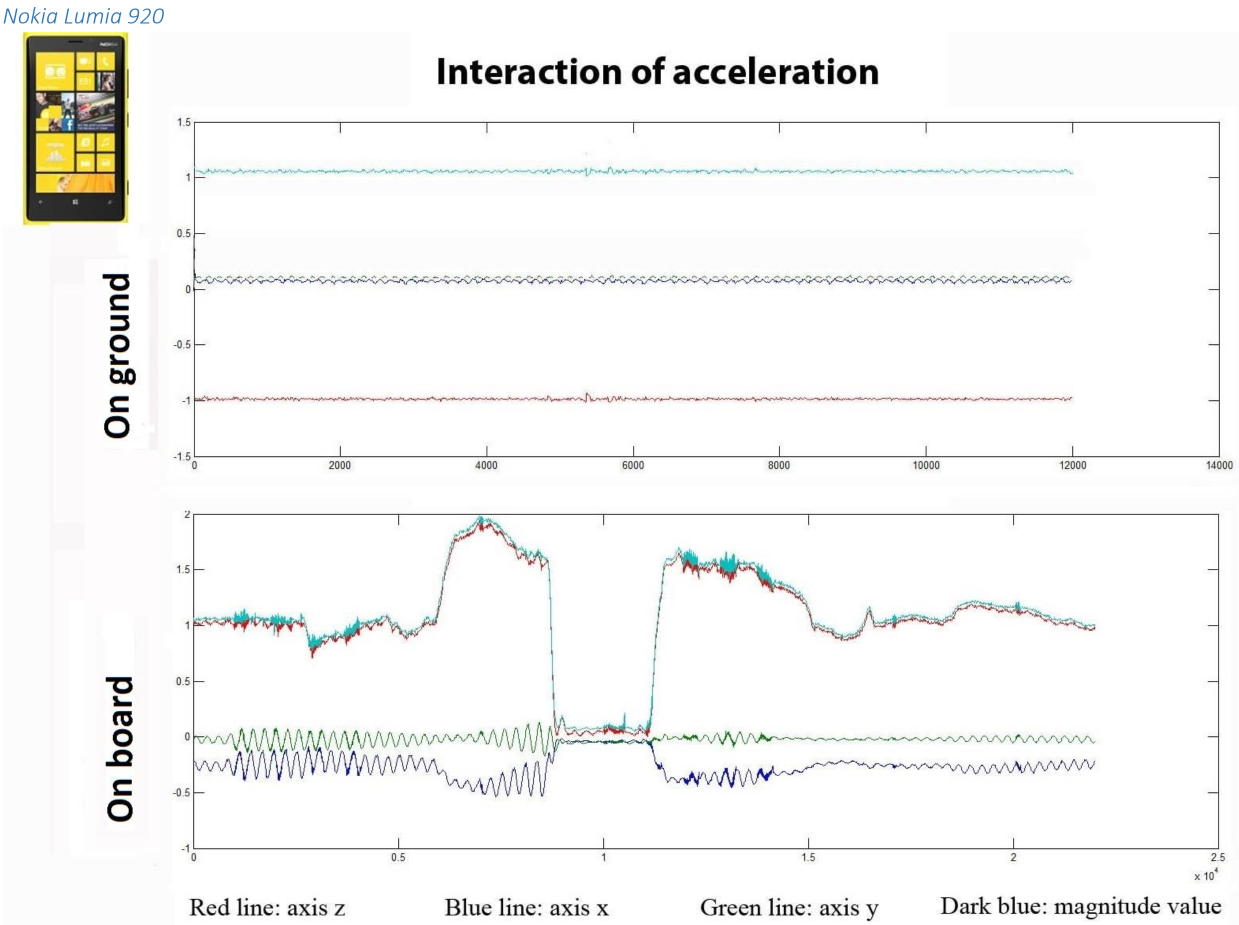


Figure 4.5: The interaction of Lumia 920 accelerometer on ground and on board with velocity is 20 cycles per minute.

On ground: The figure 4.5 presents interaction of sensor on ground in the second part of chart. It is clear to see that the value of sensor on three dimensions x, y, and z is very stable. The value on the x axis (blue line) and axis y (green line) are almost close each other. Two lines go around the value 0.1g, the result gets some differences to theory that green line will be close zero line. The reason is galaxy S2 did not place completely horizontal, it was incline about 20 degree, so there is a small part of gravity is projected to the axis x, that make its value above zero. The value of sensor in the axis y is completely is value of centrifugal acceleration that is created when the fan rounding. With speed level is 20 cycles per minute, it make an acceleration on axis y, and it is about 0.1G. In this situation, we can see that the magnitude value is completely close z axis value, it is near 1G. Of course, expression (1) gives answer to explain this phenomenon because value x axis value, y axis value is too small, and smaller when it squared, that makes magnitude value is fully affected by z axis gravity.

On board: The first part of above figure presents inter action of Lumia 920 accelerometer On board, there are three conditions of gravity On board. They are unknown gravity, hyper gravity and micro gravity conditions. There are two reaches that represent hyper gravity conditions time, the bottom represents micro gravity condition time and another is unknown gravity condition time. Unknown gravity condition time is time when gravity changes from normal gravity (1G) to hyper gravity (2G). There is a large difference phenomenon when it is On ground. Firstly, the sensor does not work stability, and it depends on the gravity very much. The value of sensor in axis x and axis z are the projection of gravity vector, that why their value fluctuates dramatically. On theory, the value on x axis does not affected by gravity, it is always zero in all time, but in experiment, it gets difference. The reason is the phone is not placed in flat, it is inclined 20 degree. There is a part of real gravity is projected to x axis, and real gravity changes very quickly. That why the green line is above zero line and its value is fluctuated from 0g to 0.3G. The value of sensor in axis y is just projection of centrifugal acceleration which is created when blade rounding. Gravity does not affect directly to y axis value, but it affects to the velocity of blades. Velocity of blades are stable when gravity stable like on ground condition, when gravity changes all time, it makes velocity change. But the monitor try to make the fan rounds stalely, when velocity is higher than 20 cycles per minute, monitor control fan to reduce speed. So the acceleration is quite high. Then the fan does not rotate stability that makes its centrifugal change with large intensity. The value of sensor in axis y is very small and depend on the length of centrifugal acceleration vector, its value go around between 0g and

0.5G. Value of axis z changed following the real gravity of environments, it fluctuated between 0g to 2g. Secondly, we get that the magnitude value is depend on the gravity on all the time except micro gravity time. In unknown gravity and hyper gravity condition, magnitude value is depend much more on the gravity, of course, in those situations the z axis value larger than x axis and y axis value very much. In those conditions. Three lines value are very small, they are near to zero line. With speed is 20 cycles per minute, it just make a small centrifugal acceleration and that value does not affect to magnitude value to much in all time experiment. Thirdly, the interaction of sensor is stable when the gravity stable. In the graph, at hyper gravity there is a small time that red line is very stable (small amplitude), in the same time green and blue line are stable too. In micro gravity all of three lines fluctuate with very small amplitude.

The sensor works pretty well On ground. The gotten value of Lumia 920 motion sensor is very close to the calculated value. On board with three gravity conditions, the working of sensor depends on real gravity very much. Unknown gravity and hyper gravity sensor value is not stable. In micro gravity, the sensor value is close to zero and it is ideal to using its value. Finally, gravity affect very much to the action of sensor in all the time include microgravity with 20 cycles per minute rounding.

4.1.2. Interaction of acceleration with 40 cycles per minute blades velocity

Galaxy S2:

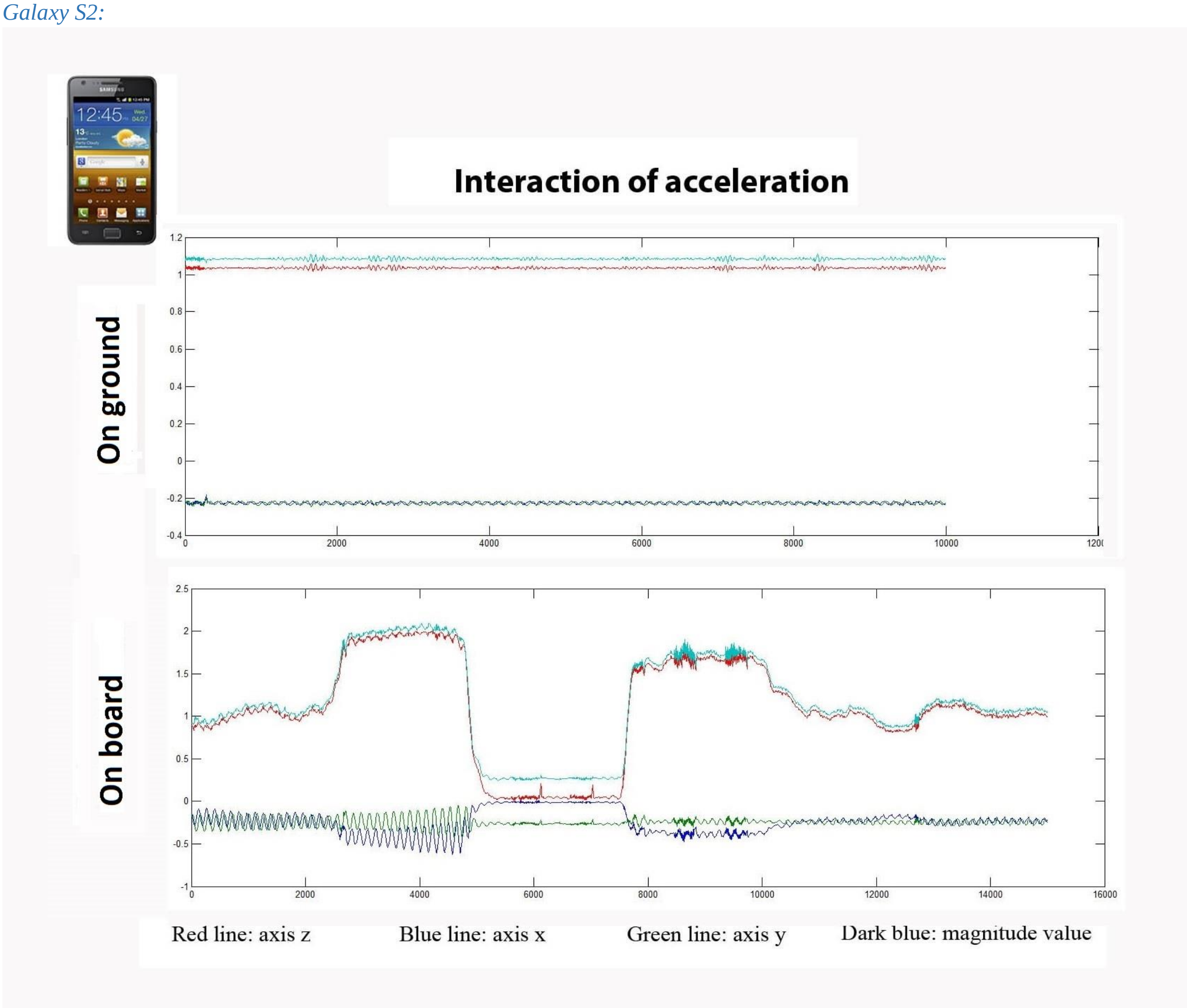


Figure 4.6: The interaction of Samsung Galaxy S2 accelerometer on ground and on board with 40 cycles per minutes

On ground: The second part of figure presents the interaction of sensor On ground. The value of sensor in three dimensions x, y, and z are very stable. The value on the x axis (blue line) and axis y (green line) are almost close each other. Two lines go around the value 0.2g. There is some difference to theory that the value in axis x is zero. The reason is galaxy S2 device dose not place completely horizontal on box, it is incline about 20 degree, so there is a small part of gravity is projected to the axis x, that make its value above zero. Rest part of real gravity projects to z axis. The value of sensor in the axis y is completely is value of centrifugal acceleration that was made when the fan rounding. With speed level is 40 cycles per minute, it make an acceleration on axis y, and it is about 0.2G. In this situation, we can see that the magnitude value is completely close z axis value, it is near 1G. The magnitude value is calculated using expression (1) and another hand the x axis value, y axis value is too small, that makes magnitude value is close z axis value.

On board: The first part of chart shows the interaction of Galaxy S2 On board condition. On board, there are three special gravity conditions that are unknown gravity, hyper gravity and microgravity condition. The bottom is correspond to micro gravity condition, tow reaches beside are hyper gravity condition and another part is unknown gravity condition. Unknown gravity condition is the time between normal gravity and hyper gravity. In this time, the gravity changes very fast, form 1G to 2G or 2G to 1G. There is a large change of acceleration sensor with its interaction On ground. Firstly, the working sensor depends on environment gravity very much. The value of sensor in axis x and axis z are the projection of gravity vector, that why their value fluctuate dramatically. The reason that the sensor got value in axis x is the phone was not placed in flat, it is inclined 20 degree. So there is a part of real gravity is projected to axis x, its value is fluctuated from 0g to 0.5G. The value of sensor in axis y is just projection of centrifugal acceleration which is created when blade rounding. Although, environment gravity does not affect directly to y axis value, but it affects to the velocity of fan. When the gravity change the velocity changes too, that why the acceleration is quite high. The fan did not rotate stability that make its centrifugal change

with large intensity. The value of sensor in axis y is not small and depend on the length of centrifugal acceleration vector, its value go around between 0g and 0.4G. In unknown gravity condition, the x axis value and y axis value is very close, but in hyper gravity x axis value is greater than y axis value. The reason for this happen because in hyper gravity, environment gravity is max, that make the projection on x axis increase too, and it becomes greater than y axis value. Value of axis z changed following the gravity of environments, it fluctuated between 0g to 2g, it is projection of real gravity to x axis, that why it value is not stable. Secondly, the magnitude value is depend on the gravity on all the time except micro gravity time. In unknown gravity and hyper gravity, magnitude value is depend much more on the gravity, of course, in those situations the z axis value larger than x axis and y axis value very much. But in micro gravity condition, magnitude vector not be affected by z axis value, because although the value of x and z axis still exist in micro gravity condition but they are quite small to angular acceleration- y axis value. With speed is 40 cycles per minute, it just make large centrifugal acceleration and that value affects directly to magnitude value. And the interaction of sensor is stable when the gravity stable, at micro gravity all of three lines fluctuate with very small amplitude.

All above give the answer that sensor works pretty well On ground, its value is quite stable. The result value of Galaxy S2 motion sensor is very close to the calculated value. On board gravity condition, the working of sensor depends on environment gravity. On unknown and hyper gravity condition, sensor value is not stable, all line fluctuates with high amplitude. In micro gravity time, the value of sensor does not depend on real gravity condition, it depends on the angular acceleration of fan. Finally, gravity affect very much to the action of sensor in all the time except microgravity condition time with 40 cycles per minute.

IPod Gen4

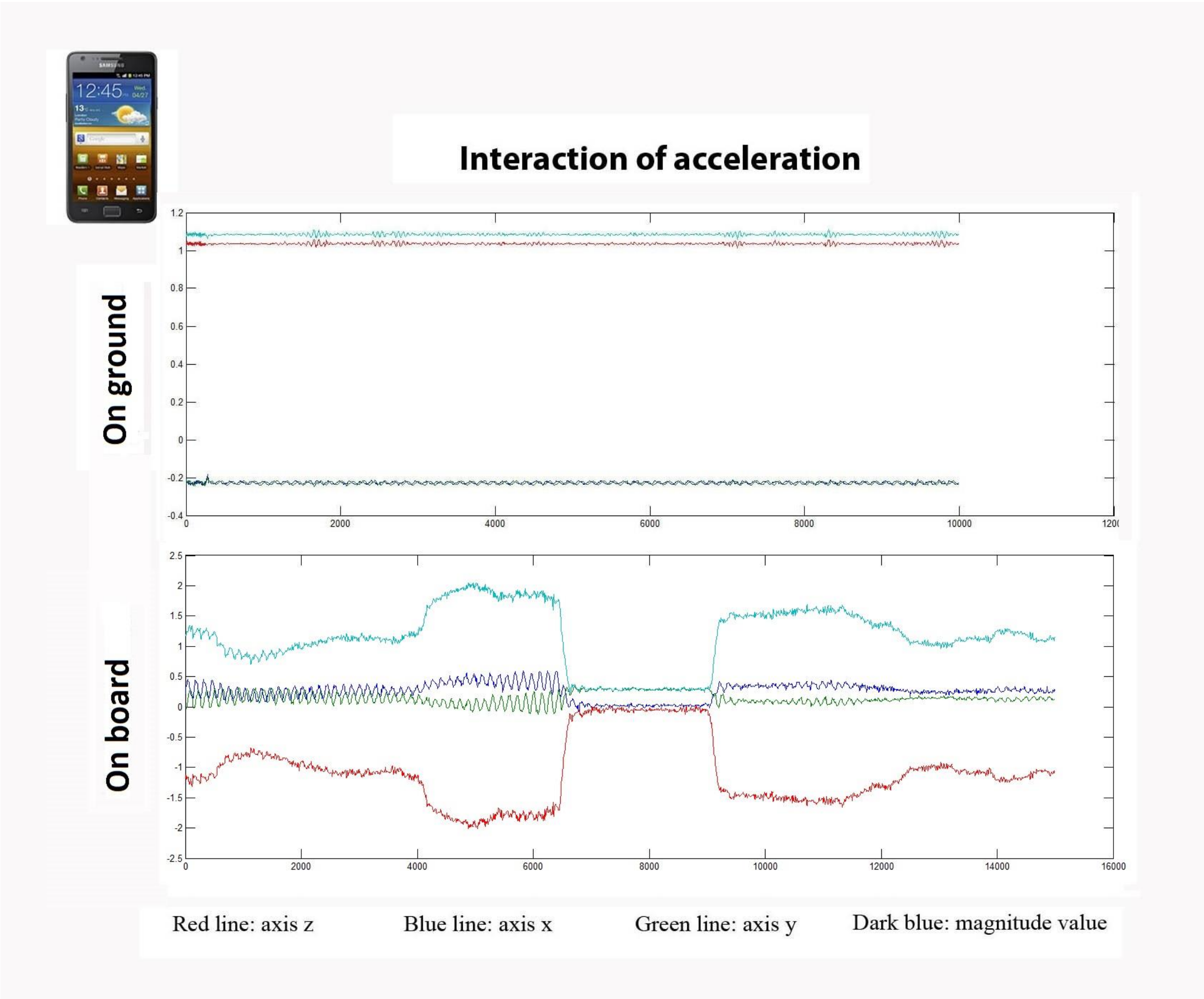


Figure 4.7: The interaction of IPod Gen4 accelerometer on ground and on board with 40 cycles per minutes

On ground: The second part of figure 4.7 presents the interaction of sensor On ground. It gives that all value of sensor in three dimensions x, y, and z is very stable. The value on the axis x (blue line) and axis y (green line) are almost close each other. Two lines go around the value 0.2G.In theory, blue line is overlap zero line, and it is difference to real experiment. The reason is IPod Gen 4 does not place completely horizontal, it was incline about 20 degree, that exists a small part of gravity is projected to the axis x, so the blue line is above than zero. Rest part of environment gravity projects to z axis, that why z axis value is very large. The value of sensor in the axis y is completely is value of centrifugal acceleration that was made when the fan rounding. With speed level is 40 cycles per minute, it make an acceleration on axis y, and it is about 0.2G. In this situation, the magnitude line is close red line and it is near 1G. Expression (1) gives the answer for this phenomenon, when the x axis value, y axis value is small, and smaller when it squared. Finally, magnitude value is most affected by environment gravity with angular velocity is 40 cycles per minutes.

On board: First part of figure shows the interaction of real On board, there is a large change of acceleration sensor with its interaction On ground. On board conditions includes three special gravity conditions which is not easy archive on ground. They are unknown gravity, hyper gravity, and micro gravity conditions. Unknown gravity condition is the time between the charging of two states: hyper gravity and normal gravity, in this time, the environment gravity charges very fast. The figure shows that the working of sensor depends on the real gravity very much. The value of sensor in axis x and axis z are the projection of real gravity to each axis, that why their value fluctuates dramatically. In theory, the blue line have to overlap or very close zero line, but it is not same as experiment. The reason for this phenomenon is that devices is not placed in flat on box, it is inclined 20 degree. So, there is a part of environment gravity projects to x axis and makes value on axis x is not zero, its value is fluctuated from 0g to 0.5G. The value of sensor in axis y is just projection of centrifugal acceleration which was created when blade rounding. The environment gravity does not affect directly to y axis value, but it affects to angular velocity. When the real gravity charges more, it makes angular acceleration is high more. Then the fan does not rotate stability that make its centrifugal changes with large intensity. The value of sensor in axis y is not small and depend on the length of centrifugal acceleration vector, its value go around between 0g and 0.4G. In unknown gravity condition, we see that the x axis value and y axis value is very close, but in hyper gravity condition part x axis value is greater than y- axis value. The reason for this phenomenon is that in hyper gravity, its value increase that makes the projection on axis increase too. Value of axis z changed following the gravity of environments, it fluctuated between 0g to 2g. Secondly, we get that the magnitude value is depend on the gravity on all the time except micro gravity time. In unknown gravity and hyper gravity, magnitude value is depend much more on the gravity, of course, in those situations the z axis value larger than x axis and y axis value very much. But in micro gravity condition, magnitude vector not be affected by z axis value, because although the value of y axis still exist in micro gravity condition but it is larger than x axis and z axis very much. With speed is 40 cycles per minute, it just makes large centrifugal acceleration and that value affects directly to magnitude value. Thirdly, we see that, the interaction of sensor is stable when the gravity stable, micro gravity for example. In micro gravity all of three lines fluctuate with very small amplitude. It is not bad ideal to use magnitude value in micro gravity, because it above than zero very much and it is not affected by environment gravity.

All above shows that, the sensor works pretty well On ground. The gotten value of IPod Gen4 motion sensor is very close to the calculated value. In the charging gravity condition, the working of sensor depends more on environment gravity. It is not ideal to using motion sensor in unknown or hyper gravity. Finally, gravity affect very much to the action of sensor in all the time expect microgravity. With 40 cycles per minute rounding, the magnitude value is affected directly from angular acceleration.

Nokia Lumia 920

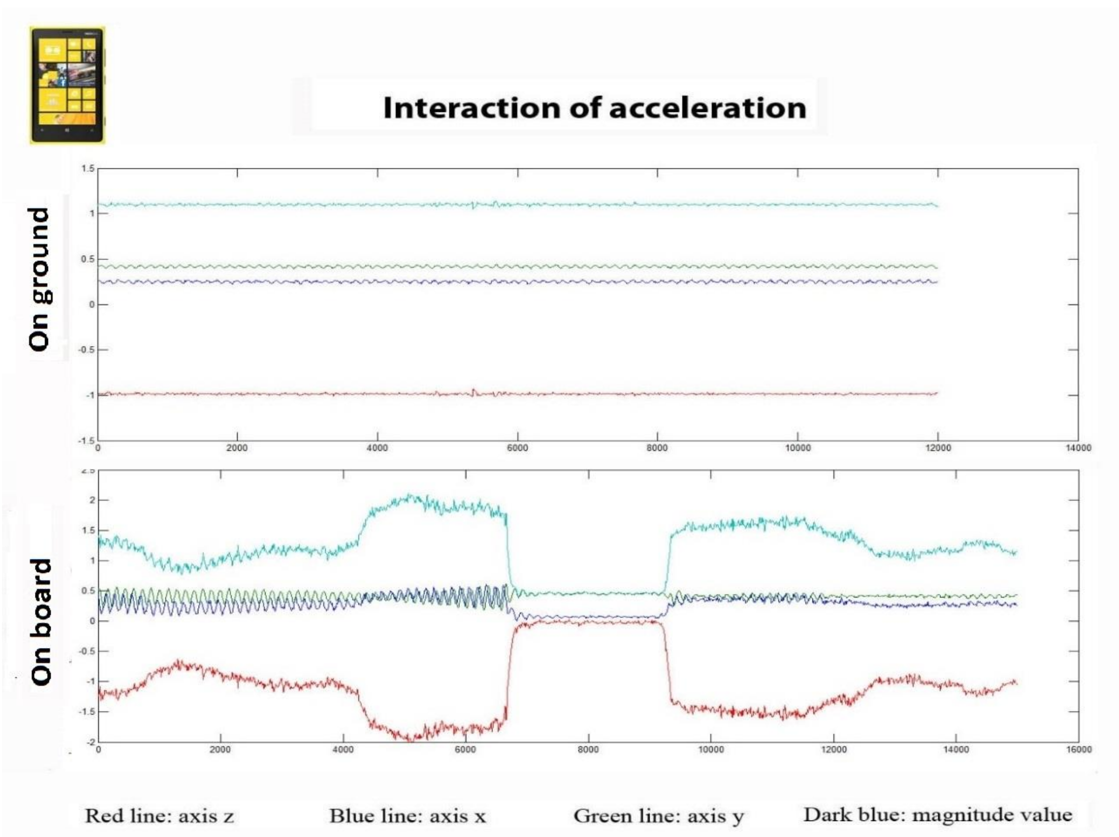


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Figure 4.8: The interaction of NOKIA Lumia 920 accelerometer on ground and on board with 40 cycles per minutes

On ground: the second part of figure 4.8 gives the presentation of accelerometer On ground. The value of sensor in three dimensions x, y, and z is very stable. The value on the axis x (blue line) and axis y (green line) are almost close each other. Two lines go around the value 0.2G. In theory, the blue line is overlap zero line because it not affected by environment gravity. But in real experiment, the Nokia phone does not place completely horizontal, it was incline about 20 degree, so there is a small part of gravity is projected to the axis x, that make its value above zero. Another part of real gravity is projected to the z axis. Its values are very high and close to 1G. The value of sensor in the axis y is completely is value of centrifugal acceleration that is made when the fan rounding. With speed level is 40 cycles per minute, it make an acceleration on axis y, and it is about 0.2G. In this situation, we can see that the magnitude value is completely close z axis value, it is near 1G and depends on real gravity very much. Expression (1) gives the answer for this phenomenon, and the x axis value, y axis value is too small, and smaller when it squared.

On board: the first chart of figure 4.8 describes the inter action of sensor On board, that includes three conditions are: unknown gravity, hyper gravity and micro gravity. Unknown gravity is time between charring form normal gravity to hyper gravity to each other. On board, there is a large change of acceleration sensor with its interaction On ground. Firstly, the working of sensor depends on the gravity very much. The value of sensor in axis x and axis z are the projection of gravity vector, that why their value fluctuate dramatically. The reason that the sensor got value in axis x is the phone was not placed in flat, it is inclined 20 degree. That why the projection of gravity in axis x is not zero, its value is fluctuated from 0g to 0.5G. Red line value is the projection of environment gravity to z axis. The value of sensor in axis y is just projection of centrifugal acceleration which was created when blade rounding. Then the fan did not rotate stability that make its centrifugal change with large intensity. The value of sensor in axis y is not small and depend on the length of centrifugal acceleration vector, its value go around between 0g and 0.4G. In the first part of graph (unknown), we see that the y axis value is larger than x axis value, but in next part x axis value is greater than y- axis value. The reason for this happen because in hyper gravity, its value increase that make the projection on x axis increase too. Value of axis z changed following the gravity of environments, it fluctuated between 0g to 2g. Secondly, we get that the magnitude value is depend on the gravity on all the time includes micro gravity time. In unknown gravity and hyper gravity, magnitude value is depend much more on the gravity, of course, in those situations the z axis value larger than x axis and y axis value very much. But in micro gravity condition, magnitude vector not be affected by z axis value, because although the value of y axis still exist in micro gravity condition and it larger than x axis and z axis very much. With speed is 40 cycles per minute, it just make larges centrifugal acceleration and that value affects directly to magnitude value. Thirdly, we see that, the interaction of sensor is stable when the gravity stable. In the graph, at micro gravity all of three lines fluctuate with very small amplitude.

All above shows that, the sensor works pretty well On ground. The gotten value of NOKIA Lumina 920 motion sensor is very close to the calculated value. In the charging gravity condition, the working of sensor depends more on environment gravity. It is not ideal to using motion sensor in unknown or hyper gravity. Finally, gravity affect very much to the action of sensor in all the time expect microgravity. With 40 cycles per minute rounding, the magnitude value is affected directly from angular acceleration.

4.1.3. Interaction of acceleration with 60 cycles per minute blades velocity

Galaxy S2

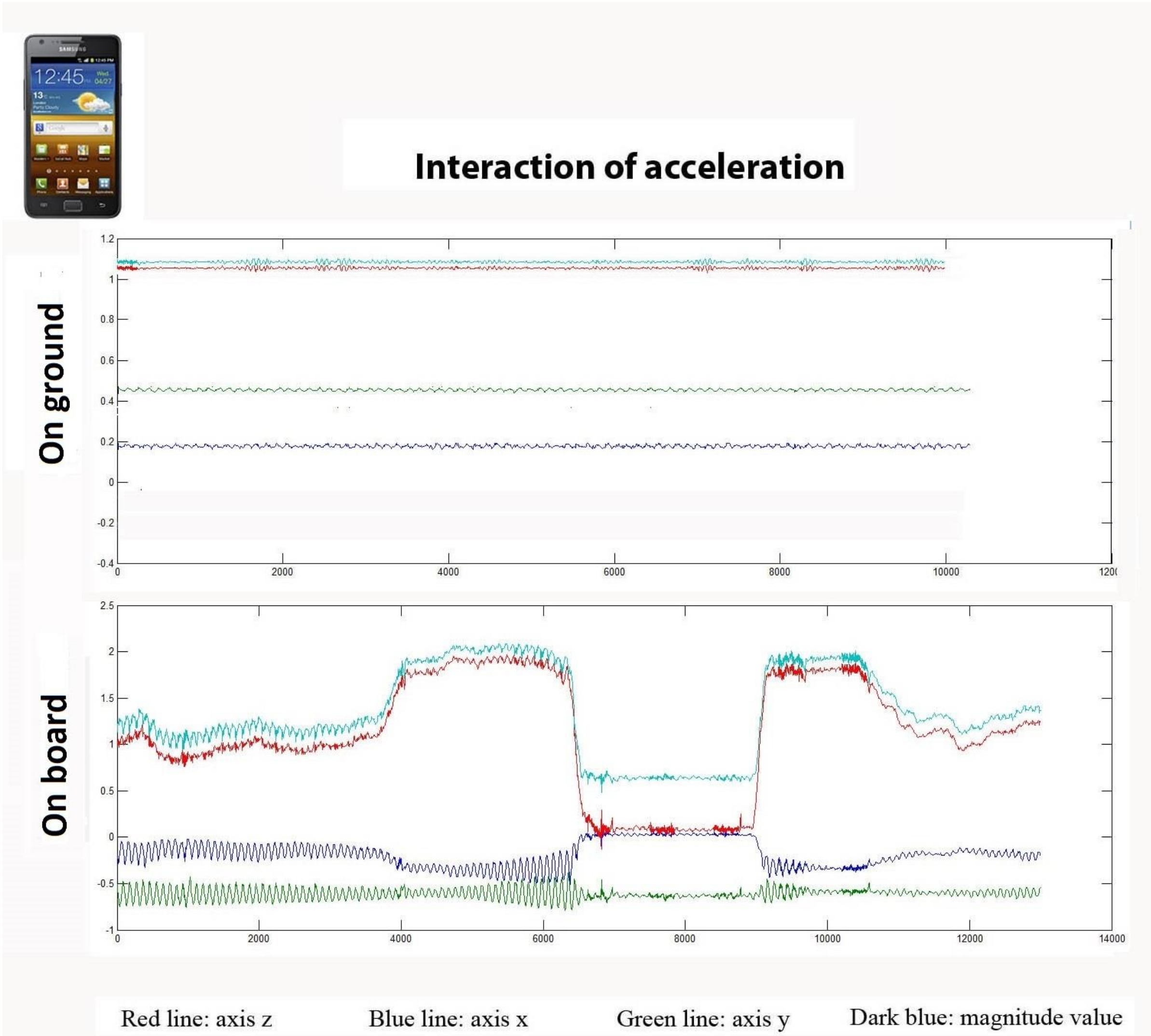

Figure 4.9: The interaction of Samsung Galaxy S2 accelerometer on ground and on board with 60 cycles per minutes

On ground: The second part of figure 4.9 presents the interaction of Sam Sung Galaxy S2 on ground: normal gravity condition (1G). Blue line represents sensor value of x axis, it is about 0.2G. There is some difference to theory that the value in axis x is zero. The reason is galaxy S2 device does not place completely horizontal on box, it is incline about 20 degree, so there is a small part of gravity is projected to the axis x, that make its value above zero. Rest part of real gravity projects to z axis. The value of sensor in the axis y is completely is value of centrifugal acceleration that was made when the fan rounding. With speed level is 60 cycles per minute, it make an acceleration on axis y, and it is about 0.5G. In this situation, we can see that the magnitude value is completely close z axis value, it is near 1G. The magnitude value is calculated using expression (1) and another hand the x axis value, y axis value is not enough large to affect the magnitude value, that makes magnitude value is close z axis value.

On board: The first part of chart shows the interaction of Galaxy S2 On board condition. On board, there are three special gravity conditions that are unknown gravity, hyper gravity and microgravity condition. The bottom is correspond to micro gravity condition, tow reaches beside are hyper gravity condition and another part is unknown gravity condition. Unknown gravity condition is the time between normal gravity and hyper gravity. In this time, the gravity changes very fast, form 1G to 2G or 2G to 1G. There is a large change of acceleration sensor with its interaction On ground. Firstly, the working sensor depends on environment gravity very much. The value of sensor in axis x and axis z are the projection of gravity vector, that why their value fluctuate dramatically. The reason that the sensor got value in axis x is the phone was not placed in flat, it is inclined 20 degree. So there is a part of real gravity is projected to axis x, its value is fluctuated from 0g to 0.5G. The value of sensor in axis y is just projection of centrifugal acceleration which is created when blade rounding. Although, environment gravity does not affect directly to y axis value, but it affects to the velocity of fan. When the gravity change the velocity changes too, that why the acceleration is quite high. The fan did not rotate stability that make its centrifugal change with large intensity. The value of sensor in axis y is not small and depend on the length of centrifugal acceleration vector, its value go around between 0,4g and 0.6G.Value of axis z changed following the gravity of environments, it fluctuated between 0g to 2g, it is projection of real gravity to x axis, that why it value is not stable. Secondly, the magnitude value is depend on the gravity on all the time except micro gravity time. In unknown gravity and hyper gravity, magnitude value is depend much more on the gravity, of course, in those situations the z axis value larger than x axis and y axis value very much. But in micro gravity condition, magnitude vector not be affected by z axis value, because although the value of x and z axis still exist in micro gravity condition but they are quite small to angular acceleration- y axis value. With speed is 60 cycles per minute, it just makes large centrifugal acceleration and that value affects directly to magnitude value. And the interaction of sensor is stable when the gravity stable, at micro gravity all of three lines fluctuate with very small amplitude.

All above give the answer that sensor works pretty well On ground, its value is quite stable. The result value of Galaxy S2 motion sensor is very close to the calculated value. On board gravity condition, the working of sensor depends on environment gravity. On unknown and hyper gravity condition, sensor value is not stable, all line fluctuates with high amplitude. In micro gravity time, the value of sensor does not depend on real gravity condition, it depends on the angular acceleration of fan. Finally, gravity affect very much to the action of sensor in all the time except microgravity condition time with 60 cycles per minute.

IPod Gen4

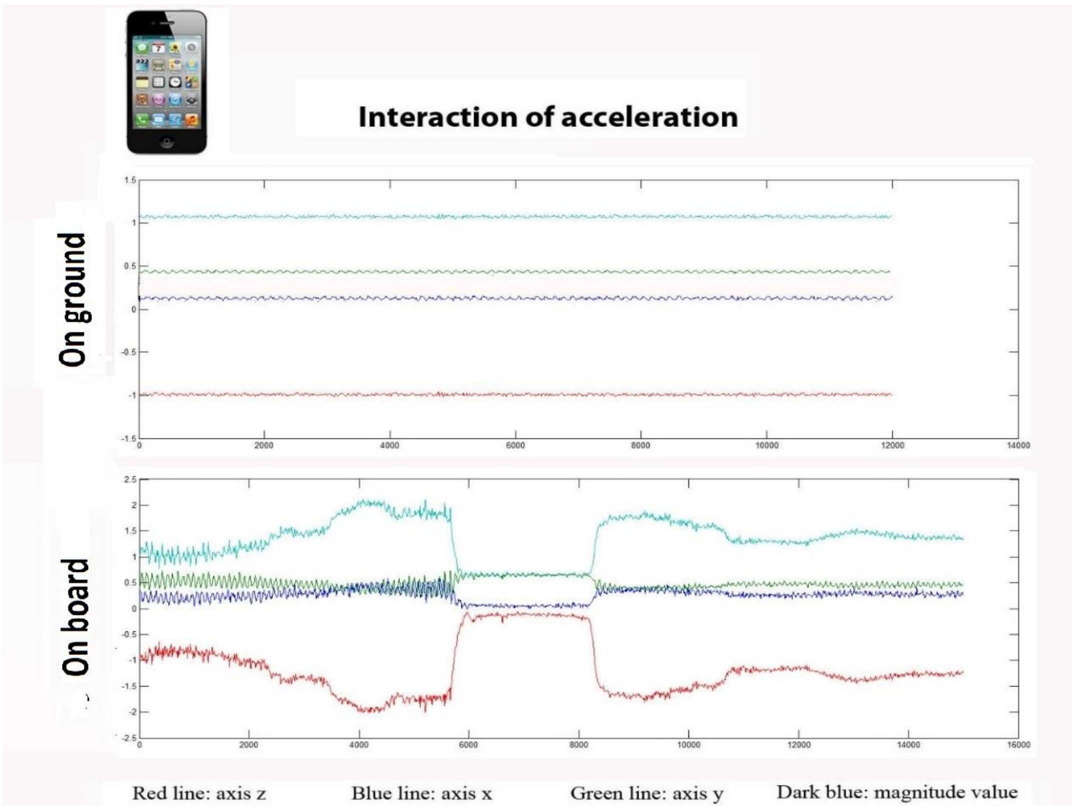

Figure 4.10: The interaction of IPod Gen4 accelerometer on ground and on board with 60 cycles per minutes

On ground: The second part of figure 4.10 presents the interaction of IPod Gen 4 on ground: normal gravity condition (1G). Blue line represents sensor value of x axis, it is about 0.2G. There is some difference to theory that the value in axis x is zero. The reason IPod device does not place completely horizontal on box, it is incline about 20 degree, so there is a small part of gravity is projected to the axis x, that make its value above zero. Rest part of real gravity projects to z axis. The value of sensor in the axis y is completely is value of centrifugal acceleration that was made when the fan rounding. With speed level is 60 cycles per minute, it make an acceleration on axis y, and it is about 0.6G. In this situation, we can see that the magnitude value is completely close z axis value, it is near 1G. The magnitude value is calculated using expression (1) and another hand the x axis value, y axis value is not enough large to affect the magnitude value, that makes magnitude value is close z axis value.

On board: The first part of chart shows the interaction of Galaxy S2 On board condition. On board, there are three special gravity conditions that are unknown gravity, hyper gravity and microgravity condition. The bottom is correspond to micro gravity condition, tow reaches beside are hyper gravity condition and another part is unknown gravity condition. Unknown gravity condition is the time between normal gravity and hyper gravity. In this time, the gravity changes very fast, form 1G to 2G or 2G to 1G. There is a large change of acceleration sensor with its interaction On ground. Firstly, the working sensor depends on environment gravity very much. The value of sensor in axis x and axis z are the projection of gravity vector, that why their value fluctuate dramatically. The reason that the sensor got value in axis x is the phone was not placed in flat, it is inclined 20 degree. So there is a part of real gravity is projected to axis x, its value is fluctuated from 0g to 0.5G. The value of sensor in axis y is just projection of centrifugal acceleration which is created when blade rounding. Although, environment gravity does not affect directly to y axis value, but it affects to the velocity of fan. When the gravity change the velocity changes too, that why the acceleration is quite high. The fan did not rotate stability that make its centrifugal change with large intensity. The value of sensor in axis y is not small and depend on the length of centrifugal acceleration vector, its value go around between 0,4g and 0.6G.Value of axis z changed following the gravity of environments, it fluctuated between 0g to 2g, it is projection of real gravity to x axis, that why it value is not stable. Secondly, the magnitude value is depend on the gravity on all the time except micro gravity time. In unknown gravity and hyper gravity, magnitude value is depend much more on the gravity, of course, in those situations the z axis value larger than x axis and y axis value very much. But in micro gravity condition, magnitude vector not be affected by z axis value, because although the value of x and z axis still exist in micro gravity condition but they are quite small to angular acceleration- y axis value. With speed is 60 cycles per minute, it just makes large centrifugal acceleration and that value affects directly to magnitude value. And the interaction of sensor is stable when the gravity stable, at micro gravity all of three lines fluctuate with very small amplitude.

All above give the answer that sensor works pretty well On ground, its value is quite stable. The result value of IPod Gen 4 motion sensor is very close to the calculated value. On board gravity condition, the working of sensor depends on environment gravity. On unknown and hyper gravity condition, sensor value is not stable, all line fluctuates with high amplitude. In micro gravity time, the value of sensor does not depend on real gravity condition, it depends on the angular acceleration of fan. Finally, gravity affect very much to the action of sensor in all the time except microgravity condition time with 60 cycles per minute.

Nokia Lumia 920

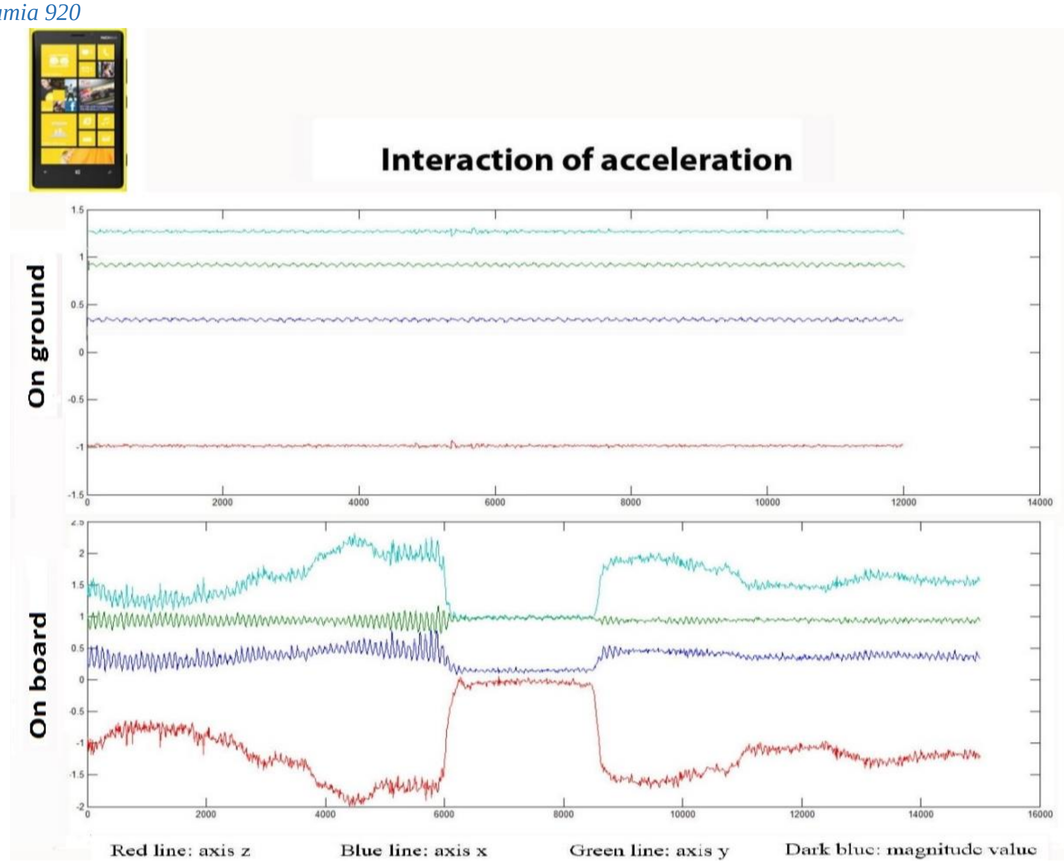

Figure 4.11: The interaction of NOKIA Lumia 920 accelerometer on ground and on board with 60 cycles per minutes

On ground: The first part of figure 4.11 presents the interaction of NOKIA Lumia 920 on ground: normal gravity condition (1G). Blue line represents sensor value of x axis, it is about 0.4G. There is some difference to theory that the value in axis x is zero. The reason device does not place completely horizontal on box, it is incline about 20 degree, so there is a small part of gravity is projected to the axis x, that make its value above zero. Rest part of real gravity projects to z axis. The value of sensor in the axis y is completely is value of centrifugal acceleration that was made when the fan rounding. With speed level is 60 cycles per minute, it make an acceleration on axis y, and it gets value is about 0.9G. In this situation, we can see that the magnitude value is completely close z axis value, it is near 1G. The magnitude value is calculated using expression (1) and another hand the x axis value, y axis value is enough large to affect the magnitude value, that makes magnitude value is far z axis value and it very large about 1.4G. It interaction gets some difference to Samsung Galaxy S2 and IPod Gen 4.

On board: The first part of chart shows the interaction of NOKIA Lumia 920 On board condition. On board, there are three special gravity conditions that are unknown gravity, hyper gravity and microgravity condition. The bottom is correspond to micro gravity condition, tow reaches beside are hyper gravity condition and another part is unknown gravity condition. Unknown gravity condition is the time between normal gravity and hyper gravity. In this time, the gravity changes very fast, form 1G to 2G or 2G to 1G. There is a large change of acceleration sensor with its interaction On ground. Firstly, the working sensor depends on environment gravity very much. The value of sensor in axis x and axis z are the projection of gravity vector, that why their value fluctuate dramatically. The reason that the sensor got value in axis x is the phone was not placed in flat, it is inclined 20 degree. So there is a part of real gravity is projected to axis x, its value is fluctuated from 0g to 0.5G. The value of sensor in axis y is just projection of centrifugal acceleration which is created when blade rounding. Although, environment gravity does not affect directly to y axis value, but it affects to the velocity of fan. When the gravity change the velocity changes too, that why the acceleration is quite high. The fan did not rotate stability that make its centrifugal change with large intensity. The value of sensor in axis y is not small and depend on the length of centrifugal acceleration vector, its value go around between 0.9g and 1.1G.Value of axis z changed following the gravity of environments, it fluctuated between 0g to 2g, it is projection of real gravity to x axis, that why it value is not stable.. In unknown gravity and hyper gravity, the magnitude value is depends on both real gravity and angular velocity, the angular gets high value when it is near 1G line, it is enough large to affect magnitude value. But in micro gravity condition, magnitude vector not be affected by z axis value, because although the value of x and z axis still exist in micro gravity condition but they are quite small to angular acceleration- y axis value. With speed is 60 cycles per minute, it just makes large centrifugal acceleration and that value affects directly to magnitude value. And the interaction of sensor is stable when the gravity stable, at micro gravity all of three lines fluctuate with very small amplitude.

All above give the answer that sensor interaction gets some difference to theory and to the Galaxy S2 and IPod devices. On board gravity condition, the working of sensor depends on both environment gravity and angular acceleration. On unknown and hyper gravity condition, sensor value is not stable, all line fluctuates with high amplitude. In micro gravity time, the value of sensor does not depend on real gravity condition, it depends on the angular acceleration of fan. Finally, gravity affect very much to the action of sensor in all the time except microgravity condition time with 60 cycles per minute.

4.2. Interaction of Gyroscope

4.2.1. Interaction of Gyroscope with 20 cycles per minute blades velocity

Samsung Galaxy S2

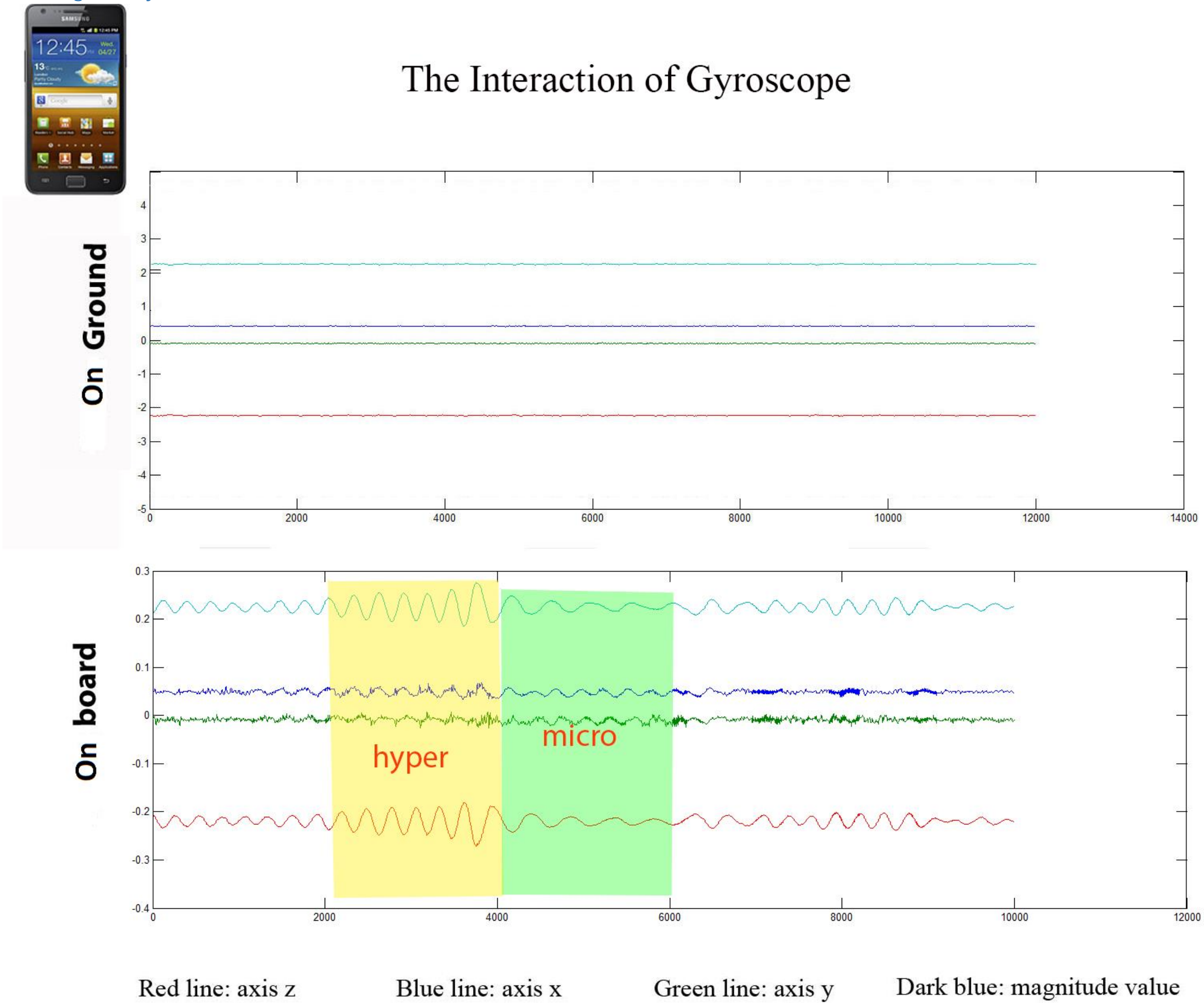

Figure 4.12: The interaction of Samsung Galaxy S2 gyroscope on ground and on board with 20 cycles per minute.

On ground: the first part of figure 4.12 shows the inter action of sensor On ground: normal gravity condition (1G). Three value of gyroscope sensor is very stable in the normal gravity condition, all of three axis lines fluctuate with a very small amplitude which near zero. Because the fan rotates around z-axis so the phone sensor will only gets the data of z-axis in theory. But there are some differences to real experiment. The axis x value was always larger than zero; it is not same as in theory result. The reason for this happen is the mobile did not fix completely horizontal in the box, it was incline about 20 degree. So in running time of experiment, when rotating around z-axis, it also rotates around axis x. That make x axis value is larger than zero. The green line (axis y) is very stable, it is completely zero because there is no any motion around axis y in all three conditions. Y axis interaction is same the interaction by theory. The red line (axis z) got value around 2.0 rad/s, it fluctuates with a very small magnitude. With 20 cycles per minute implies calculate the expected z axis acceleration that is about 2.1 rad /s. So z axis data very close expected result.

On board: The second part of figure represents the interaction of sensor On board that includes three special conditions, which is not easy to reach on ground: unknown gravity, hyper gravity (yellow area) and micro gravity (green area) that show in figure. There are some differences between on board and on ground data. It is easy to get that, there is a motion around x axis, but it is very small and that motion did not be affected by gravity, the gravity affected in axis z and axis y. Y axis value is still close to zero, it is fine because there is no motions that go around y axis with the way the mobile is placed into the box. Two line data are same with the expected result. In the graph, we see that the red line will go fluctuate around 2.1 most the time of experiment. In unknown gravity time its value is still stable but in hyper gravity condition, x axis value changes very fast. The red line fluctuates dramatically with high amplitude. The reason for this phenomenon is that the gravity is high, that affects to the monitor that control velocity of fan. When gravity increase it makes velocity charges fast. Another hand, the calculated value of z axis is also 2.1 (it same 20 cycles per minute), so most the time of experiment the sensor got the right data. We can see that there is a dramatically fluctuation of red line in the experiment time. In the micro gravity condition, red line very smooth. It mean that, in this situation the gravity does not affect to working of gyroscope. All time of experiment the magnitude is affected by the value of red line, it right because the x-axis and y-axis value are too small and using expression (1) to get the magnitude value.

All above shows that, the gyroscope working well in both on board and on ground. Its working is not depend on the gravity and its working is good on micro gravity.

IPod Gen4

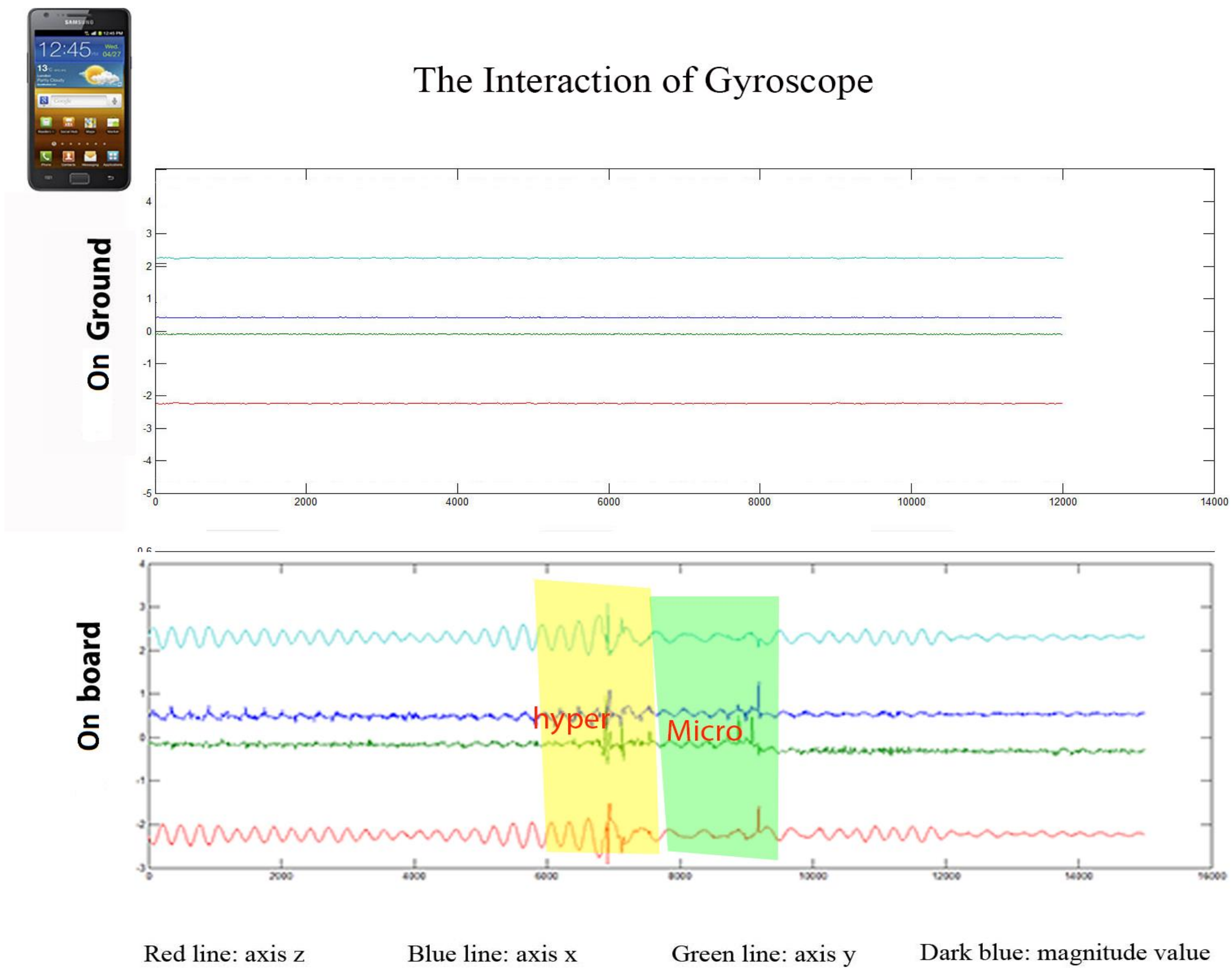

Figure 4.13: The interaction of IPod Gen 4 gyroscope on ground and on board with 20 cycles per minute.

On ground: the first part of figure 4.13 shows the inter action of sensor On ground: normal gravity condition (1G). Three value of gyroscope sensor is very stable in the normal gravity condition; all of three axis lines fluctuate with very small amplitude, which is near zero. By the way devices is fixed into boxes, the fan rotates around z axis so the phone will only get the data of z axis in theory. But there are some difference to real experiment. The axis x value was always larger than zero, it is not same as expected result. The reason for this happen is the mobile did not fix completely horizontal in the box, it was incline about 20 degree. So in running time of experiment, besides rotating around z axis, it rotates around axis x. That make x axis value is larger than zero. The green line (axis y) is very stable, it complete zero because there is no any motion around axis y. Y axis interaction is same the interaction by theory. The red line (axis z) got value around 2.0 rad/s, it fluctuates with a very small magnitude. With 20 cycles per minute implies calculate the expected z axis acceleration that is about 2.1 rad /s. So z axis data very close expected result.

On board: The second part of figure represents the interaction of sensor On board condition that includes three special conditions which is not easy to reach on ground: unknown gravity, hyper gravity (yellow area) and micro gravity (green area) that show in figure. There are some differences between on board and on ground data. It is easy to get that, there is a motion around x axis, but it is very small and that motion did not be affected by gravity, the gravity affected in axis z and axis y. Y axis value is still close to zero, it is fine because there is no motions that go around y axis with the way the mobile is placed into the box. Two line data are same with the expected result. In the graph, we see that the red line will go fluctuate around 2.1 most the time of experiment. In unknown gravity time its value is still stable but in hyper gravity condition, x axis value changes very fast. The red line fluctuates dramatically with high amplitude. The reason for this phenomenon is that the gravity is high, that affects to the monitor that control velocity of fan. When gravity increase it makes velocity charges fast. Another hand, the calculated value of z axis is also 2.1 (it same 20 cycles per minute), so most the time of experiment the sensor got the right data. We can see that there is a dramatically fluctuation of red line in the experiment time. In the micro gravity condition, red line very smooth. It mean that, in this situation the gravity does not affect to working of gyroscope. All time of experiment the magnitude is affected by the value of red line, it right because the x axis and y axis value is too small and using expression (1) to get the magnitude value.

All above shows that, the gyroscope working very well in both on board and on ground. Its working is not depend on the gravity and its working is good on micro gravity.

Nokia Lumia 920

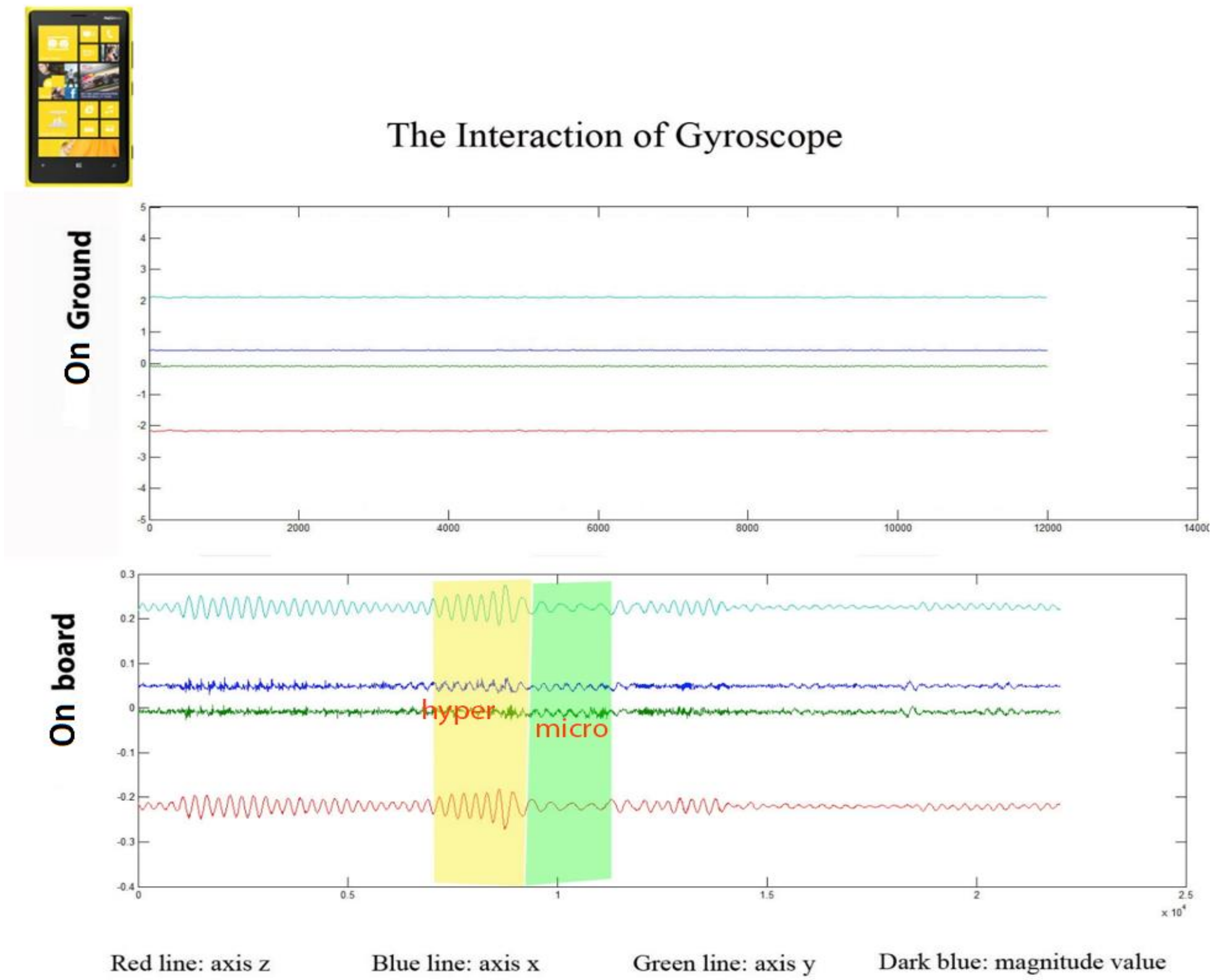

Figure 4.13: The interaction of Nokia Lumia 920 gyroscope on ground and on board with 20 cycles per minute.

On ground: the first part of figure 4.13 shows the inter action of sensor On ground: normal gravity condition (1G). Three value of gyroscope sensor is very stable in the normal gravity condition, all of three axis lines fluctuate with a very small amplitude which near zero. By the way devices are fixed into boxes, the fan rotates around z-axis so the phone will only get the data of z-axis in theory. But there are some difference to real experiment. The axis x value was always larger than zero, it is not same as expected result. The reason for this happen is the mobile did not fix completely horizontal in the box, it was incline about 20 degree. So in running time of experiment, besides rotating around z axis, it rotates around axis x. That make x axis value is larger than zero. The green line (axis y) is very stable, it complete zero because there is no any motion around axis y. Y axis interaction is same the interaction by theory. The red line (axis z) got value around 2.0 rad/s, it fluctuates with a very small magnitude. With 20 cycles per minute implies calculate expected z-axis acceleration that is about 2.1 rad /s. So z axis data very close expected result.

On board: The second part of figure represents the interaction of sensor On board that includes three special conditions, which is not easy to reach on ground: unknown gravity, hyper gravity (yellow area) and micro gravity (green area) that show in figure. There are some differences between on board and on ground data. It is easy to get that, there is a motion around x axis, but it is very small and that motion did not be affected by gravity, the gravity affected in axis z and axis y. Y axis value is still close to zero, it is fine because there is no motions that go around y axis with the way the mobile is placed into the box. Two line data are same with the expected result. In the graph, we see that the red line will go fluctuate around 2.1 most the time of experiment. In unknown gravity time its value is still stable but in hyper gravity condition, x axis value changes very fast. The red line fluctuates dramatically with high amplitude. The reason for this phenomenon is that the gravity is high, that affects to the monitor that control velocity of fan. When gravity increase it makes velocity charges fast. Another hand, the calculated value of z axis is also 2.1 (it same 20 cycles per minute), so most the time of experiment the sensor got the right data. We can see that there is a dramatically fluctuation of red line in the experiment time. In the micro gravity condition, red line very smooth. It mean that, in this situation the gravity does not affect to working of gyroscope. All time of experiment the magnitude is affected by the value of red line, it right because the x axis and y axis value is too small and using expression (1) to get the magnitude value.

All above shows that, the gyroscope working very in both on board and on ground. Its magnitude is not depend on the gravity and its working is good on micro gravity.

4.2.2. Interaction of Gyroscope with 40 cycles per minute blades velocity

Samsung Galaxy S2

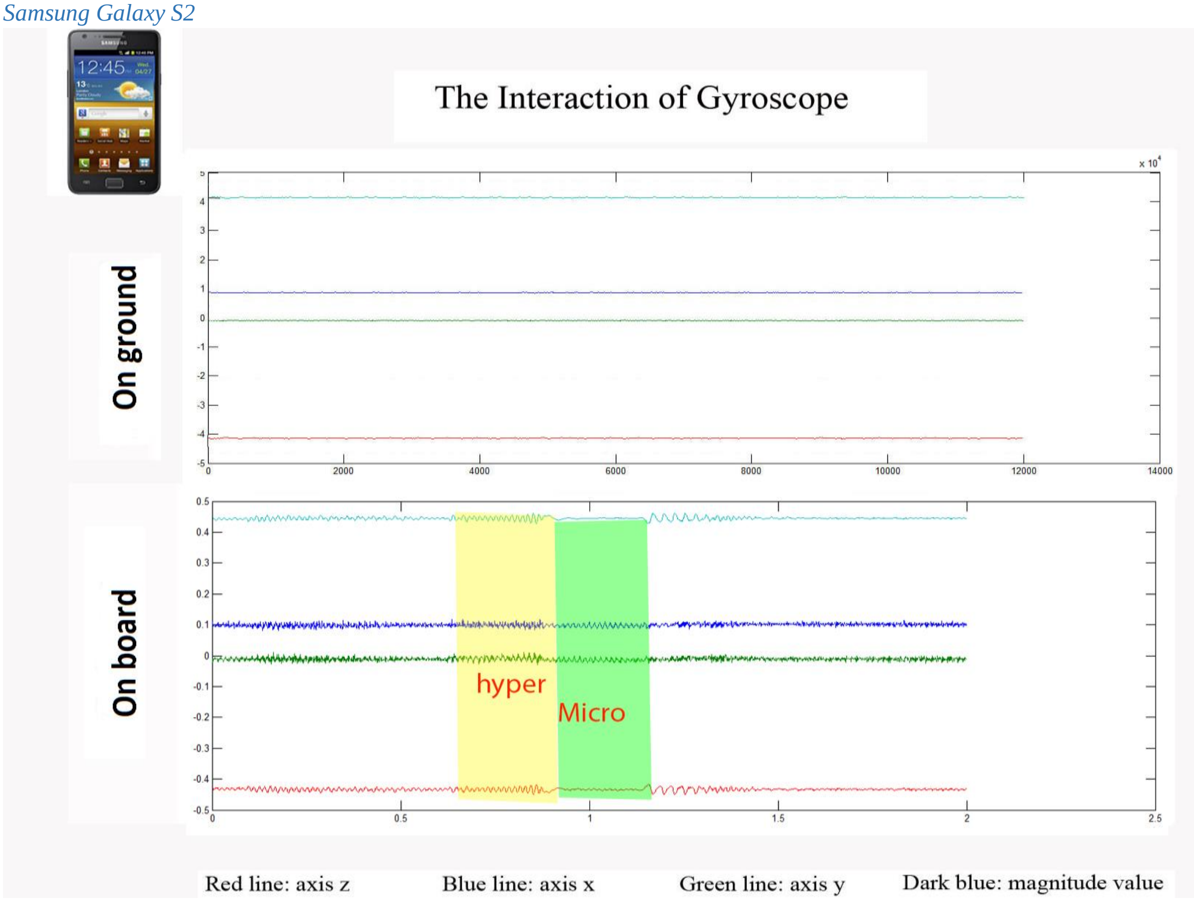

Figure 4.14: The interaction of Samsung Galaxy S2 gyroscope on ground and on board with 40 cycles per minute.

On ground: the second part of figure 4.14 shows the inter action of sensor On ground: normal gravity condition (1G). Three value of gyroscope sensor is very stable in the normal gravity condition, all of three axis lines fluctuate with a very small amplitude which near zero. By the way devices is fixed into boxes, the fan rotates around z axis so the phone will only get the data of z axis in theory. But there are some difference to real experiment. The axis x value was always larger than zero, it is not same as expected result. The reason for this happen is the mobile did not fix completely horizontal in the box, it was incline about 20 degree. So in running time of experiment, besides rotating around z axis, it rotates around axis x. That make x axis value is larger than zero. The green line (axis y) is very stable, it complete zero because there is no any motion around axis y. Y axis interaction is same the interaction by theory. The red line (axis z) got value around 4.0 rad/s, it fluctuates with a very small magnitude. With 40 cycles per minute implies calculate the expected z axis acceleration that is about 4.1 rad /s. So z axis data very close expected result.

On board: The first part of figure represents the interaction of sensor On board that includes three special conditions, which is not easy to reach on ground: unknown gravity, hyper gravity (yellow area) and micro gravity (green area) that show in figure. There are some differences between on board and on ground data. It is easy to get that, there is a motion around x axis, but it is very small and that motion did not be affected by gravity, the gravity affected in axis z and axis y. Y axis value is still close to zero, it is fine because there is no motions that go around y axis with the way the mobile is placed into the box. Two line data are same with the expected result. In the graph, we see that the red line will go fluctuate around 4.1 most the time of experiment. In unknown gravity time its value is still stable but in hyper gravity condition, x axis value changes very fast. The red line fluctuates with small amplitude; it is difference to its action with velocity level is 20 cycles per minute. The reason for this phenomenon is that when angular velocity is high, the affects of gravity to the monitor that control velocity of fan reduce. Another hand, the calculated value of z axis is also 4.1 (it same 40 cycles per minute), so most the time of experiment the sensor got the right data. We can see that there is a small fluctuation of red line in the experiment time. In the micro gravity condition, red line very smooth. It mean that, in this situation the gravity does not affect to working of gyroscope. All time of experiment the magnitude is affected by the value of red line, it right because the x-axis and y-axis value is too small and using expression (1) to get the magnitude value.

All above shows that, the gyroscope working very in both on board and on ground. Its magnitude is not depend on the gravity and its working is good on micro gravity.

IPod Gen4

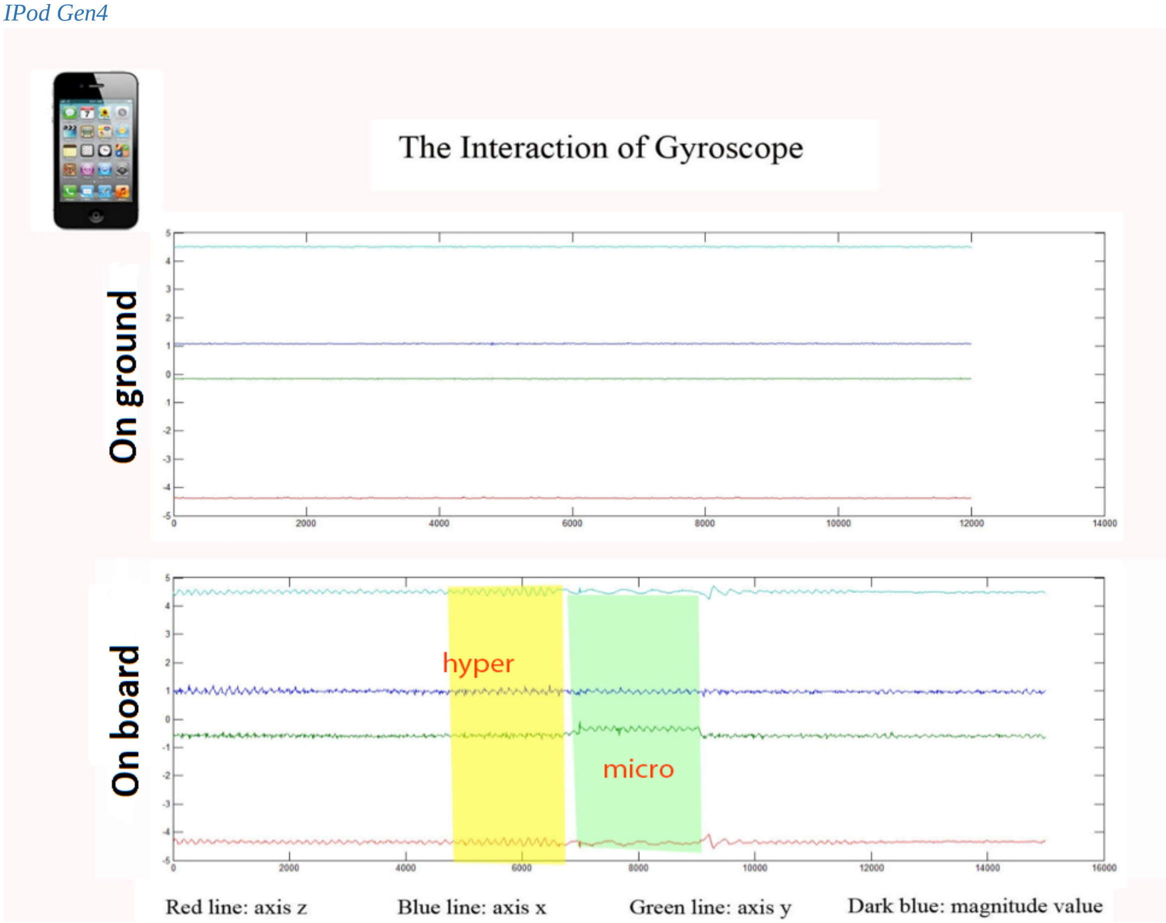

Figure 4.15: The interaction of IPod Gen 4 gyroscope on ground and on board with 40 cycles per minute

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On ground: the first part of figure 4.15 shows the inter action of sensor On ground: normal gravity condition (1G). Three value of gyroscope sensor is very stable in the normal gravity condition, all of three axis lines fluctuate with a very small amplitude which near zero. By the way devices is fixed into boxes, the fan rotates around z axis so the phone will only get the data of z axis in theory. But there are some difference to real experiment. The axis x value was always larger than zero, it is not same as expected result. The reason for this happen is the mobile did not fix completely horizontal in the box, it was incline about 20 degree. So in running time of experiment, besides rotating around z axis, it rotates around axis x. That make x axis value is larger than zero. The green line (axis y) is very stable, it complete zero because there is no any motion around axis y. Y axis interaction is same the interaction by theory. The red line (axis z) got value around 4.0 rad/s, it fluctuates with a very small magnitude. With 40 cycles per minute implies calculate the expected z axis acceleration that is about 4.1 rad /s. So z axis data very close expected result.

On board: The second part of figure represent the interaction of sensor On board condition that includes three special conditions which is not easy to reach on ground: unknown gravity, hyper gravity (yellow area) and micro gravity (green area) that show in figure. There are some differences between on board and on ground data. It is easy to get that, there is a motion around x axis, but it is very small and that motion did not be affected by gravity, the gravity affected in axis z and axis y. Y axis value is still close to zero, it is fine because there is no motions that go around y axis with the way the mobile is placed into the box. Two line data are same with the expected result. In the graph, we see that the red line will go fluctuate around 4.0 most the time of experiment. In unknown gravity time its value is still stable but in hyper gravity condition, x-axis value changes with a small amplitude. The phenomenon is difference to 20 cycles per minute. When angular velocity increases the affect of gravity to monitor that control blades speed reduces. So that why three lines look totally stable in all time. Another hand, the calculated value of z-axis is also 4.1 (it same 40 cycles per minute), so most the time of experiment the sensor got the right data. In the micro gravity condition, red line very smooth. It mean that, in this situation the gravity does not affect to working of gyroscope. All time of experiment the magnitude is affected by the value of red line, it right because the x axis and y axis value is too small and using expression (1) to get the magnitude value.

All above shows that, the gyroscope working very in both on board and on ground. Its magnitude is not depend on the gravity and its working is good on micro gravity.

Nokia Lumia 920

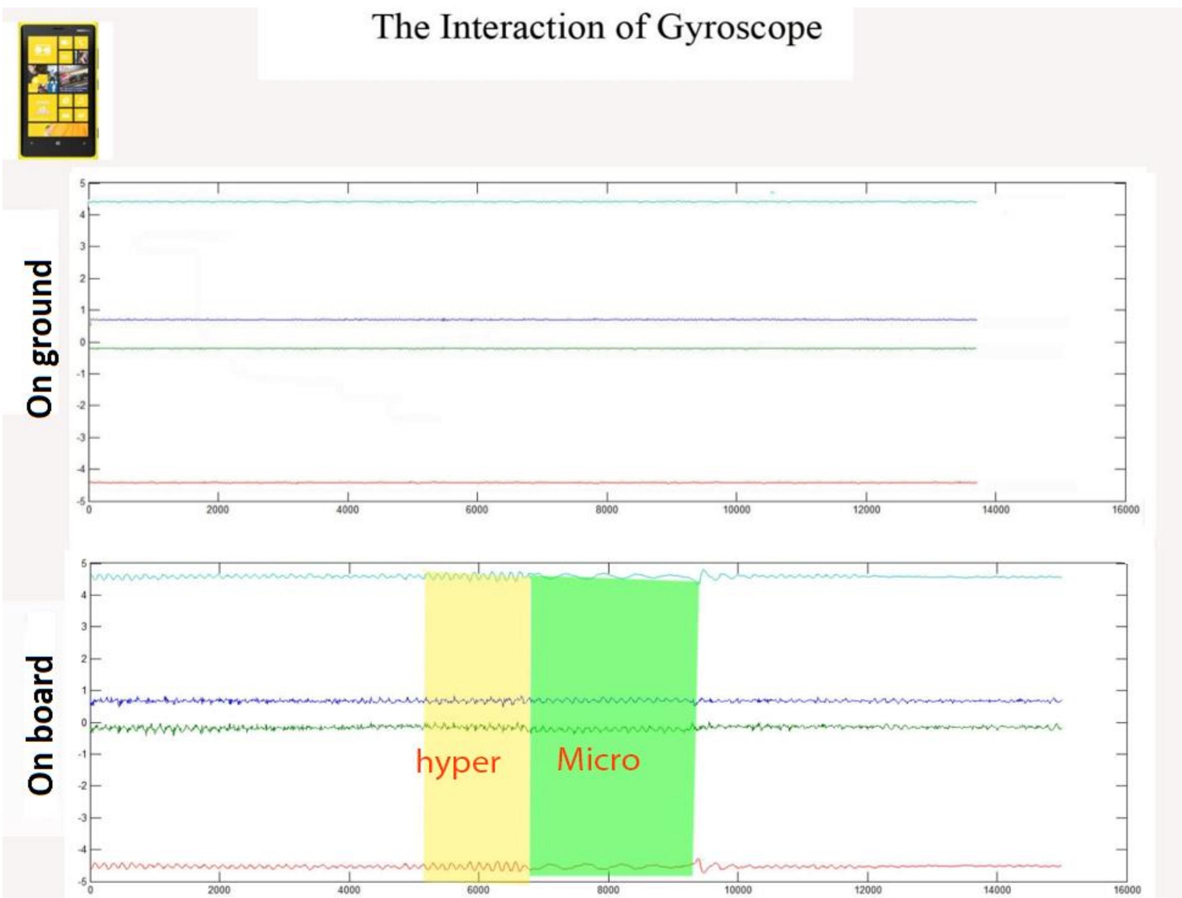

Figure 4.16: The interaction of Nokia Lumia 920 gyroscope on ground and on board with 40 cycles per minute.

On ground: the second part of figure 4.16 shows the inter action of sensor On ground: normal gravity condition (1G). Three value of gyroscope sensor is very stable in the normal gravity condition, all of three axis lines fluctuate with a very small amplitude which near zero. By the way devices is fixed into boxes, the fan rotates around z axis so the phone will only get the data of z axis in theory. But there are some difference to real experiment. The axis x value was always larger than zero, it is not same as expected result. The reason for this happen is the mobile did not fix completely horizontal in the box, it was incline about 20 degree. So in running time of experiment, besides rotating around z axis, it rotates around axis x. That make x axis value is larger than zero. The green line (axis y) is very stable, it complete zero because there is no any motion around axis y. Y axis interaction is same the interaction by theory. The red line (axis z) got value around 4.0 rad/s, it fluctuates with a very small magnitude. With 40 cycles per minute implies calculate the expected z axis acceleration that is about 4.1 rad /s. So z axis data very close expected result.

On board: The second part of figure represent the interaction of sensor On board condition that includes three special conditions which is not easy to reach on ground: unknown gravity, hyper gravity (yellow area) and micro gravity (green area) that show in figure. There are some differences between on board and on ground data. It is easy to get that, there is a motion around x axis, but it is very small and that motion did not be affected by gravity, the gravity affected in axis z and axis y. Y axis value is still close to zero, it is fine because there is no motions that go around y axis with the way the mobile is placed into the box. Two line data are same with the expected result. In the graph, we see that the red line will go fluctuate around 4.0 most the time of experiment. In unknown gravity time its value is still stable but in hyper gravity condition, x-axis value changes with a small amplitude. The phenomenon is difference to 20 cycles per minute. When angular velocity increases the affect of gravity to monitor that control blades speed reduces. So that why three lines look totally stable in all time. Another hand, the calculated value of z-axis is also 4.1 (it same 40 cycles per minute), so most the time of experiment the sensor got the right data. In the micro gravity condition, red line very smooth. It means that, in this situation the gravity does not affect to working of gyroscope. All time of experiment the magnitude is affected by the value of red line, it right because the x-axis and y-axis value is too small and using expression (1) to get the magnitude value.

All above shows that, the gyroscope working very in both on board and on ground. Its magnitude is not depend on the gravity and its working is good on micro gravity.

4.2.3.Interaction of Gyroscope with 60 cycles per minute blades velocity

Samsung Galaxy S2

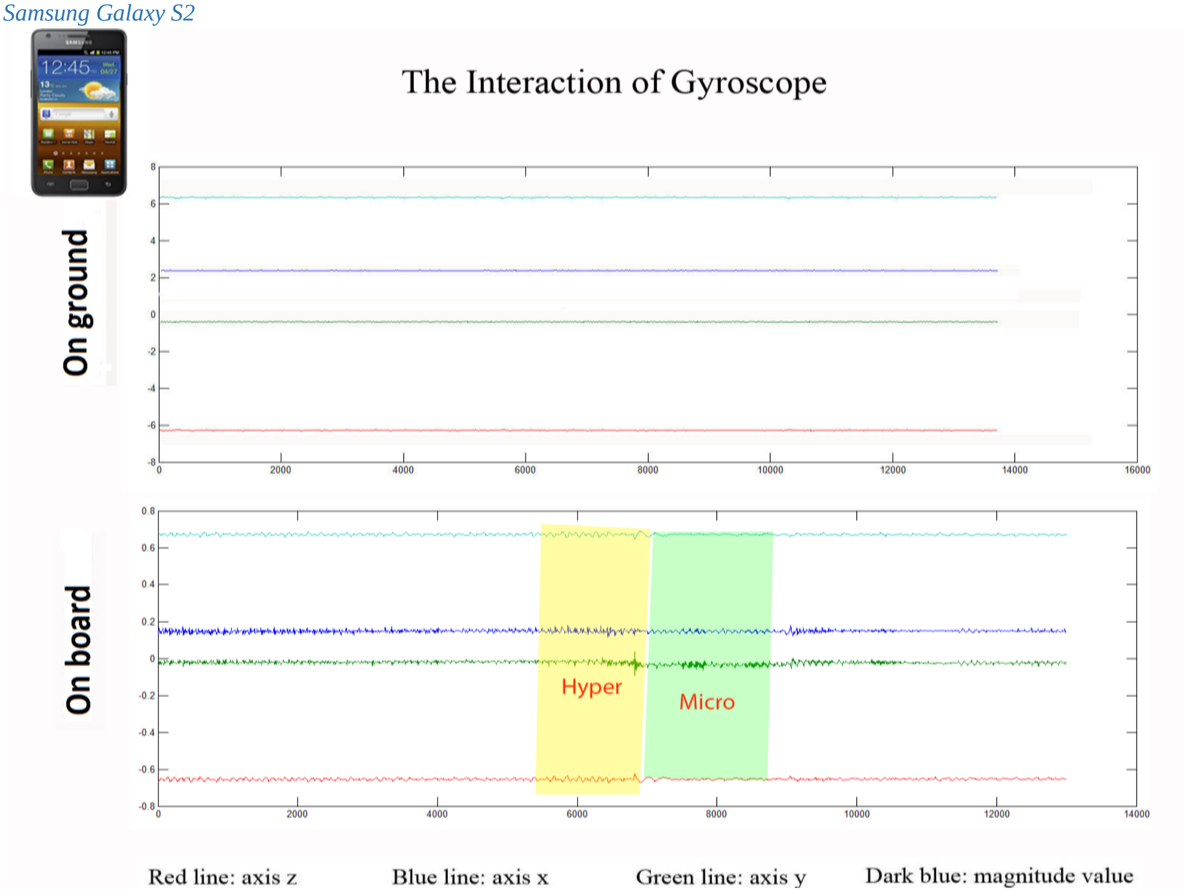

Figure 4.17: The interaction of Samsung Galaxy S2 gyroscope on ground and on board with 60 cycles per minute.

On ground: the first part of figure 4.17 shows the interaction of sensor On ground: normal gravity condition (1G). Three value of gyroscope sensor is very stable in the normal gravity condition, all of three axis lines fluctuate with a very small amplitude which near zero. By the way devices is fixed into boxes, the fan rotates around z axis so the phone will only get the data of z axis in theory. But there are some difference to real experiment. The axis x value was always larger than zero, it is not same as expected result. The reason for this happen is the mobile did not fix completely horizontal in the box, it was incline about 20 degree. So in running time of experiment, besides rotating around z axis, it rotates around axis x. That make x axis value is larger than zero. The green line (axis y) is very stable, it complete zero because there is no any motion around axis y. Y axis interaction is same the interaction by theory. The red line (axis z) got value around 6.1 rad/s, it fluctuates with a very small magnitude. With 60 cycles per minute implies calculate the expected z-axis acceleration that is about 6.2 rad /s. So z axis data very close expected result.

On board: The second part of figure shows the interaction of sensor On board condition that includes three special conditions which is not easy to reach on ground: unknown gravity, hyper gravity (yellow area) and micro gravity (green area) that show in figure. There are some differences between on board and on ground data. It is easy to get that, there is a motion around x axis, but it is very small and that motion did not be affected by gravity, the gravity affected in axis z and axis y. Y axis value is still close to zero, it is fine because there is no motions that go around y axis with the way the mobile is placed into the box. Two line data are same with the expected result. In the graph, we see that the red line will go fluctuate around 6.1 most the time of experiment. In unknown gravity time its value is still stable. In hyper gravity condition, the red line fluctuates with very small amplitude. When the angular velocity increases, the affect from the gravity to motor that control blades speed reduces, it difference when velocity is 20 or 40 cycle per minute. Another hand, the calculated value of z-axis is also 6.2 (it same 60 cycles per minute), so most the time of experiment the sensor got the right data. We can see that there is a small fluctuation of red line in all experiment time. In the micro gravity condition, red line very smooth. It mean that, in this situation the gravity does not affect to working of gyroscope. All time of experiment the magnitude is affected by the value of red line, it right because the x axis and y axis value is too small and using expression (1) to get the magnitude value.

All above shows that, the gyroscope working very in both on board and on ground. Its magnitude is not depend on the gravity and its working is good on micro gravity.

IPod Gen4

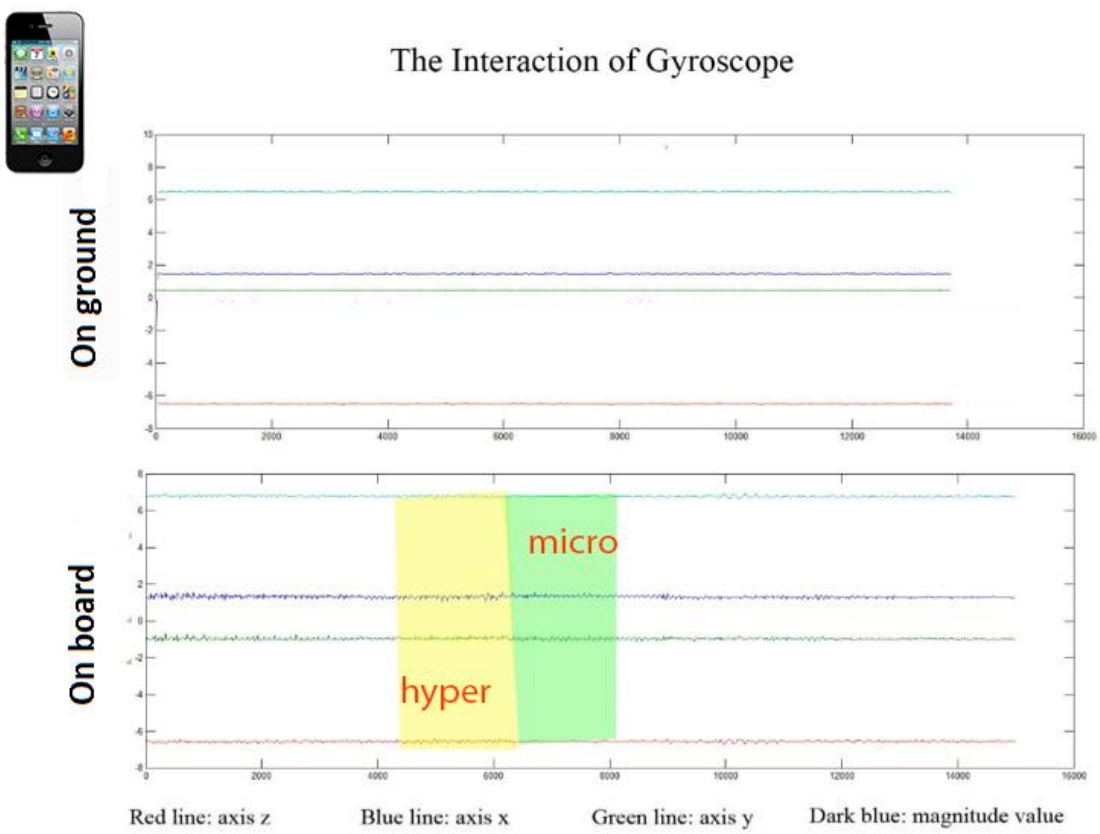

Figure 4.18: The interaction of IPod Gen 4 gyroscope on ground and on board with 60 cycles per minute

On ground: the first part of figure 4.18 shows the inter action of sensor On ground: normal gravity condition (1G). Three value of gyroscope sensor is very stable in the normal gravity condition, all of three axis lines fluctuate with a very small amplitude which near zero. By the way devices is fixed into boxes, the fan rotates around z axis so the phone will only get the data of z axis in theory. But there are some difference to real experiment. The axis x value was always larger than zero, it is not same as expected result. The reason for this happen is the mobile did not fix completely horizontal in the box, it was incline about 20 degree. So in running time of experiment, besides rotating around z axis, it rotates around axis x. That make x axis value is larger than zero. The green line (axis y) is very stable, it complete zero because there is no any motion around axis y. Y axis interaction is same the interaction by theory. The red line (axis z) got value around 6.0 rad/s, it fluctuates with a very small magnitude. With 60 cycles per minute implies calculate the expected z axis acceleration that is about 6.1 rad /s. So z axis data very close expected result.

On board: The second part of figure shows the interaction of sensor On board condition that includes three special conditions which is not easy to reach on ground: unknown gravity, hyper gravity (yellow area) and micro gravity (green area) that show in figure. There are some differences between on board and on ground data. It is easy to get that, there is a motion around x axis, but it is very small and that motion did not be affected by gravity, the gravity affected in axis z and axis y. Y axis value is still close to zero, it is fine because there is no motions that go around y axis with the way the mobile is placed into the box. Two line data are same with the expected result. In the graph, we see that the red line will go fluctuate around 6.1 most the time of experiment. In unknown gravity time its value is still stable. In hyper gravity condition, the red line fluctuates with very small amplitude. When the angular velocity increases, the affect from the gravity to motor that control blades speed reduces, it difference when velocity is 20 or 40 cycle per minute. Another hand, the calculated value of z-axis is also 6.2 (it same 60 cycles per minute), so most the time of experiment the sensor got the right data. We can see that there is a small fluctuation of red line in all experiment time. In the micro gravity condition, red line very smooth. It means that, in this situation the gravity does not affect to working of gyroscope. All time of experiment the magnitude is affected by the value of red line, it right because the x-axis and y-axis value is too small and using expression (1) to get the magnitude value.

All above shows that, the gyroscope working very in both on board and on ground. Its magnitude is not depend on the gravity and its working is good on micro gravity.

Nokia Lumia 920

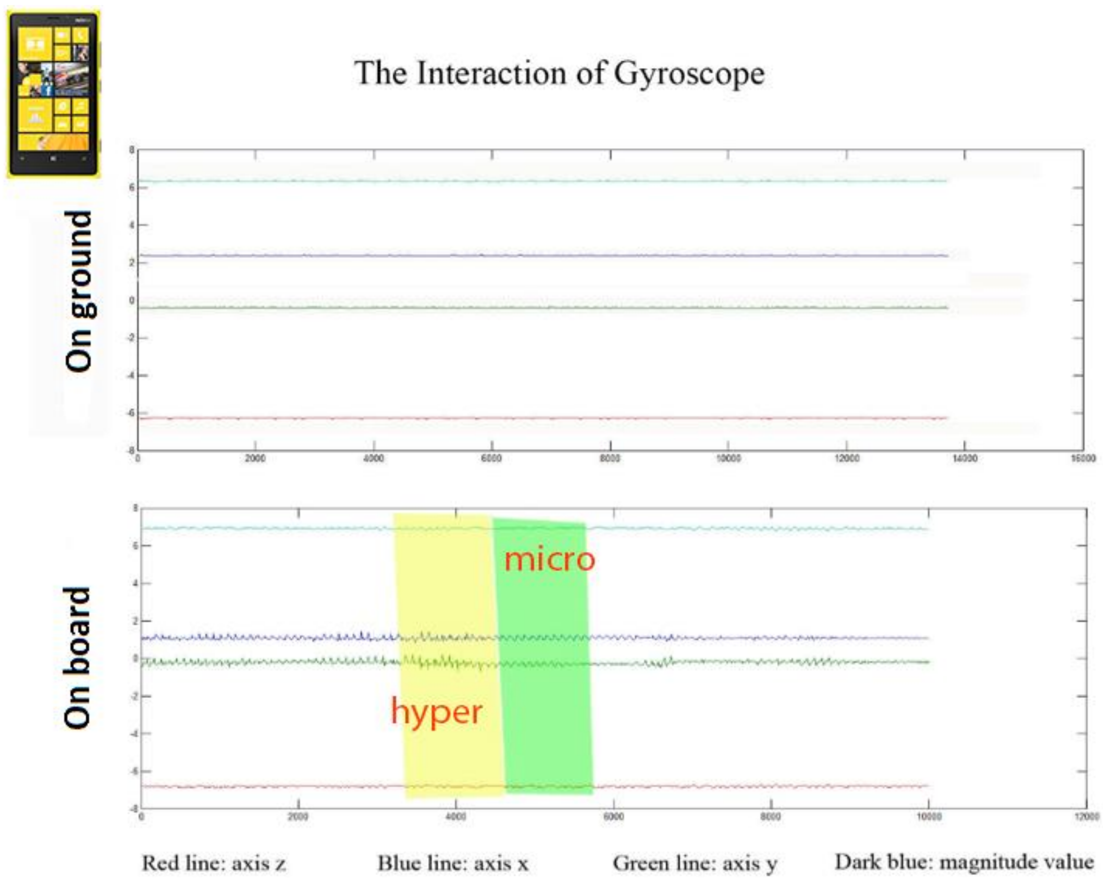

Figure 4.19: The interaction of Nokia Lumia 920 gyroscope on ground and on board with 60 cycles per minute.

On ground: the second part of figure 6.19 shows the inter action of sensor On ground: normal gravity condition (1G). Three value of gyroscope sensor is very stable in the normal gravity condition, all of three axis lines fluctuate with a very small amplitude which near zero. By the way devices is fixed into boxes, the fan rotates around z axis so the phone will only get the data of z axis in theory. But there are some difference to real experiment. The axis x value was always larger than zero, it is not same as expected result. The reason for this happen is the mobile did not fix completely horizontal in the box, it was incline about 20 degree. So in running time of experiment, besides rotating around z axis, it rotates around axis x. That make x axis value is larger than zero. The green line (axis y) is very stable, it complete zero because there is no any motion around axis y. Y axis interaction is same the interaction by theory. The red line (axis z) got value around 6.1 rad/s, it fluctuates with a very small magnitude. With 60 cycles per minute implies calculate the expected z-axis acceleration that is about 6.2 rad /s. So z axis data very close expected result.

On board: The second part of figure shows the interaction of sensor On board condition that includes three special conditions which is not easy to reach on ground: unknown gravity, hyper gravity (yellow area) and micro gravity (green area) that show in figure. There are some differences between on board and on ground data. It is easy to get that, there is a motion around x axis, but it is very small and that motion did not be affected by gravity, the gravity affected in axis z and axis y. Y axis value is still close to zero, it is fine because there is no motions that go around y axis with the way the mobile is placed into the box. Two line data are same with the expected result. In the graph, we see that the red line will go fluctuate around 6.2 most the time of experiment. In unknown gravity time its value is still stable. In hyper gravity condition, the red line fluctuates with very small amplitude. When the angular velocity increases, the affect from the gravity to motor that control blades speed reduces, it difference when velocity is 20 or 40 cycle per minute. Another hand, the calculated value of z-axis is also 6.2 (it same 60 cycles per minute), so most the time of experiment the sensor got the right data. We can see that there is a small fluctuation of red line in all experiment time. In the micro gravity condition, red line very smooth. It means that, in this situation the gravity does not affect to working of gyroscope. All time of experiment the magnitude is affected by the value of red line, it right because the x-axis and y-axis value is too small and using expression (1) to get the magnitude value.

All above shows that, the gyroscope working very in both on board and on ground. Its magnitude is not depend on the gravity and its working is good on micro gravity

Summary

			 **Galaxy S2**	 **IPod Gen4**	 **Lumia 920**
20 cycles/ min	**On Ground**	**Accelerometer**	Magnitude value goes around 1G, just depends on environment gravity	Magnitude value goes around 1G, just depends on environment gravity	Magnitude value goes around 1G, just depends on environment gravity
		Gyroscope	Magnitude value is most depending on the z- axis value, it goes around 2.1 rad/s	Magnitude value is most depending on the z- axis value, it goes around 2.1 rad/s	Magnitude value is most depending on the z- axis value, it goes around 2.1 rad/s
	On Board	**Accelerometer**	Magnitude value totally depends on z-axis value all time, and fluctuates from 0G to 2G. In micro gravity its value is near zero, not be affected by angular acceleration.	Magnitude value totally depends on z-axis value all time, and fluctuates from 0G to 2G. In micro gravity its value is near zero, not be affected by angular acceleration.	Magnitude value totally depends on z-axis value all time, and fluctuates from 0G to 2G. In micro gravity its value is near zero, not be affected by angular acceleration.

		Gyroscope	Its value does not depends on environment gravity. But its fluctuation is depended, with more changes gravity more fluctuations. Gyroscope sensor is still work well on micro gravity with small fluctuation, it goes around 2.1 rad/s	Its value does not depends on environment gravity. But its fluctuation is depended, with more changes gravity more fluctuations. Gyroscope sensor is still work well on micro gravity with small fluctuation, it goes around 2.1 rad/s	Its value does not depends on environment gravity. But its fluctuation is depended, with more changes gravity more fluctuations. Gyroscope sensor is still work well on micro gravity with small fluctuation, it goes around 2.1 rad/s
40 cycles/ min	**On Ground**	**Accelerometer**	Magnitude value depends more on gravity, it also is affected by angular acceleration. Its value goes around 1.2 G.	Magnitude value depends more on gravity, it also is affected by angular acceleration. Its value goes around 1.2 G.	Magnitude value depends more on gravity, it also is affected by angular acceleration. Its value goes around 1.2 G.
		Gyroscope	Magnitude value just depend on z-axis value, it goes around 4.2 rad/s.	Magnitude value just depend on z-axis value, it goes around 4.2 rad/s.	Magnitude value just depend on z-axis value, it goes around 4.2 rad/s.
	On Board	**Accelerometer**	Magnitude value depends much more gravity on unknown gravity time and hyper gravity time. In micro gravity, its value just depends on angular acceleration, just around 0.3G and small fluctuation. Magnitude values goes around 0.3G to 2G.	Magnitude value depends much more gravity on unknown gravity time and hyper gravity time. In micro gravity, its value just depends on angular acceleration, just around 0.3G and small fluctuation. Magnitude values goes around 0.3G to 2G.	Magnitude value depends much more gravity on unknown gravity time and hyper gravity time. In micro gravity, its value just depends on angular acceleration, just around 0.3G and small fluctuation. Magnitude values goes around 0.3G to 2G.
		Gyroscope	Magnitude value does not depend on environment gravity, but its fluctuation depend more on changing of gravity. In micro gravity, sensor work well, its value goes around 4.2 rad/s and small fluctuation.	Magnitude value does not depend on environment gravity, but its fluctuation depend more on changing of gravity. In micro gravity, sensor work well, its value goes around 4.2 rad/s and small fluctuation.	Magnitude value does not depend on environment gravity, but its fluctuation depend more on changing of gravity. In micro gravity, sensor work well, its value goes around 4.2 rad/s and small fluctuation.
60 cycles/ min	**On Ground**	**Accelerometer**	The magnitude value depends more on gravity and angular acceleration. Its value goes around 1.3 G.	The magnitude value depends more on gravity and angular acceleration. Its value goes around 1.3 G.	The magnitude value depends more on gravity and angular acceleration. Its value goes around 1.3 G.

		Gyroscope	Its values just depends on the z-axis value, and small part from x-axis value.	Its values just depends on the z-axis value, and small part from x-axis value.	Its values just depends on the z-axis value, and small part from x-axis value.
	On Board	Accelerometer	Magnitude value depends much more gravity on unknown gravity time and hyper gravity time. In micro gravity, its value just depends on angular acceleration, just around 0.4G-0.5G and small fluctuation. Magnitude values goes around 0.4G to 2G.	Magnitude value depends much more gravity on unknown gravity time and hyper gravity time. In micro gravity, its value just depends on angular acceleration, just around 0.4G-0.5G and small fluctuation. Magnitude values goes around 0.4G to 2G.	Magnitude value depends much more gravity on unknown gravity time and hyper gravity time. In micro gravity, its value just depends on angular acceleration, just around 0.4G-0.5G and small fluctuation. Magnitude values goes around 0.4G to 2G.
		Gyroscope	Magnitude value does not depend on environment gravity, but its fluctuation depend more on changing of gravity. In micro gravity, sensor work well, its value goes around 6.1 rad/s and small fluctuation.	Magnitude value does not depend on environment gravity, but its fluctuation depend more on changing of gravity. In micro gravity, sensor work well, its value goes around 6.1 rad/s and small fluctuation.	Magnitude value does not depend on environment gravity, but its fluctuation depend more on changing of gravity. In micro gravity, sensor work well, its value goes around 6.1 rad/s and small fluctuation.

4.3. Player's experience test result – playing game in microgravity experience

Below is the accuracy of playing FLOW game in different condition (on ground and microgravity environment) and different game mode (accelerometer mode and gyroscope mode).

With Gyroscope mode playing on ground: the accuracies range from 93% (excellent performance) to 100% (perfect)

With Accelerometer mode playing on ground: the accuracies range from 90% (excellent performance) to 100% (perfect)

With Gyroscope mode playing on board (microgravity): the accuracies range from 85% (great performance) to 99% (perfect)

With Accelerometer mode playing on board (microgravity): the accuracies range from 10% (extremely bad performance) to 94% (great performance)

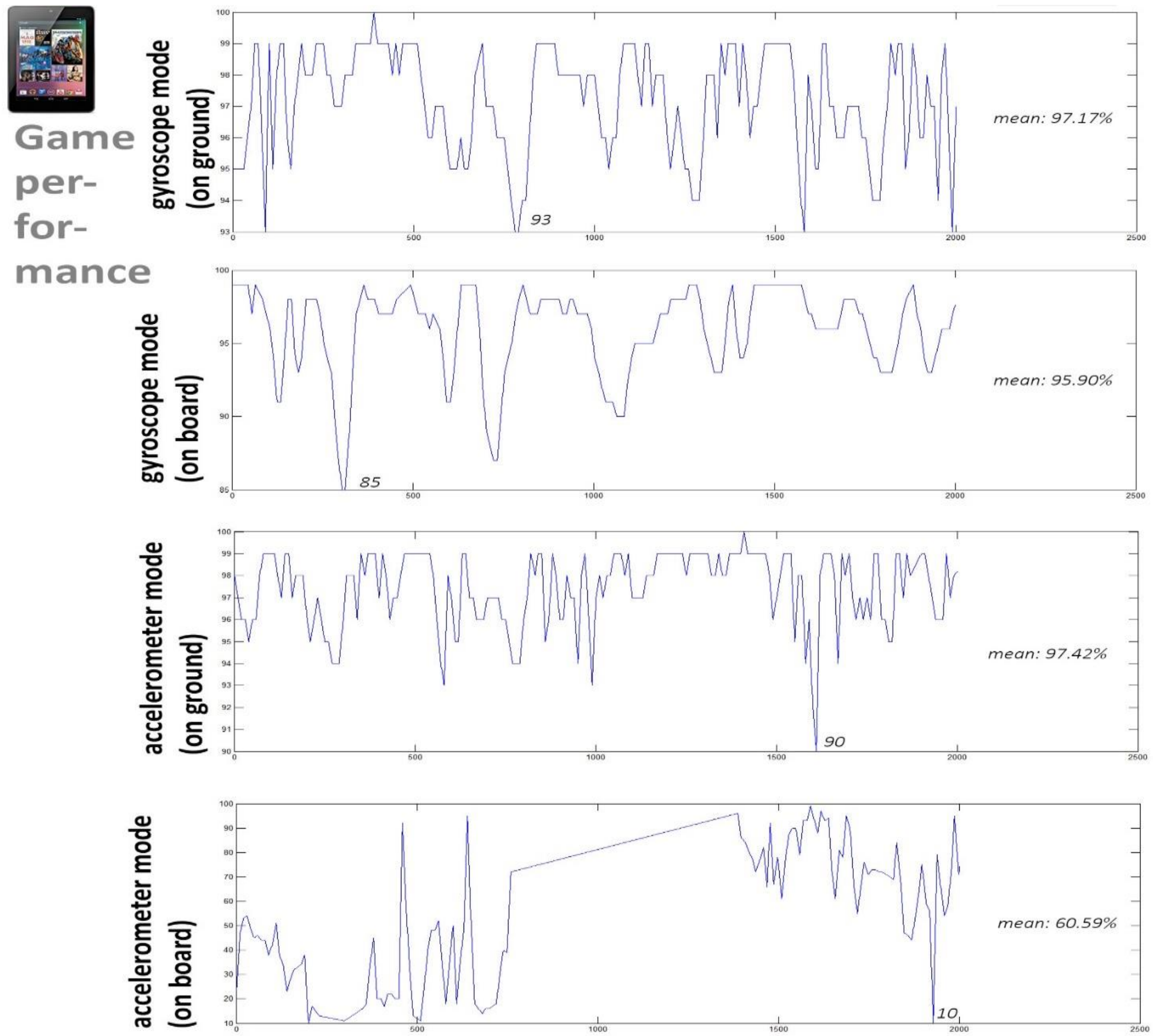

Figure 4.20: Gaming performances with Gyroscope mode and Accelerometer mode, on ground and on board (in microgravity phase only)

Overall result

Microgravity interval only				
Device	Designed value	Type of Data	Mean (of 3 times playing)	Standard deviation
Nexus 7	Accuracy of gaming performance	Gyroscope mode (on ground)	97.29 %	1.58
		Gyroscope mode (on board)	95.42 %	2.92
		Accelerometer mode (on ground)	97.35 %	1.56
		Accelerometer mode (on board)	58.27 %	27.58

The special game designed for this experiment, FLOW, also shows a very clear statistic of the player's accuracy that it dropped dramatically from about 97% when playing on ground to approximately 60% when playing on board, the orientation detection gave the output fluctuated wildly. As result of the messed-up gravity data, all the popular game tested on board (Need for speed, temple run, temple run 2, angry bird GO) were unplayable during the microgravity phase. Whereas, come back to the FLOW game, when it was played in gyroscope mode, the accuracy of gaming performance just had a slightly difference in compare with that on ground (97% and 95% respectively), but players seem to make bigger mistake when playing in microgravity condition (the standard deviation value on board is double that on ground)

The two experimenters also reported their experience when playing games in micro/hyper gravity condition. With the game using Gyroscope mechanic (FLOW), they commented that it was "adjustable" to play. "When everything and I myself were floating around, it was a little bit hard to determine which side is the up side, which is down. However, I was still able to play the game and kept high accuracy. You know, it felt like standing on your head while watching television, you can still get what's happening in a movie" - one of the two experimenters said. The problems they faced were that:

+ The zero-gravity experience is far different from what they imagined, the body became awkward, and it took time to improve the gaming performance.

+ The changing constantly between hyper-gravity phase and microgravity phase also affect the performance.

+ Have to pay attention to multiple things at one time: getting used to controlling the body, hold the device properly otherwise it floats, concentrate on the game.

Those are the experience when playing gyroscope-based game, which games using Accelerometer mechanic (FLOW-accelerometer mode, Need for speed, Temple run, Angry bird go!), it was hopeless to play. No matter how hard you tilt the device during the microgravity phase, the character of the game just zig a little in your will, and then it would shake wildly on the screen. Overall, it is impossible to play accelerometer-based game in zero-gravity, while it was sort of pleasure to play gyroscope-based one.

5. Conclusion and future work

5.1. Conclusion

As we can see on the upper section, all tested smartphone gyroscope sensors work well on both normal gravity environment and microgravity environment. But the accelerometer sensors do not work correctly on the microgravity. So basically gyroscope based applications (such as games, navigator applications) can work well on the microgravity but the accelerometer based applications does not work well on the microgravity.

Although Gyroscope have been used widely lately, in fact, this sensor just appears on nearly one fourth of all smartphones produced in 2013 (in order to reduce the cost). Whereas, all smartphone have accelerometer. So it would be easier for developer to just optimize their game/app for accelerometer.

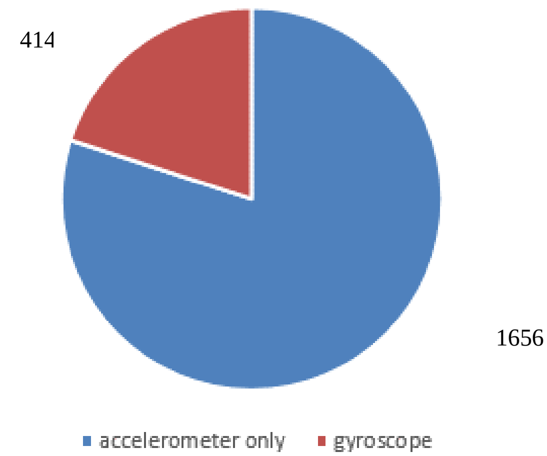

Figure 5.1 *Number of phone series on sale in 2013*

However, it is possible that developers can add some tweaks so their game can "live the best of both worlds". In zero-gravity environment, the tilting gesture of player still makes acceleration at the beginning of the gesture. The game can catch that event and then make the character/object turn left or turn right; as long as the acceleration signal caught by device's accelerometer is strong enough to be read (in compare with environment (e.g. spaceship) noise). Using the data collected on the parabolic flight experiment, we will determine the threshold at which the accelerometer will recognize and decide when a tilting gesture is done. Signal-to-noise ratio will also be used to determine the threshold. Signal-to-noise ratio, often written S/N or SNR, is a measure of signal strength relative to background noise. The ratio is usually measured in decibels (dB). If the incoming signal strength in microvolts is Vs, and the noise level, also in microvolts, is Vn, then the signal-to-noise ratio, S/N, in decibels is given by the formula:

$$S/N = 20 \log_{10}(Vs/Vn)$$

If Vs = Vn, then S/N = 0. In this situation, the signal borders on unreadable, because the noise level severely competes with it. Ideally, Vs is greater than Vn, so S/N is positive which results in the signal being clearly readable. If Vs is less than Vn, then S/N is negative. In this type of situation, reliable communication is generally not possible unless steps are taken to increase the signal level and/or decrease the noise level at the destination (receiving) computer or terminal.

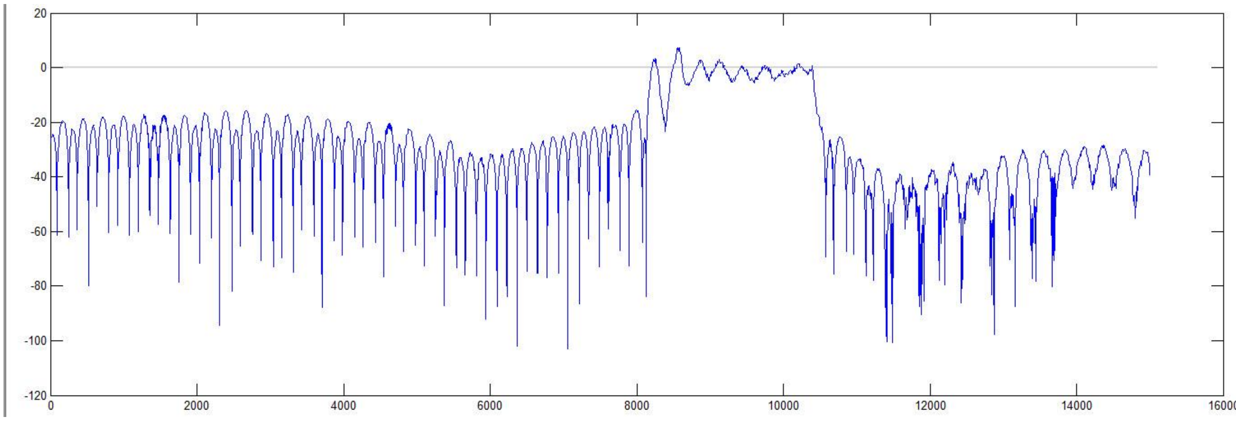

Figure 5.2 *Given an acceleration of 0.05G (when device rotate at 20 rpm)*

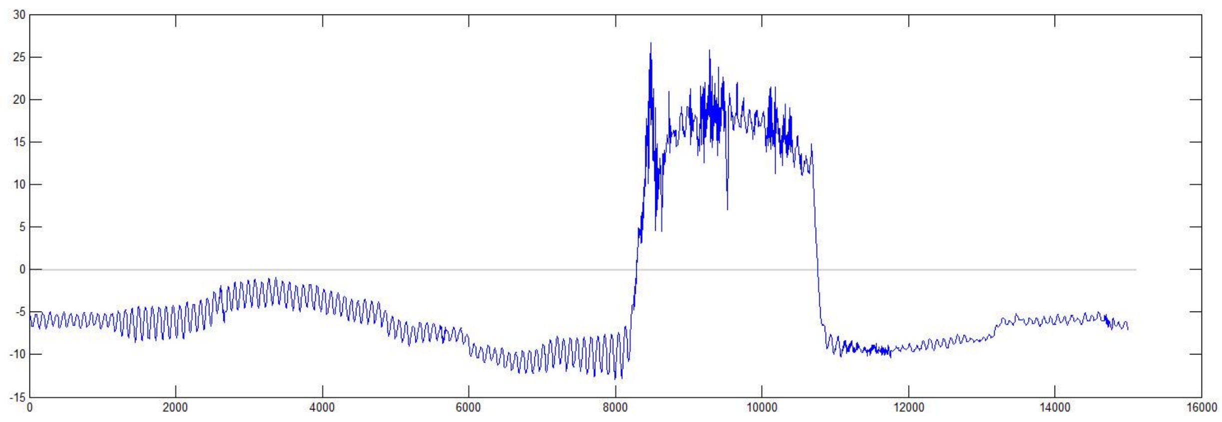

Figure 5.2 *Given an acceleration of 0.21G (when device rotate at 40 rpm)*

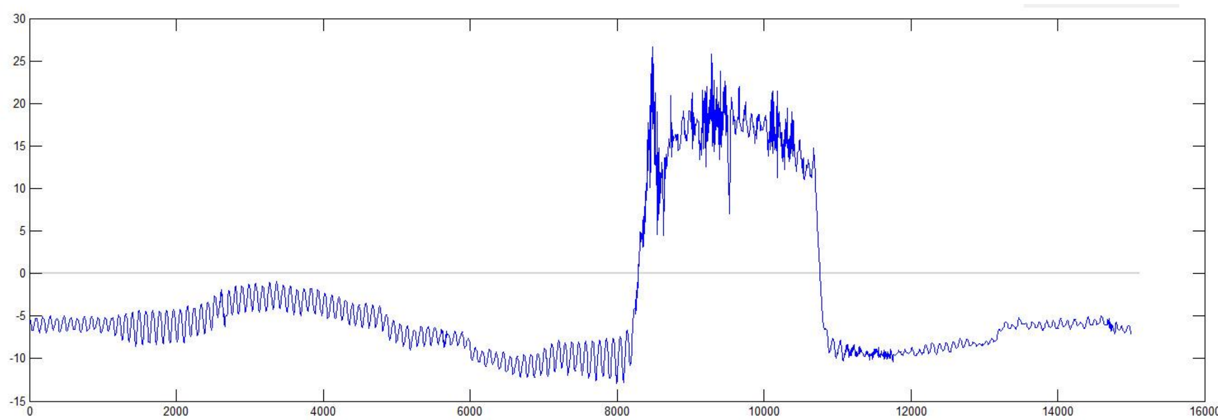

Figure 5.3 *Given an acceleration of 0.48G (when device rotate at 80 rpm)*

From the line graph above, we can see that the gesture can only be recognized when the device is given an acceleration more than 0.05G (somewhere between 0.05G and 0.21G).

So, basically, with gyroscope-supported smartphones or some tweaks for accelerometer data, a game/app can work in any condition, zero gravity or on ground. But the change will take time, at this moment, for mostly 99% of the game, the answer would be no.

6.2. Future work

Since Game Companies prefer to use Accelerometer data only in order to make the game compatible with most of the worldwide hardware, we are investigate on a solution to use the Accelerometer only to detect the device's orientation in reference with the object carrying the device.

In 2013, NASA successfully launched PhoneSat satellites using smartphone as brain. The construction cost of the PhoneSat satellite is much cheaper than the average satellite but it had a faster CPU and more memory than the average satellite, cameras, multiple acceleration and rotation sensors, a compass, a GPS receiver. This is a significant piece of evidence shows that smartphones and its applications can play important role in microgravity environment.

For our further plan, this data will be used testing the ability of navigating smartphone-based mini-satellite. The change of sensor data in different environments and the difference between mobile operating systems can make an application error and some issues for application development process. This problem is able to solve by processing and correcting native motion sensor data from mobile operating system before this data is used by applications. To do this, a new architecture will be researched and developed. In this architecture, a new software library or mobile operating system module called "virtual layer" can be added to the applications or mobile operating systems. A virtual layer acts as a bridge between mobile operating system and the applications.

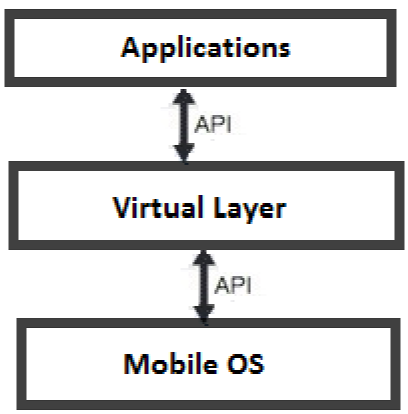

Figure 6.4 A virtual layer acts as a bridge between mobile operating system and the applications

The virtual layer aims to reduce the application errors and develop new application rapidly and flexibility. The virtual layer receives motion sensor data from native mobile operating system through application programming interface (API), process data and provide clear data for application to use.

Future work might attempt to collect more mobile sensor data and analyze this data to make this virtual layer.

Acknowledgement

The preparation of this report "The interaction of smartphone's accelerometer and gyroscope in microgravity environment" would not have been possible without the valuable contribution of Computer Science faculty – University of Engineering and Technology, Vietnam Space Technology Institute and Japan Aerospace Exploration Space Agency.

We would like to express our special thanks of gratitude to my supervisor, Dr. Lê Thanh Hà, who gave us the golden opportunity to do this wonderful project on the topic of zero-gravity condition. We are extremely grateful and indebted to him for his expert, sincere and valuable guidance and encouragement extended to us.

We take this opportunity to record our sincere thanks to Dr. Muneo Takaoki for your enthusiastic help and encouragement.

We also place on the record, our sense of gratitude to one and all who, directly or indirectly, have lent their helping hand in this project.

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