Action Recognition Algorithm Research with G-sensor and Gyroscope

M.Sc. (Software Design and Development)

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Glossary Of Abbreviations

Abbreviation	Full Title
AI	Artificial Intelligence
GPRS	General Packet Radio Service
App	Application

Abstract

Nowadays, Artificial Intelligence (AI) has become more and more popular, and the action recognition algorithm is a very important part and researched by more and more experts. Exactly, the action recognition algorithm is not a strangle thing that has been used not only on a robot, but also in our daily lives, such as iPhone, iPad, smart watch and smart pen etc. In this thesis, we are going to study two devices, Accelerometer and Gyroscope, how they work and how they are used with some recognition algorithms, and the most important part is the last chapter which discuss a hypothesis which tries to use those two devices with some recognition algorithm to make sure a multiple function glow sticks.

Acknowledgements

First and foremost, I would like to thank my supervisor, Dr. Frank Glavin for his continued support, especially for me, since I nearly did my internship in some company for more than half year in the second academic year. However, it is still going well due to Dr.Frank paying lots attention to me and checking the progress almost once a week that I appreciate so much

1 Introduction

1.1 Background Information

Nowadays, the rapid development of science and technology has brought lots of conveniences to human daily life and action recognition technologies have already permeated every corner of our lives. Maybe you still have not noticed it yet, but exactly you have high possibility of using it before. There are some examples of the applications in our daily lives of this technology: healthy smart watch that helps us to recorde the steps every day we walk; robots that can simulate some actions of human; racing game that you just need to move your hands to play games. Absolutely, action recognition technologies is not only just those, in this thesis, it shows a possibility to use the gyro and accelerometer to another field and create a new product, a multiple function glow-stick maybe it will appear in near future.

For general people not in this technical field, they sometimes will feel confused or be curious about this technology; for example, some players of racing game on iPhone sometimes will think of how the phone can be used to implement this kind of games. Here, this dissertation explains this confusion or technology in two parts, hardware and software; to be more in detail, many kinds of sensors and some algorithms are the key points for this thesis to elaborate this technology.

When talking about the action recognition, there are many kinds of sensors used to catch data for assisting those functions which must be mentioned, such as inertial sensor , Accelerometer, Gyroscope and Gravity Sensor etc. For this dissertation, accelerometer and gyroscope are two main sensors used, and the basic working principles of those two sensors will be elaborated in following content. Why picking up those two sensors is because they are very popular on lots of devices such as iPhone and can get the data easily for research.

On the other hand, the action algorithm is a big part researched in this thesis and also a very popular technique currently; exactly, it is already a mature technology and many kinds of advanced algorithms have been researched and used in many fields, some relevant algorithms such as Kalman Filter (这里是不是可

以加一些，文献什么的)and Complementary Filter Algorithm etc. Therefore, to understand and use some relative algorithms is also a purpose of researching this paper.

1.2 The Research Problem

//找资料，在这里，交代动作识别算法的背景

The research problem can also be divided to two parts to describe: first one is how to catch the data of Accelerometer and Gyroscope and also how to use it and the second one is what kinds of algorithms can be used to recognize actions and also are easy to explain.

At beginning, the author used a development kit of IT Company as a tool to catch the data of accelerometer and gyroscope and analyze data to find some regulations; this is a good way to catch real-time data and also very convenient to observe. However, it is complicated to store the data in a file, so it is not convenient for analysis. After then, iPhone 6s was also found a good tool to observe the regulations of the wave diagrams of the data of the accelerometer and gyroscope, because many version iPhones are already mounted those kinds of sensors. On the other hand, there are also many APPs in iPhone which can be used to collect the data of those sensors in a file and transferred easily by email. Exactly, there are absolutely many other devices or methods which can also be used to collect those data, here, not to mention too much.

After the data being collected in files, researching the algorithms is the most difficult part for this thesis, as what kinds of algorithms are suitable for realizing gesture recognition and also can be organized in this thesis is the key part of this thesis. There are some algorithms and methods mentioned or researched in this thesis, such as Peak Detection Algorithm and Transform Domain Algorithm in Chapter 3.

1.3 Objective of the Study

There two purposes for this thesis, one is to introduce what the gyroscope and accelerometer are, how they work and some basic application in our daily lives; another one is to research some action recognition algorithms through putting forward a hypothesis for a new product, a multifunctional glow-stick, using those two devices. The author is really interested in this technology and hope to do something for helping someone who is also interested and wants to study to get a basic principle for those two devices and basic action recognition strategies.

The study of the gesture recognition algorithms is the key point in this paper, after researching this paper, the readers should have a basic concept of what is the gesture recognition algorithm and how it is used in a procedure, so you may want to use those two devices with some algorithms to create something new or realize some functions you want, such as the multi-functional glow-stick mentioned in the chapter 5.

1.4 Thesis Structure

This paper is structured to bring the readers to familiarize the hardware devices and software algorithms from some easy-understanding concept of gyroscope and accelerometer at beginning to the application of some hard-understanding action recognition algorithms.

Chapter 1 briefly explains the background and purpose of the whole article, aiming to attract the attention of readers.

Chapter 2 aims to introduce those two devices and concepts of the action recognition algorithm, which helps readers to ground a good fundamental for the following knowledge.

Chapter 3 illustrates the pedometer in detail as an example of using Accelerometer, and also explains some relevant algorithms through some marked figures and codes.

Charter 4 mentions a demonstration of using Gyroscope, racing game on the Phone, which clearly explains how a gyroscope works in a phone.

Chapter 5 bases on the last three chapters; in this chapter, a hypothesis is put forward and proven using procedures and diagrams. This is a key point of this thesis and displays a process from studying some mature knowledge to using them to prove some new hypotheses, so this paper implicitly describes a strategy of self-learning a new technique.

Chapter 6 summarizes the entire dissertation and put some imaginations for some future development in this field.

2 Literature Review

2.1 Accelerometer

2.1.1 What is an Accelerometer?

Wikipedia explains: "An accelerometer is a device that measures proper acceleration. Proper acceleration, being the acceleration of a body in its own instantaneous rest frame, is not the same as coordinate acceleration, being the

acceleration in a fixed coordinate system" . Exactly, an accelerometer is not hard to be understood and just need to know it is used to test the physical acceleration, which is taught in high school physics course and is the rate of change of velocity of an object.

2.1.2 Working Principle of an Accelerometer

As I mentioned before that an accelerometer is used to test the acceleration of an object. What is the acceleration here? Exactly, it is the change rate of the velocity of an object and can be described as the 'a' in formula: F=-kx=ma, we studied in middle or high school courses. (Nisticò, 2013)

$$F = -kx = ma$$
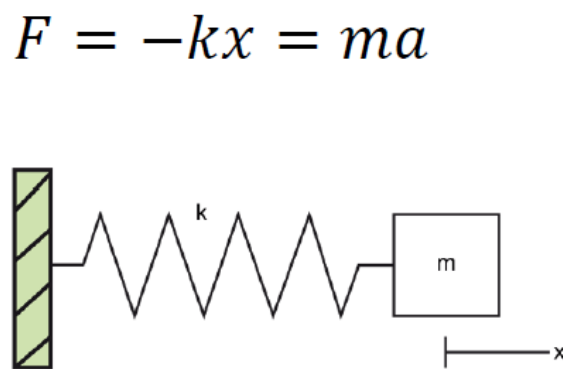
Figure 2-1: Working Principle Of A Capacitive Accelerometer. (Nisticò, 2013)
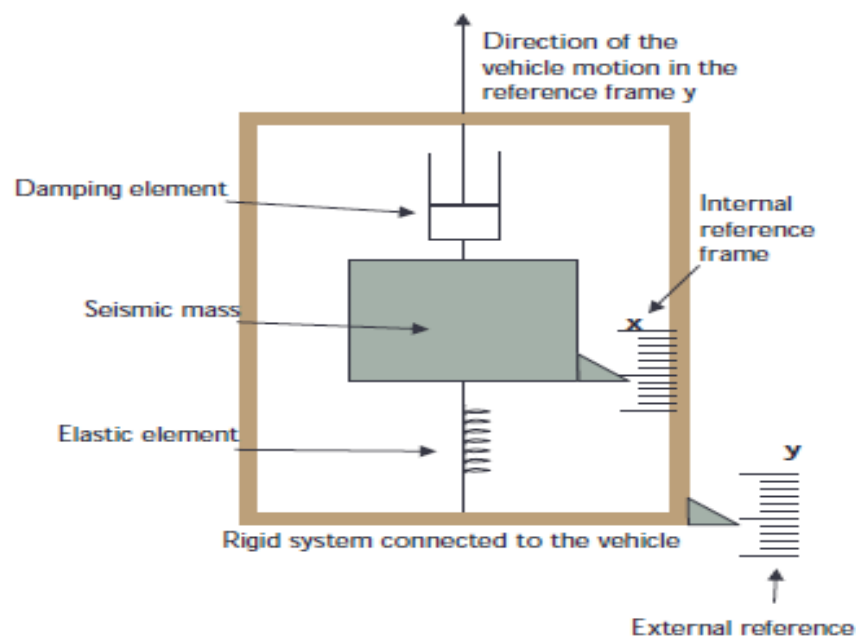
Figure 2-2: Accelerometer Theory & Design (Nisticò, 2013)

As Figure 2.2 above shows the inner structure of a kind of accelerometers, which be comprised of Seismic mass, a Damping element, a spring (Elastic element), External reference and Internal reference frame. When the vehicle is moved with an acceleration, the mass will move to another position, the spring will stretches and x and y, Internal reference and External reference, will change, so there is a relationship happened between the vehicle acceleration and the references of x and y.

 In our daily lives, the most popular type of accelerometer is the Three-Axis Acceleration Sensor in the market. Just as its name implies, the three-axis accelerometer does not only test one direction's acceleration, but three directions' accelerations: X, Y and Z.

2.1.3 How Accelerometer Works in Mobile Phone.

Here, we just use the three-axis accelerometer of an iPhone as an example to describe how an accelerometer works in an iPhone. As we mentioned before, a three -axis accelerometer is used to test three different directions' acceleration. There are two figures (YingWen, 2014), which show three-dimensional axes and the acceleration of every axis can be tested by the accelerometer installed in the phone.

When an object is in static condition, it has only the gravitational acceleration in perpendicular direction with the ground. The two figures below show the accelerations of a phone in static condition, and it just prove that no matter the accelerometer put in which direction, in static condition that it only be affected by gravity.

$A_X = 0 m/s^2$
$A_Y = 9.81 m/s^2$
$A_Z = 0 m/s^2$

Y-axis

X-axis

Z-axis

$A_X = 9.81 m/s^2$
$A_Y = 0 m/s^2$
$A_Z = 0 m/s^2$

X-axis

Y-axis

Z-axis
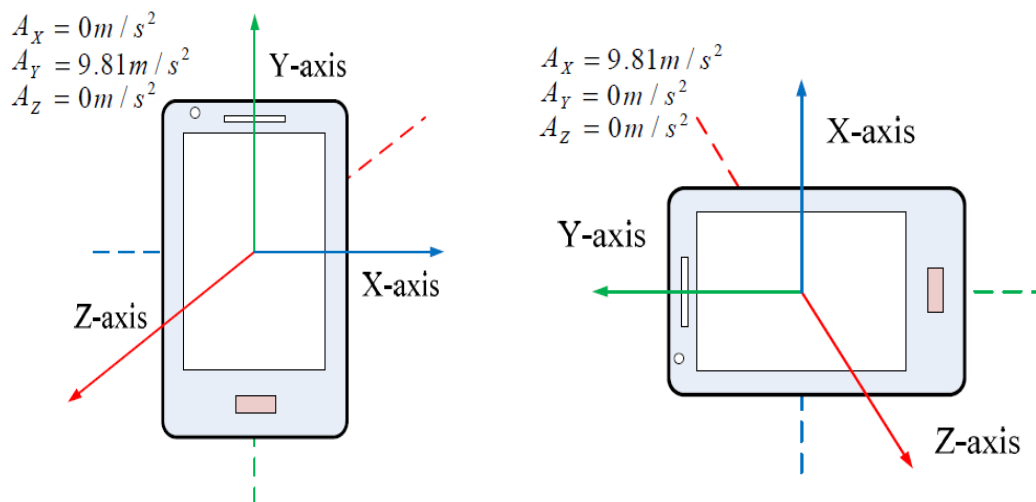
Figure 2-3: Three-Axis Accelerometer in a Phone (YingWen, 2014)

And maybe some beginners will ask how to get the three axes data from an iPhone. Exactly, there are some APPs creating the function to catch the efficient data directly from the phone, which can get not only the data of accelerometer from the iPhone to email to your email box, but also Gyroscope data which will be discuss in next chapter and Magnetometer sensor.

2.2 Gyroscope

2.2.1 What is a Gyroscope?

According to the English Oxford Dictionary (Oxforddictionaries, Mid 19th century), a Gyroscope is a "device consisting of a wheel or disc mounted so that it can spin rapidly about an axis which is itself free to alter in direction. The orientation of the axis is not affected by tilting of the mounting." Exactly, gyroscope is often used to detect the orientation that has similar function with compass. Nowadays the gyroscope becomes more and more popular and it has many applications such as used in inertial navigation systems and gyro compasses.

The most popular application is to be installed in the mobile phone. For example, it can work together with GPS in phones to help people navigate easier and more precise.

2.2.2 Working Principle Of A Gyroscope

There are different kinds of gyroscopes, such as MEMS gyroscope、fibre optic gyroscope and the sensitive quantum gyroscope. Different types base on different principles of operation, and in this thesis, we just introduce the working principle of the most popular one used in iPhone.
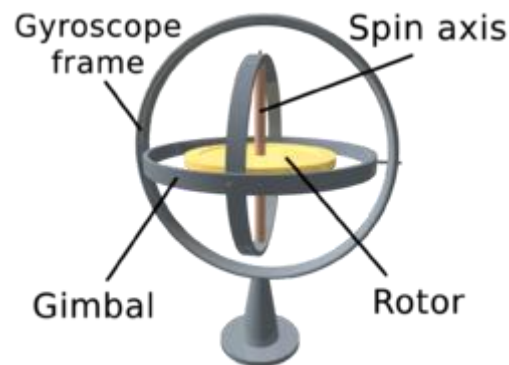
Figure 2-4: Wili Commons. (Wilimedia, 2006)

As you can see the figure above, there is a Rotor which can spin freely 360 degrees around a Spin axis in a Gyroscope frame and a Gimbal. This is a basic frame of the Gyroscope and the angular velocity in each direction can be detected by the free rotation of the rotor.

There is another picture below, figure 3.2 (Pigeon's nest, n.d.), there is a clear space match between the gyroscope frame and coordinate graphs. Based on angular momentum the Rotor resists to changes in orientation, thereby allowing to measure the changes of the angles. The rotation or the angle changes in different directions or positions will affect a change of resistance of a gyroscope and in this way, we can calculate the angular velocity in those three axes orientations, so this is a basic principle of how the gyroscope works.
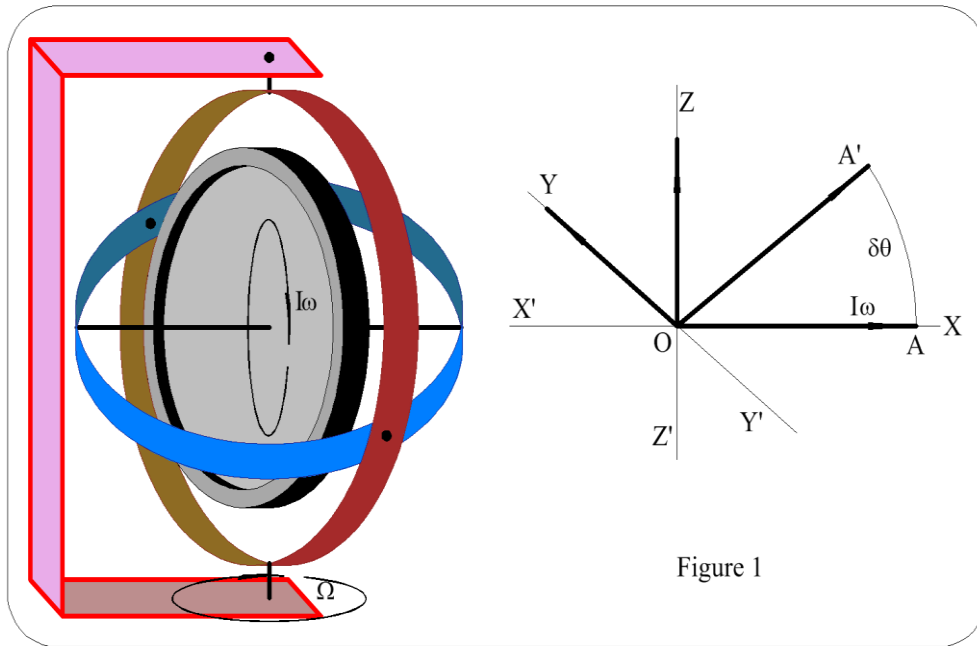
Figure 2-5: Gyroscope Principles (Pigeon's nest, n.d.)

2.3 The Relationship Between Gyroscope And Accelerometer

At first, it is clear that two devices have different functions: Gyroscope senses the rotation, whereas another one is used to test the accelerometer. (put some reference) The restriction of functions in two devices decides that they have to work together often.

There is an example to clarify the different functions of them. When an aircraft flies in the sky, the accelerometer can used to test the change of movement. For example, when an aircraft flies too fast in suddenly, the accelerometer can remind the pilot of the unsafe signal for the sudden change of the speed during flying forward. However, when the aircraft has some faults with an unsafe shake around itself, here the accelerometer cannot sense it, but the gyroscope can detect the any rotation of the aircraft to notice the pilot of the insecurity.

Through this example, we can further understand that they are totally different, but they can also make up for each other to achieve some functions.

2.4 Action Recognition Algorithms

2.4.1 The Concept of the Action Recognition

The action recognition is a big part of what this paper researches. For what kind of actions or movements should be researched and recognized, there are some demonstrations for the application of action recognition functions: measuring orientation of human body segments (H. J. Luinge P.H. Veltink, 2005), the recognition of complex activities such as cooking, sweeping and washing hands etc. (Stefan Dernbach,Barnan Das, Narayanan C. Krishnan,Brian L. Thomas, Diane J. Cook, 2012), driving style recognition for example turning right 90° , turn left 90° (Derick A. Johnson, Mohan M. Trivedi, 2011).

To realize those kind of functions of action recognition must use some sensors and relative algorithms. Here, Accelerometer and Gyroscope mentioned in previous sections are currently very popular sensors for detecting and recognizing actions and in this thesis, every action recognition function bases on those two sensors. After understanding the operation principles of those sensors, how to use the algorithm to analyse the data caught from Accelerometer and Gyroscope is the hardest part and also the key point for this paper.

2.4.2 The Relative Algorithms

Many kinds of action recognition algorithms have been designed and used in various products and applications.

2.5 Related Research

2.5.1 Accelerometer and Gyroscope with pedometers

The pedometer is a mature technology currently merged in many mobile devices, such as the smart phone, but the accuracy of counting steps is one of the main problems for the current pedometers, especially for walking slowly on flat lands and performing different activities, such as climbing up and down stairs and walking on inclined planes. Jayalath and Abhayasinghe (2013) uses

the gyroscope to collect data, analyses gyroscopic data and finally calculates the steps through a series of algorithms, which has higher accuracy than normal pedometers using accelerometers in those activities mentioned above. Exactly, the author also meets the same problems about the accuracy in some activities of counting steps basing on accelerometers.

The accuracy of the counting steps is the key point for the pedometer, so there is another research question: how to determine the validity and reliability of an algorithm or a method used in a pedometer in different modules, such as climbing, jogging etc. AMS algorithm is provided as an example to be evaluated by some videos in Fortune *et.al* (2013), and it provides a way determine whether an algorithm is available and reliable or not. At first, this algorithm, AMS, should be used to calculate the number of steps in different modules and gait velocities; at same time, counts the exact steps by video. And then, the validity and reliability of an algorithm can be determined through comparing between the count of steps calculate b by AMS and the exact number in different conditions. In this paper, it proves that AMS method is suitable for step counting using tri-axial accelerometers on the ankles, thigh and waist in a free-living environment.

Tudor-Locke *et.al* (2010) mainly uses the technique of the accelerometer and pedometers to realize counting the steps per day for US children and youth, and using this counts steps tested by pedometers to analyse the health status of children and youth. From this article, it does not elaborate how to use the accelerometer to realize the function of a pedometer, because this kind of technology, counting steps by accelerometer, has been widely used in our daily lives and is already very mature. Therefore, this thesis mainly uses the technology of counting steps by pedometers for youth and children, and gets the results of their health through collecting and analysing the acceleration data. Therefore, this technology has exactly penetrated the bits and pieces of our lives.

2.5.2 Racing Games on the Phone

2.5.3 Gyroscope & Accelerometer for Complexity Action recognitions

3 Accelerometer with Steps Algorithm

3.1 The Principle of Testing Steps

3.1.1 How An Accelerometer Works On Human Body

The figure below shows a pedestrian with an accelerometer. When a pedestrian is walking on the road, the accelerometer will divide the motion acceleration by three directions, Vertical Direction, Forward Direction and Side Direction, which can be also called: X, Y and Z Axis.
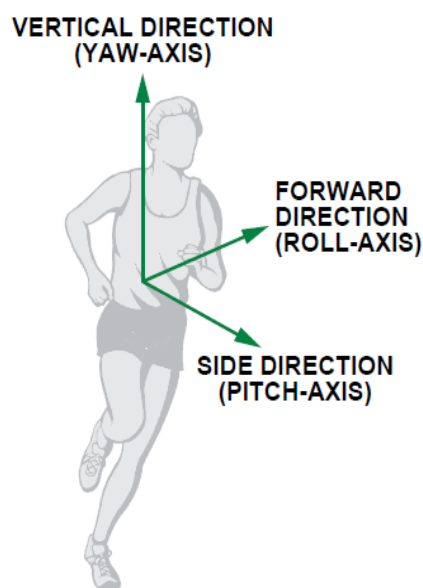
Figure 3-1: 3-Axis Digital Accelerometer (Zhao, 2008)

3.1.2 The Features of a Simple Step

There is a swing phase showed in the Figure below, which is a step period during people movement. Absolutely, there is a change process of speed of the leg movement during one step period, so we can catch the acceleration in three directions using the accelerometer.
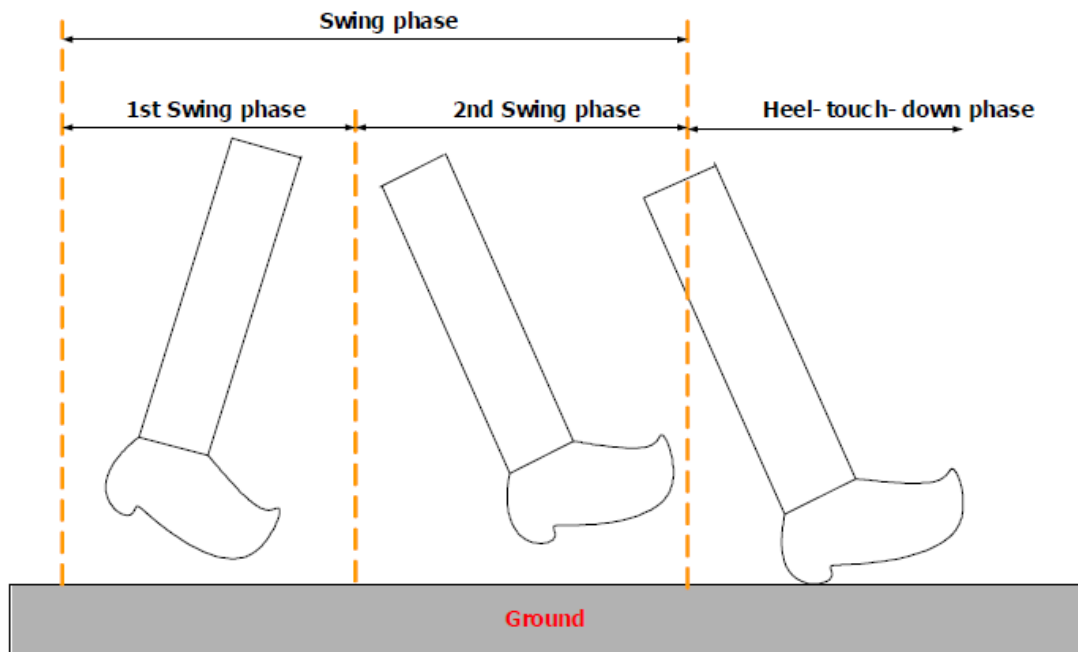
Figure 3-2: A Step, Stride and Heading Determination For The Pedestrian Navigation System

Figure 2.6 below shows the typical three axes, x, y and z (matching vertical, forward and side acceleration) data of the accelerometer in my iPhone during walking, and what conclusion can be got from this picture, so no matter how the pedometer wears the phone, there is at least one axis data have sharply periodic changes (this picture shows the Y axis changing sharply).
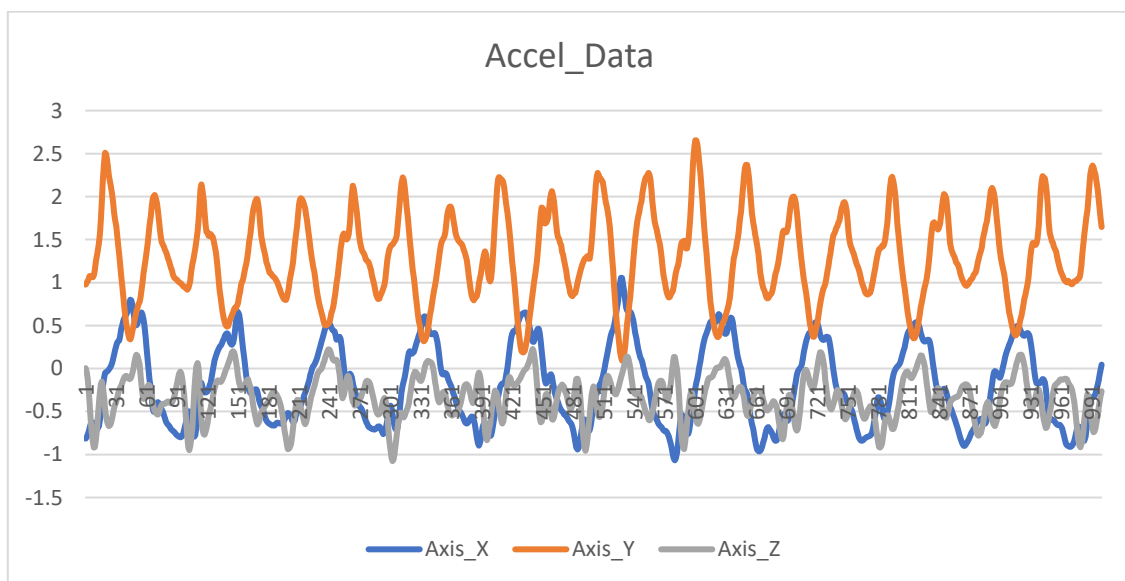
Figure 3-3:The Three Axes Data Of The Accelerometer From iPhone

Even the direction of the phone in the pocket is unpredictable, the general tends can be got. We can normally use the sum formula to get a diagram below picture. As a valid step must have only one peak value and one bottom value.
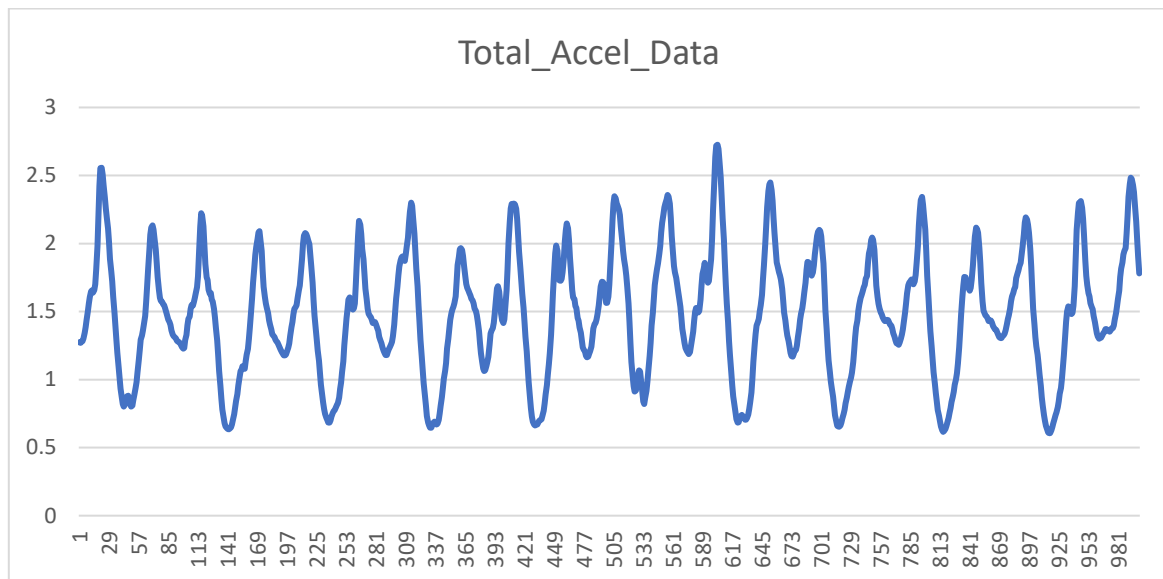
Figure 3-4: The Merged Accelerometer Data After Calculation

3.2 Key Algorithms Of Recording Steps

3.2.1 Peak Detection Algorithm

Four Basic Conditions can be used: (the frequency of the data caught in this chapter is in 50Hz)

1. Current point is going down. (The Red Point in the following diagram)
2. The previous point is going up. (The Black Point)
3. At least going up twice before coming to positive peak. (The pink lines).
4. The value of the positive peak should be bigger than 1.5g

And we can go on to understand this algorithm by referring to the following diagram.
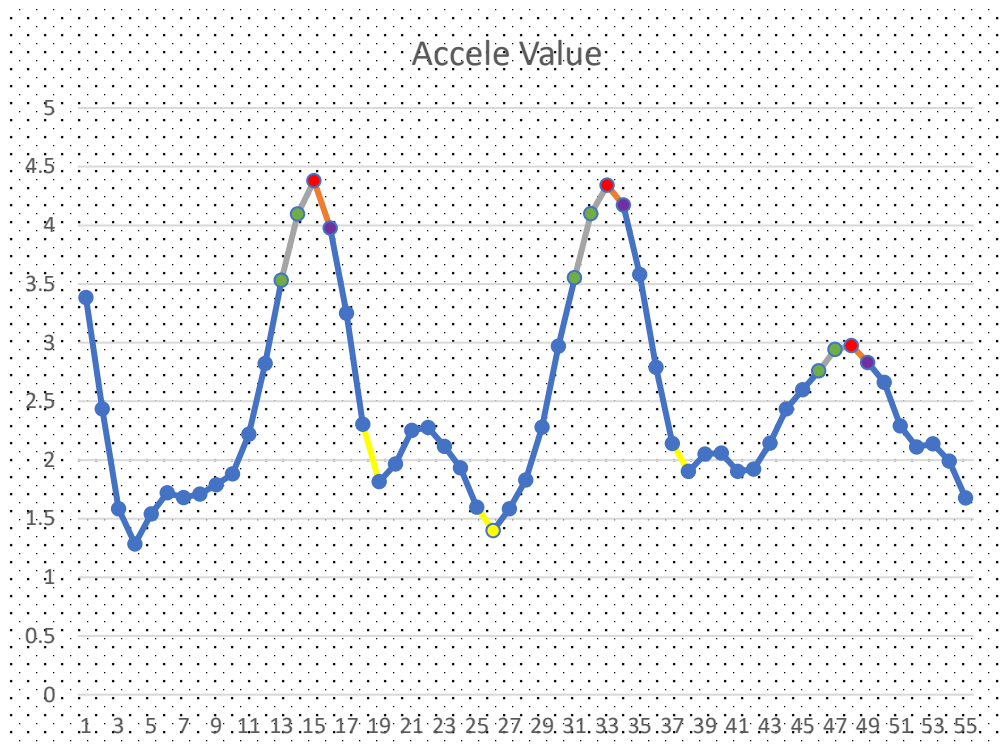
Figure 3-5:The Peak Data Of The Accelerometer

3.2.2 Transform Domain Algorithm

One condition can be used to exclude invalid data.

1. The duration of two effective adjacent peaks must be longer than 0.2S
   and shorter than 2s. (Based on common sense)
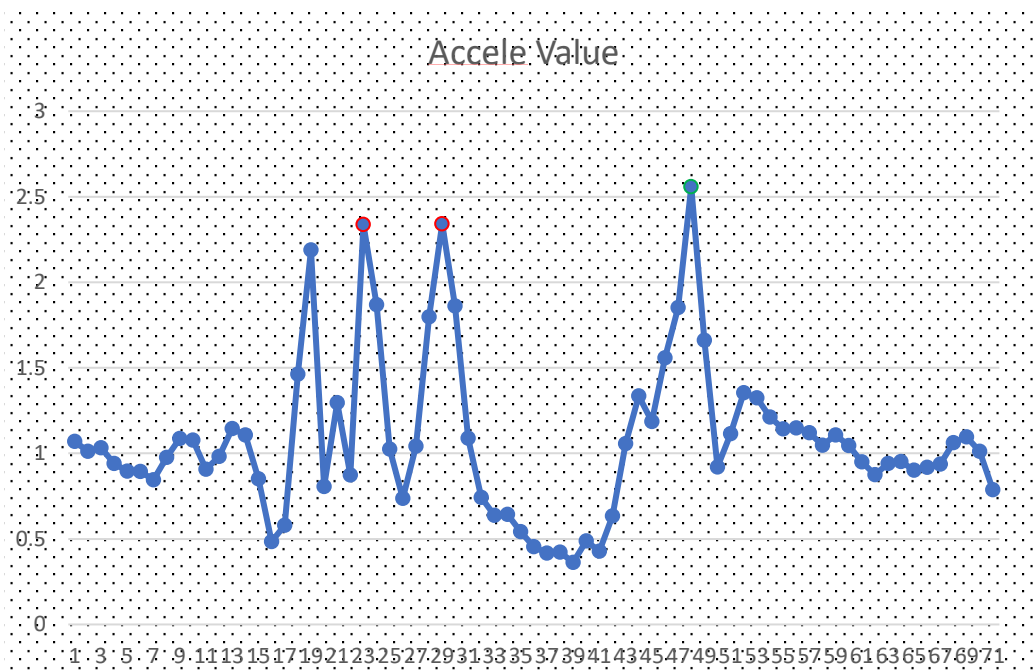
Figure 3-6: The Intervals Among The Peaks

We can see the two red peak values are invalid using this algorithm.

3.2.3 Threshold Filtering Algorithm

Two Basic Conditions:

1. The current peak value minus the last valley value must be bigger than the threshold.
2. The Threshold is Dynamic and related with different walking patterns. There is one red peak datum being filtered.

The following figure can be an example for this algorithm.
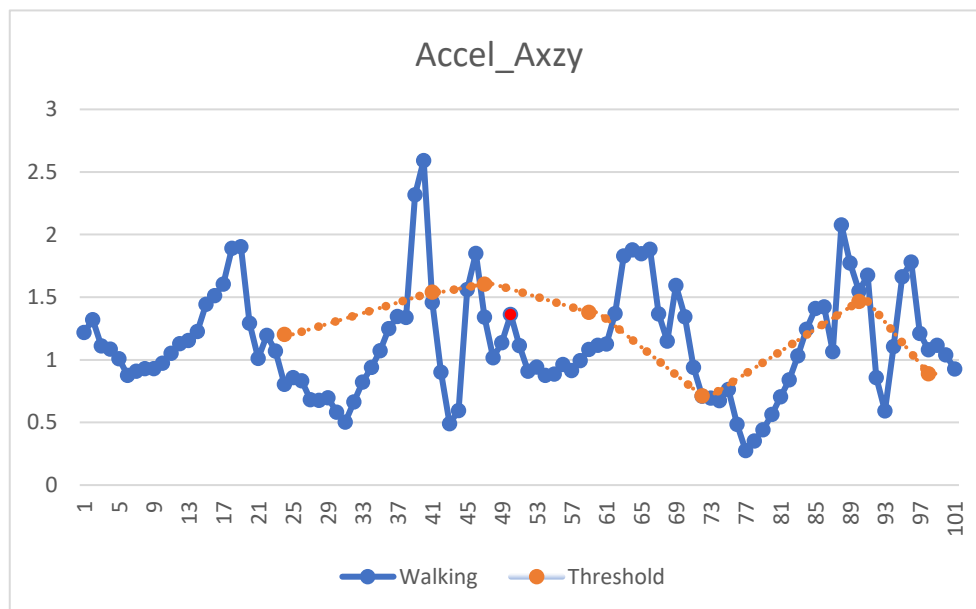
Figure 3-7: The Threshold Figure

3.2.4 Pattern Recognition Algorithm

One regulation is:

For examples:(the walking patterns)
     1. Walking, phone in pocket.
     2. Walking, phone in hands.
     3. Walking, phone beside ear.
     4. Running, phone in pocket.

In different patterns, you can see the distinction of the wave variation of accelerometer value from the picture on the right. The following diagram shows the difference between the pattern of walking with the phone in the pocket and the pattern of running with the phone in the pocket.
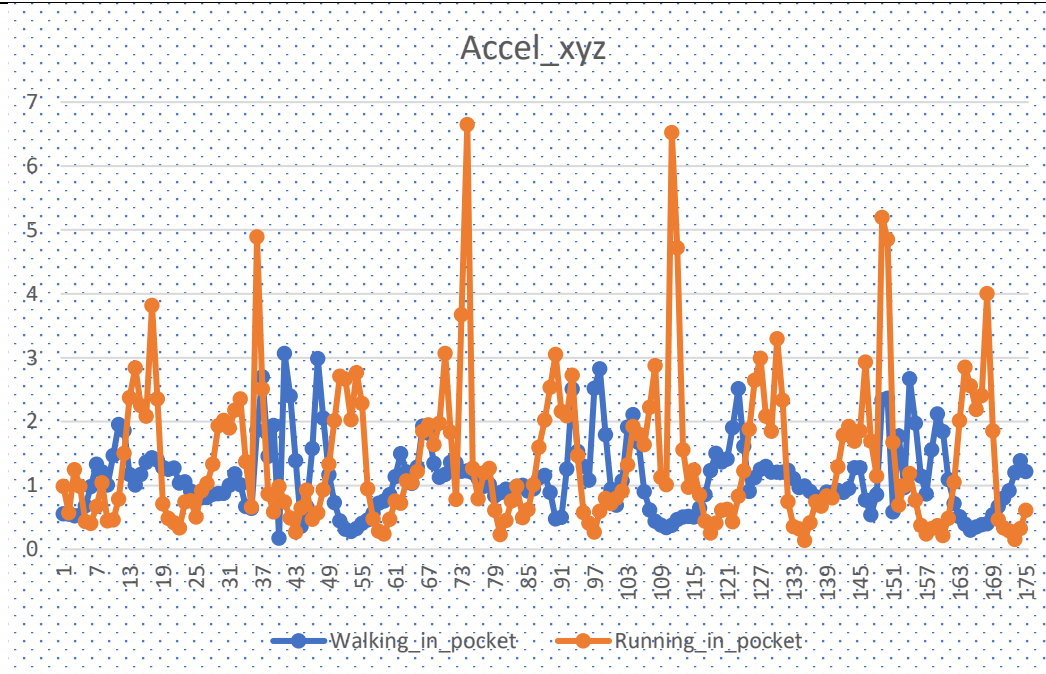
Figure 3-8:The Different Pattern Data

3.3 Developed Pedometer Program

3.3.1 The Program Operation

To run this program showed in follow picture, you can get the exact steps and the accuracy of steps calculation. How to use this program to calculate the steps, there are two procedures below should be done:

1. Fill out the path of excel file of Accelerometer data and the test frequency before click running.

2. Fill in the exact count steps in the Exact Steps and click Calculating.

Figure 3-9:The Program Of Calculating The Steps

3.3.2 The Accuracy Of Results

We can get the accuracy of this program and this algorithm showed in following form. Of course, there is not the most accurate program or algorithm, and the purpose is to show the method for calculating steps.

Action pattern	Placement of Iphone	Height	Weight	Age	ground condition	Frequncy	Number of step (exactly)	number of steps (by program)	Accuracy
Walking	in pocket of pants	173cm	60 Kilo	28	Flat	25Hz	150	250	0.6
Walking	in pocket of pants	173cm	60 Kilo	28	Flat	50Hz	235	250	0.94
walking	in hand(Natural Vertical)	173cm	60 Kilo	28	Flat	50Hz	243	258	0.94
Walking	Put the Phone Beside Ear (to answer the phone call)	173cm	60 Kilo	28	Flat	50Hz	192	250	0.77
Running	In pocket of Pants	173cm	60 Kilo	28	Flat	50Hz	258	250	0.97

.Figure 3-10:The Accuracies Of The Step Algorithms

4 Gyroscope With Balance Racing Game

4.1 The Racing Game With Gyroscope

4.1.1 How A Gyroscope Works In iPhone

Depending on the base of working principle of gyroscope, we continually discuss how a gyroscope works in an airplane, here, a figure below to show Gyroscope detecting angular velocity in three directions: Yaw, Roll and Pitch .
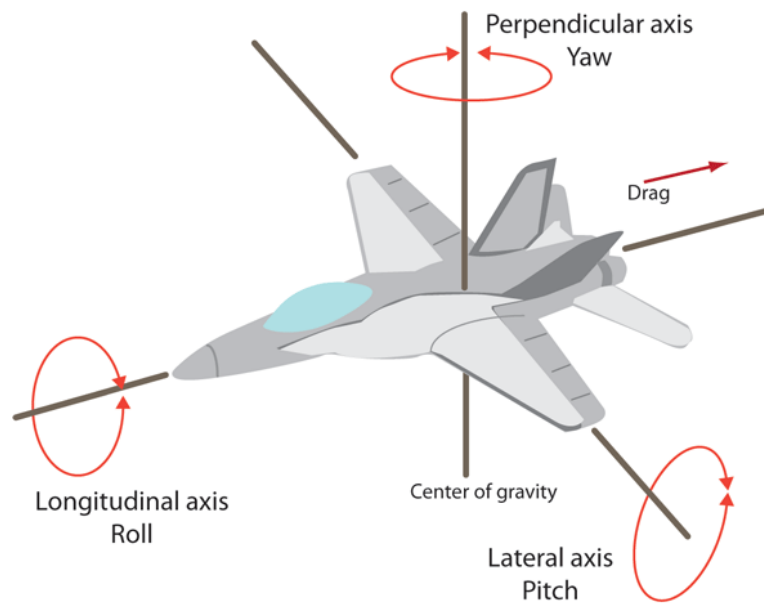
Figure 4-1: A Gyroscope Works In An Airplane (Mraz, 2014)

Absolutely, a gyroscope must be used to test the angular velocity or the orientation, so here we only need to solve two questions:

1. How to judge the current orientation of movement.

2. How to get the correct angle of the phone in every axis.

4.1.2 Get The Current Orientation Of Movement Of The Phone.

There is a figure 3.4 below showing the gyroscope in a phone with the three direction axes: roll, pitch and yaw (x, y and z). When the phone moves around any axes, the angular velocity in each axis can be detected by the Gyro in the centre position.
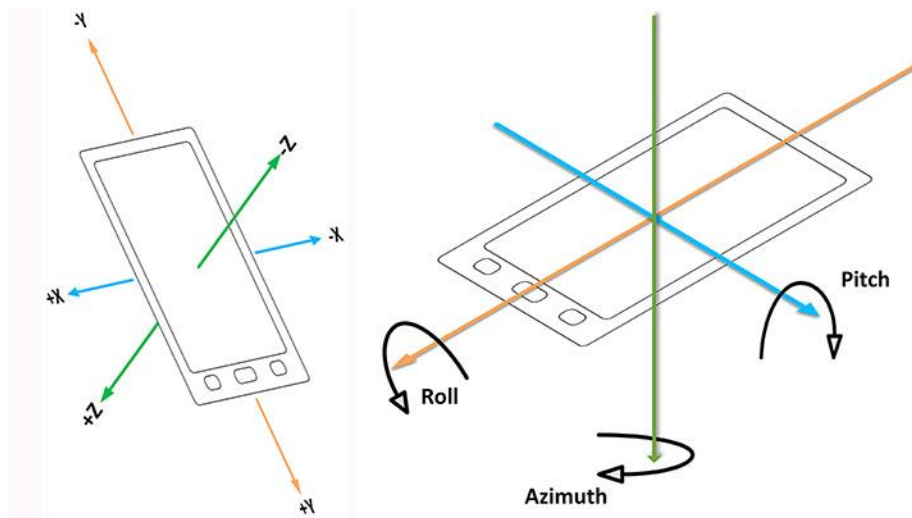
Figure 4-2: Gyroscope Sensor in A Phone (Kealy, 2017)

Here, when we try to rotate the phone up and down several times only around Pitch (x) axis, it will produce a change of the angular velocity showed in the figure below. It is clear there is almost only one orientation data change happened on Pitch(x) axis. And what the information we can summarize is that any orientation the rotation happens it will cause the angular velocity on the corresponding axis.
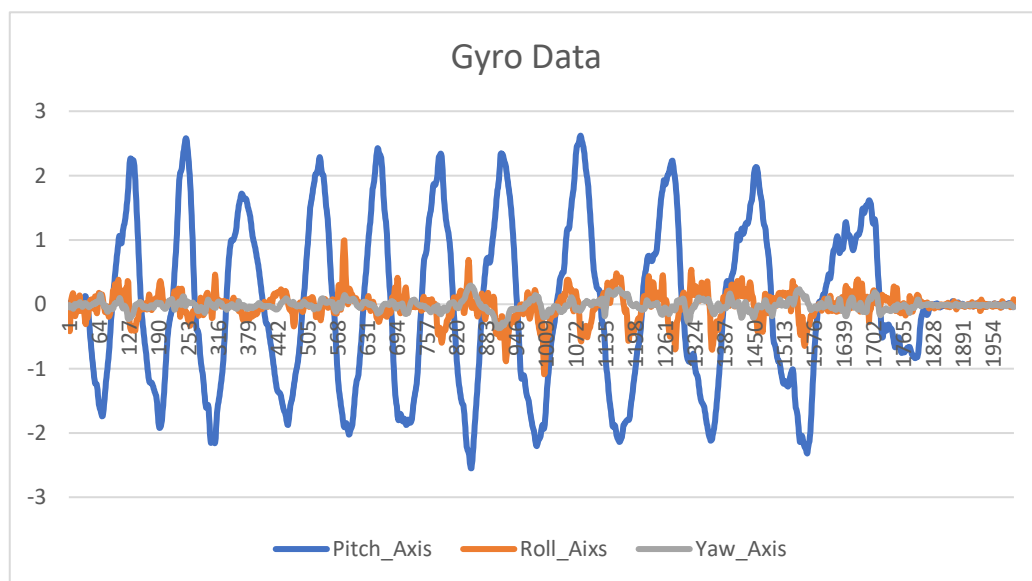
Figure 4-3: The Angular Velocities Of Three Axes Data Of Gyroscope

We can judge the orientation of current movement through the angular velocity, if there is the angular velocity in one axis, it means the phone is rotating or moving in that direction and if the value is positive, that means the phone is moving forward, vice versa.

4.1.3 Calculating the Current Angle in Pitch Axis

Before for calculating the current angle, we must be clear for two functions of the basic mathematics here. I believe everyone has studied them during high school or university Physics and Math lessons.

One of them is ϴ = dθ/dt (Pieter-Jan, 2016), ϴ means the angular velocity, dθ means radian and dt is the time period, what this function doing is to describe how to using the angular velocity to get the angle change during a period.

Since we can get the angle in a specific period using the function above, in the next step we need to think how to get the absolute angle in any time.

Therefor another function should be mentioned here:

Θ(t) = ∫(0,1t)ϴ(t)*dt ≈ Σ(o,t)ϴ(t)*Ts (Pieter-Jan, 2016)

What function does is using the integral principle to integrate the angular velocity in all the period from time 0 (t=0) to get the absolute angle. However, this is just a theoretical formula and there are some errors caused by two reasons. First one is because the sampling frequency is possible slower than the data changes and another cause is drift which causes the sensor reading not returning to 0 at the rest position, so to avoid those errors it is better to choose the high sampling frequency (100 Hz in Gyroscope used in this thesis).   The next part, there is an example for explaining how to use those equations to calculate an exact angle.

4.1.4 How a Gyroscope Works for The Racing Game

4.1.4.1 The Principle of Racing Game

Figure 4-4: Racing Game In iPhone (H, 2010)

Anybody may play the racing game in mobile phones or Pads and it is easy to get how to play it after trying several times. What you should do for operating this game is to control the horizontal balance offset for controlling the direction of the running of the car, in another word, just controlling the angle of the horizontal offset (or pitch axis in the picture below) can control the tilting direction of the car running. In a word, using the gyroscope to get the exact angle in Pitch (x) axis is the key point of this game.

Figure 4-5: Gyro With Racing Game (H, 2010)

4.1.4.2 Getting The Exact Angle Offset In Horizontal Level (Pitch axis)

Here using iPhone 6 as an example, 100 Hz sampling rate. This is ideal option of the frequency, but in different situations should be set in different frequencies for reducing the error rate.

There are gyro data caught from iPhone in the form below during playing a racing game. It simulates the action of playing race game through rotating the iPhone 6 around Pitch axis and we can ignore Roll and Yaw data, since we do not need to use them in this condition.
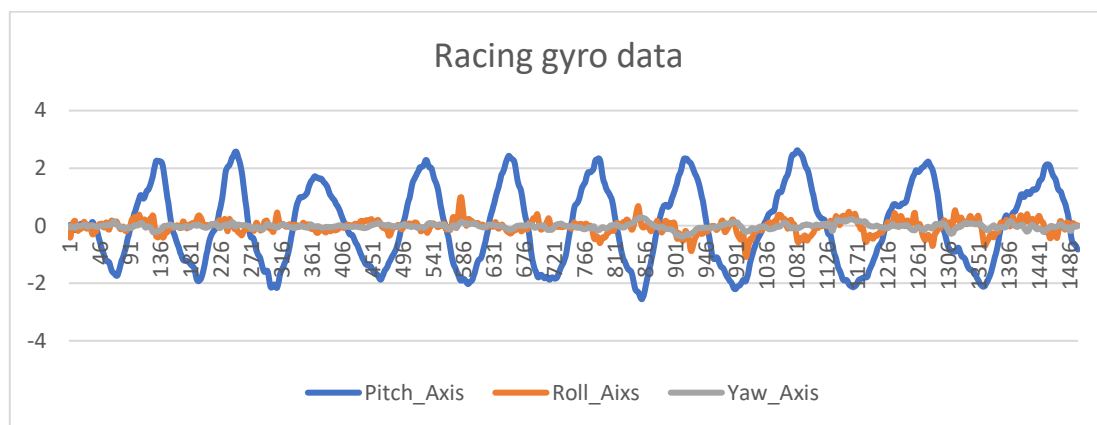
Figure 4-6:Racing Gyro Data Of Three Axes

Here，from the picture above, we can use the integral principle mentioned above to collect the corresponding angle value below. What we can see from the form below is the phone are rotated about 50 degrees around Pitch axis. Obviously, there is a certain error because of the disturbance, and another way for calculating a more accurate angle will be discussed in next chapter for enhancing the accurate rate.
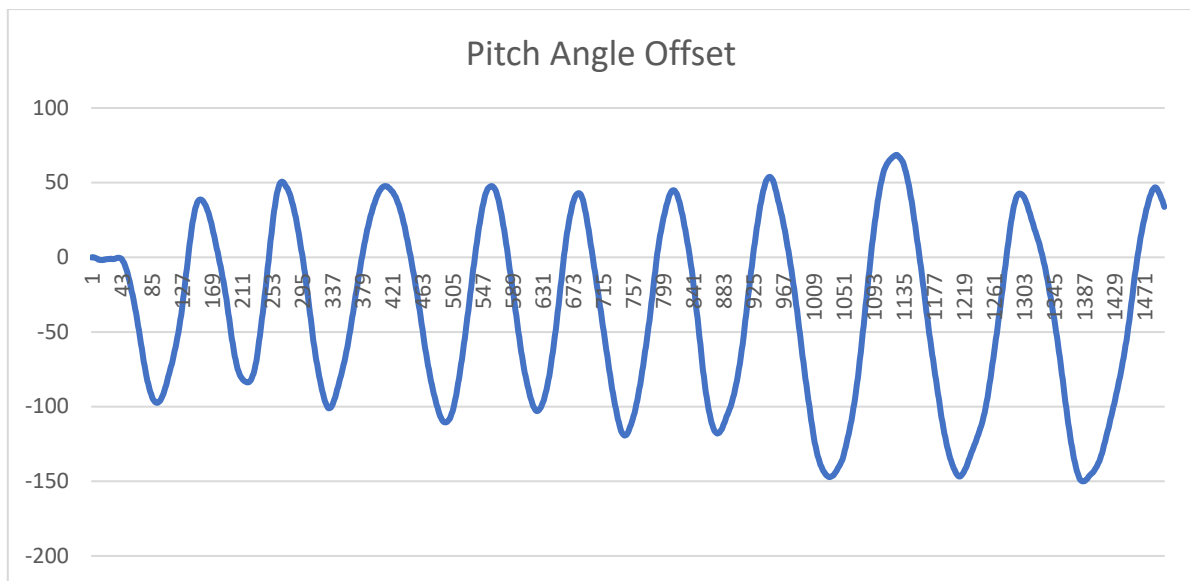
Figure 4-7: The Pitch Angle Offset From The Racing Game

5 A Glow Stick with Accelerometer and Gyroscope

From those three chapters above, we can know how to use Accelerometers and Gyroscopes to identify or detect some kinds of actions or postures, but it is possible to use it in a new action recognition and how a glow stick can show different colour lights in different actions, those will be discussed in this chapter.

5.1 Appearance and Function Description

5.1.1 A Normal Glow-Stick

How a normal glow stick works, everyone may have some experience for that. There is a picture below, when you turn on the switch on the handle, a glow stick will be lit in a specific colour.

Figure 5-1: A Kind Of Glow Sticks

 There is no doubt that it is very gorgeous in a concert when the countless light sticks come on.

Figure 5-2: A Vocal Concert

5.1.2 A Multifunctional Glow-Stick

What kinds of new functions can be created for a glow stick, absolutely it is related with action recognition algorithm.

You can imagine if the light sticks moved in different directions will show different colours of light, it will be a very interesting idea. For example, when you shake the light sticks in perpendicular to the body, the glow stick will display the blue colour, and in the parallel plane to body, the glow stick will show the yellow colour, or in a round way above your body, the glow stick will show the red colour.

The automatic action or posture recognition is the key point for this function, and it is what have been mentioned above.

On the other hand, not only the colors of light can be controlled by different postures, but also the accelerometer and gyroscope can be used to adjust the brightness of lights.

Figure 5-3: Audiences Shake Glow Sticks

5.2 Why We Need Accelerometer And Gyroscope

There are two functions mentioned above, which should be made sure in multifunctional glow sticks, and those functions are both relative with action recognition algorithm and acceleration.

5.2.1 Gestures Recognitions

 At First, function 1, shaking in different directions the glow sticks will display different colors of light. There are two kinds of movements or gestures those should be identified by the sticks, here the accelerometer and gyroscope can be used to analyze or recognize those movements; at same time, recording the times of shaking.

Action 1: shaking sticks in perpendicular to the body, the stick should display blue color. In detail,

Action 2: shaking in the parallel plane to body, the glow stick should show the yellow colour.

5.2.1.1 Accelerometer and Gyroscope in the iPhone 6

How the accelerometer and Gyroscope work in iPhone 6, which have mentioned in last two chapters. In the last charter, we already got that Gyroscope senses the rotation, whereas another is used to gain acceleration. And there is a picture below showing what exactly those two sensors test, Gyro tests the spinning angle and Accelerometer tests the angles in three directions relative with the gravity. Here, we use the iPhone to simulate a multifunctional glow-stick and setting the screen of the iPhone 6 is parallel with my body and faces forward. The figure below shows the x, y and z axes of Accelerometer and Pitch, roll and yaw of Gyroscope in iPhone 6.
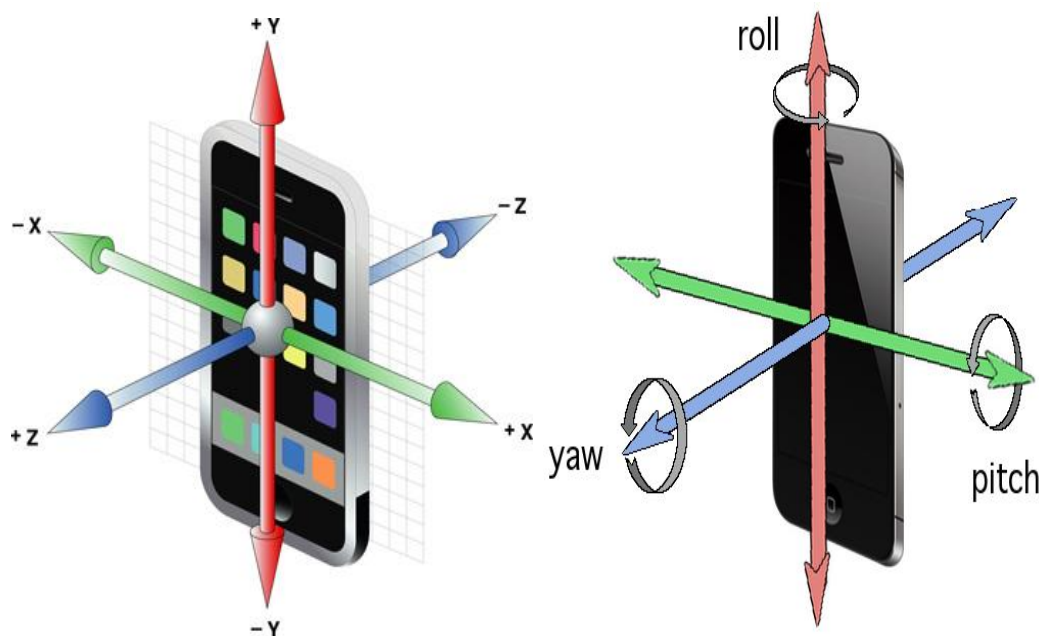
Figure 5-4: Scanning Rooms With An iPhone. (Przemek, 2014)

5.2.1.2 Using Accelerometers & Gyroscopes for twhe Angle Restrictions.

For those three actions recognition, exactly just only using the accelerometer can calculate an enough precise angle in three directions relative with the gravity. However, it is not enough for totally identifying those three actions, since sometimes the glow stick may rotate by itself, this cannot be tested by an accelerometer. In a word, the key point is to make sure the restrictions or standards for controlling an exact range of the angle changes in different

directions, so at first we need to research how to use those two devices calculate the useful angles.

The last chapter mentions only using gyroscope to calculate the angle of the rotation around pitch axis in Racing Game. However, the angle calculated in this way is inaccurate, there is an algorithm which can be used to increase the accuracy.

5.2.1.3 Using Complementary Filter Algorithm to Eliminate Drift of Gyro.

What is Complementary Filter algorithm it can be searched in lots of websites and it is easy to understand. Since the two devices reflect oppositely in long term and short term running, for example, when Gyro runs for a long time, the drift will increase and at the same time the accuracy of angle calculating will decrease. Here, we can use Complementary Filter algorithm to merge the acceleration value with gyroscope value, which can reduce the drifting error. There is a formula for merging the two kinds of values and with a diagram showing the function of the Merging Algorithm.

$Mgyro = K1 * Cgyro * Dt + K2 * Caccel;$

Rgyro: the angular velocity after merging algorithm.

Cgyro: the real-time angular velocity.

Dt: Using to integrate the angle in a period.

Caccel: the real-time acceleration.

K1: here is 0.98.

K2: here is 0.02.

The function aims to remove the noise from accelerometer and eliminate the drift of Gyro, and there are two figures below showing the difference between the change of the spinning angle without using Complementary Filter algorithm in first figure and the change of the spinning angle after using Complementary Filter in the second figure. It is absolutely that using Complementary Filter Algorithm can almost eliminate the drift of Gyroscope data.
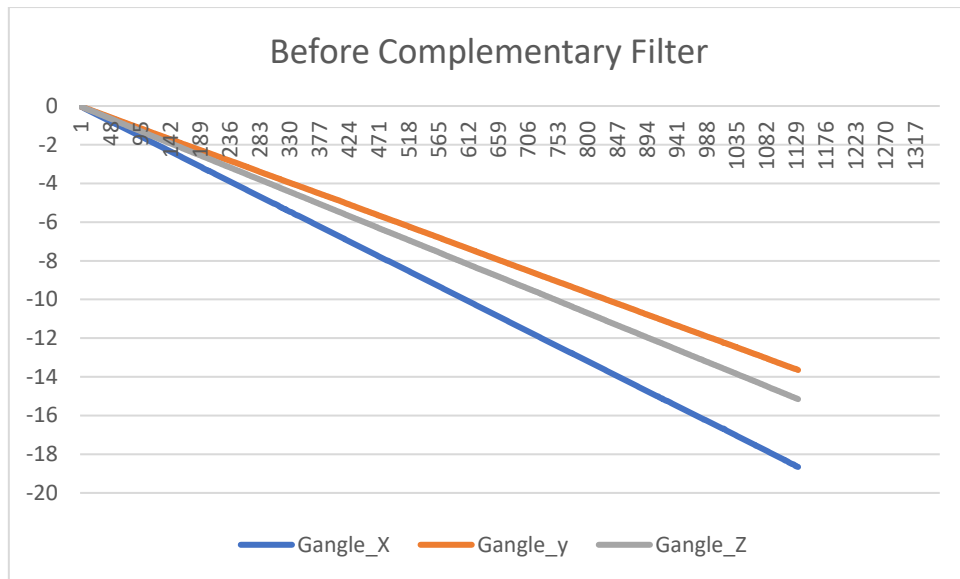
Figure 5-5:The angle change putting the phone on the flat table
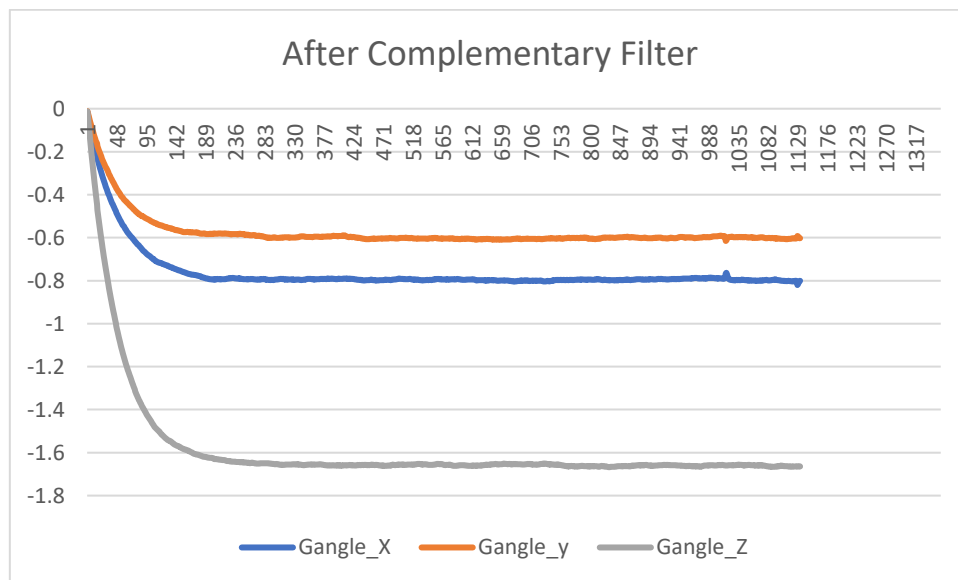
Figure 5-6: Removing drift after Complementary Filter

5.2.1.4 Calculating a Slant Angle by Accelerometers

At first, it uses the Accelerometer to calculate the angle of action 1: shaking the sticks in perpendicular to the body. We can imagine that when the glow stick is shaken in perpendicular direction with the body, nearly only the acceleration of Z axis acceleration will change during the shaking period.

How can we calculate the angle value by only accelerometer?

We should use the gravity during this process. Firstly let us see a figure below, imagine that is a phone put on the horizontal desk and the g means gravitational acceleration which is g=9.80665 m/s^2.
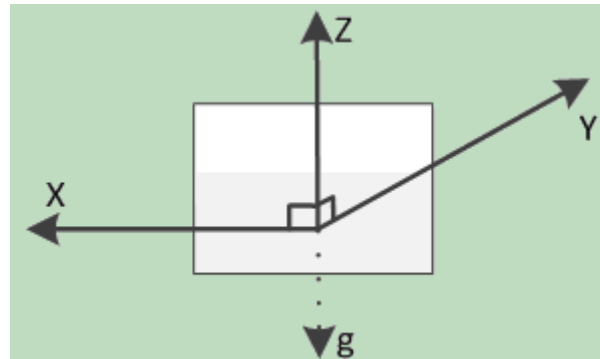
Figure 5-7: The Direction Of The Gravitational Acceleration Of An Object (CSDN Blogs, 2014)

When the position changes like the picture below, and what information we can get is that the acceleration of X , Y and Z are Ax, Ay and Az respectively, and the value of radian: α_1 、 β_1 、 γ_1 are the angles between X, Y and Z with horizontal line respectively and absolutely α 、 β 、 γ are the angles between X,Y and Z with g line: $\alpha = 90° - \alpha_1$, $\beta = 90° - \beta_1$, $\gamma = 90° - \gamma_1$. We can get: Ax = gcos α , Ay = gcos β , Az = gcos γ and changing a formula to Ax = gcos α = gcos(90° - α_1) =gsin α_1 and also Ay = gsin β_1 , Az = gsin γ_1.

Following the picture below and using Pythagorean proposition, we can get g*g = Ax*Ax + gcos α1*gcos α1, so other equations can be got using Trigonometric function theorem at same time: gcos α1 = sqrt(g*g - Ax*Ax)，gcos β1 =sqrt(g*g - Ay*Ay)，gcos γ1 =sqrt(g*g - Az*Az)). There is another equation got by principle of equilibrium: Ax*Ax + Ay*Ay + Az*Az = g*g. (CSDN Blogs, 2014)

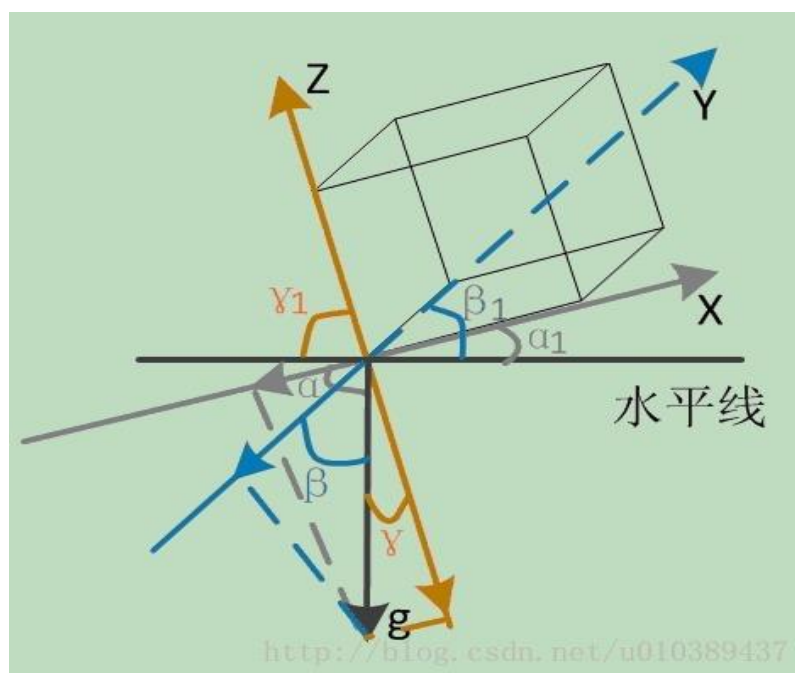Here, using the equations we already got: sin α1 = Ax/g，cos α1 = sqrt(g*g - Ax*Ax) / g. And another changing equation is tan α1 = Ax / sqrt(Ay*Ay + Az*Az) . In the same way, we can get tanβ1 = Ay / sqrt(Ax*Ax + Az*Az)，tanγ1 = Az / sqrt(Ax*Ax +Ay*Ay)。

The Radian respectively:

α1 = arctan(Ax / sqrt(Ay*Ay + Az*Az))

β1= arctan(Ay / sqrt(Ax*Ax + Az*Az))

γ1= arctan(Az / sqrt(Ax*Ax +Ay*Ay))

And using Radian = θπR/180 formula to get the real angle value: (CSDN Blogs, 2014)

θx = α1*180/π = [arctan(Ax / sqrt(Ay*Ay + Az*Az))] *180/π

θy =β1*180/π = [arctan(Ay / sqrt(Ax*Ax+Az*Az))]*180/π

θz =γ1*180/π = [arctan(Az / sqrt(Ax*Ax +Ay*Ay))]*180/π

Using the angle calculation formula, we can get a diagram below, horizontal ordinate is time that the unit is 0.01 s and vertical ordinate is the angle the unit is one degree, shows an iPhone is vertically put up from a desk. The inclination changes below in X, Y and Z axes, Y axis changes from 0° to -90° and Z axis

changes oppositely from -90° to 0°, and absolutely the X almost does not change since the X axis is always parallel with the desk level.

Figure 5-9: Put The Phone Up
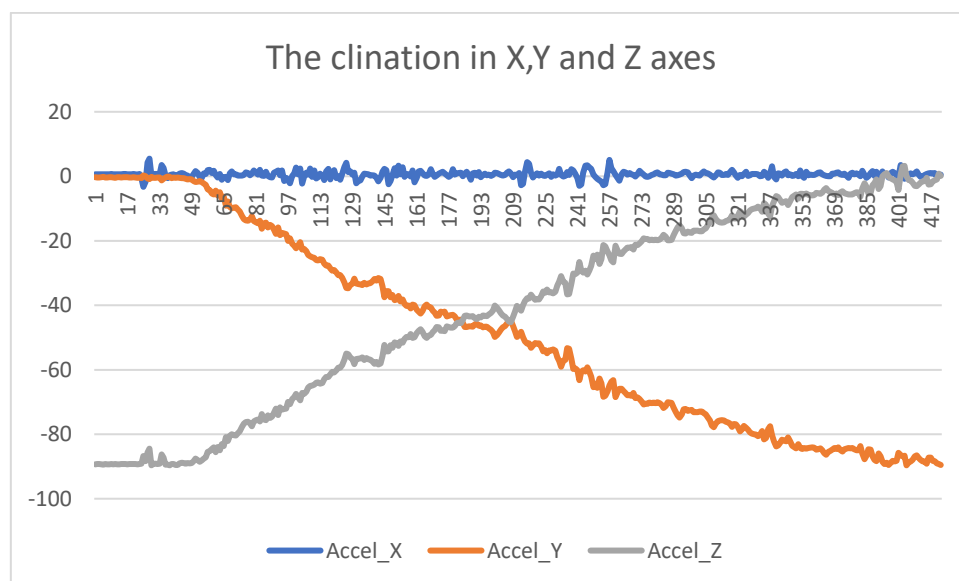
Figure 5-10: Testing the change of the inclination when puttingc the phone up vertically

This angle value calculated by the raw data from accelerometer can be achieved through a piece of code below, `Accel.Daccel_x`, `Accel.Daccel_y` and `Accel.Daccel_z` are raw data caught from accelerometer and `Accel.A_angle_x`, `Accel.A_angle_y` and `Accel.A_angle_z` are the inclination angles with X, Y and Z axes respectively.

```
#define PI 3.14159265358979323846
```

```
double Sqrt_x = sqrt(Accel.Daccel_y * Accel.Daccel_y +Accel.Daccel_z * Accel.Daccel_z);
double Sqrt_y = sqrt(Accel.Daccel_x * Accel.Daccel_x +Accel.Daccel_z * Accel.Daccel_z);
double Sqrt_z = sqrt(Accel.Daccel_x * Accel.Daccel_x +Accel.Daccel_y * Accel.Daccel_y);

Accel.A_angle_x = (atan(Accel.Daccel_x / Sqrt_x) * 180) / PI;

Accel.A_angle_y = (atan(Accel.Daccel_y / Sqrt_y) * 180) / PI;

Accel.A_angle_z = (atan(Accel.Daccel_z / Sqrt_z) * 180) / PI;
```

5.3 Action Recognition Algorithms

5.3.1 Identifying Two Gestures by Two Kinds of Angles

Basing on the last two sections, we can get the spinning angle and the inclination angle in three axes. In this section, first of all, it is to analyze the changes of the angles during a movement to find the regulations; and then, the next step is to make the restriction conditions of the change scope of those two kinds of angles.

There are two ranges of self-spinning angle and inclination angle from gyro and accelerometer, which be used together to identify two gestures. For example, the action1, when you rotate the glow sticks in three axes over the range tested by Gyro, it will be judged as a wrong action or not action1 even the inclination can meet the standards. On the other hand, when you shake the glow stick in a very small angle change range tested by accelerometer, it cannot be identified since the angle change does not meet the standards.

5.3.2 The Period of Data Collection and Filtering Noise

The testing frequency is always 100 Hz during collecting data, which means the collection period is 0.01s, so the unit of the horizontal ordinate is 0.01s in the figures of the data of the spinning angle or inclination angle in three axes.

We can use the fastest duration between two movements to falter the noise, which has been maintained in the Charter 2.3.2 as Transform Domain Algorithm.

From this kind movements, we can get that the duration of two effective adjacent peaks or movement must be longer than 0.04S and shorter than 2.5s.

There is piece of code below, the `struct Domain_Num` recording the number of the last time datum and `numi` recording the number of the current datum, and the following piece of code realizes the transform domain algorithm to filer the noise.

```c
 //Transform Domain Algorithm
struct Domain_Num {
        int numi;
        int numi_last;
};

// bewtween 0.08s and 2.50s
if ((Domain.numi - Domain.numi_last) > 40 && (Domain.numi - Domain.numi_last) < 2500)
        act = 1;
else
        act = 0;

Domain.numi_last = Domain.numi;
```

5.3.3 Collecting and Organizing Data

There is an example already mentioned in 4.2 chapter, when put the phone up from the desk level, the Z-axis angle increases when Y-axis decreases. Using this principle can make a set of algorithms to identify gestures and also count the times of the gesture happened, since there are some differences of the tendency of the angle change between those two gestures. Let illustrate one by one:

Gesture 1: Shake the sticks in perpendicular to the body, the stick should display blue color. Holding the phone makes the screen facing the same direction with you and shakes forward and behind.
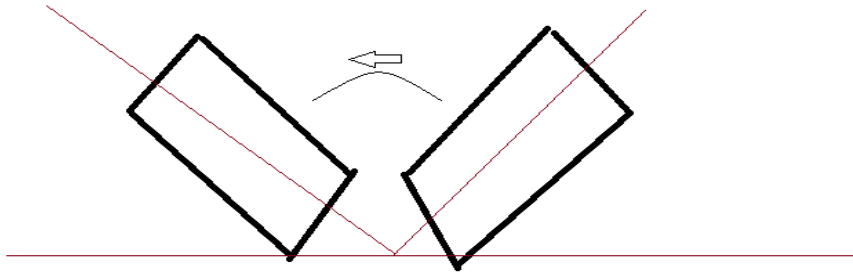
Figure 5-11: Shank The Phone In Gesture1

There are two basic conditions to judge a valid gesture 1.

Condition 1: First is to analyze the self-rotation angle change to make threshold values of restrictions in three axes which are defined in Table 1 below. When the values of self-rotation angle in three directions can meet the threshold values, it means the data satisfy this condition.

Figure 5-12: Spinning Angle Changes in Gesture 1

Table 5.1: Spinning Angle Restrictions in Gesture 1

Gyro testing angle	Minimum	Maximum

X-axis Spinning Angle	−150°	150°
Y-aixs Spinning Angle	−60°	60°
Z-aixs Spining Angle	−60°	60°

The piece of code below realize this a judgement.

`action_123[0].gyro_x[0]` and `action_123[0].gyro_x[1]` represent the threshold data of spinning angle with X-axis.

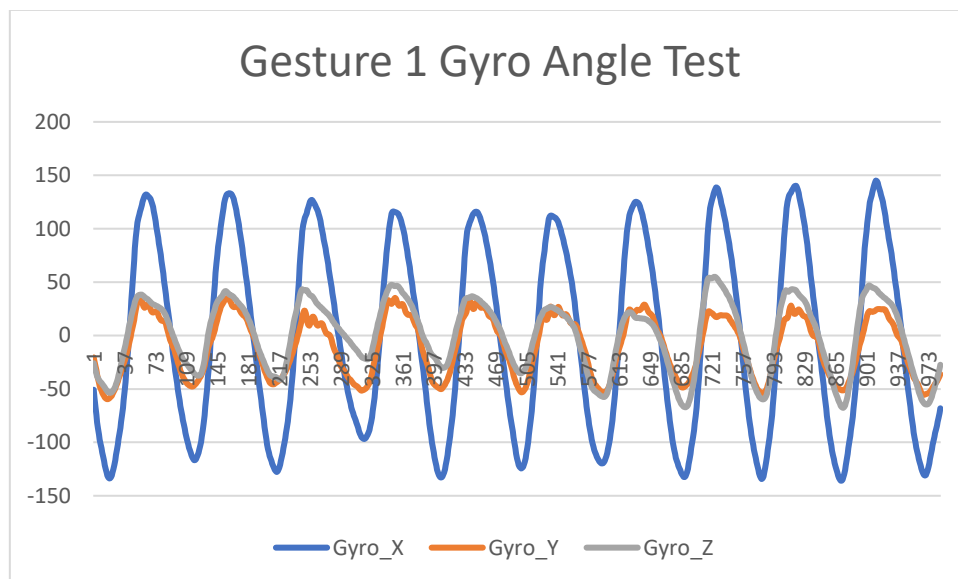`action_123[0].gyro_y[0]` and `action_123[0].gyro_y[1]` represent the threshold data of spinning angle with Y-axis.

`action_123[0].gyro_z[0]` and `action_123[0].gyro_z[1]` represent the threshold data of spinning angle with Z-axis.

```
if (Gyro.G_angle_x > action_123[0].gyro_x[1] || Gyro.G_angle_x <  action_123[0].gyro_x[0])
                continue;
if (Gyro.G_angle_y > action_123[0].gyro_y[1] || Gyro.G_angle_y < action_123[0].gyro_y[0])
                continue;
if (Gyro.G_angle_z > action_123[0].gyro_z[1] || Gyro.G_angle_z < action_123[0].gyro_z[0])
                continue;
```

Condition 2: Restricting a range of the change of inclination angles with three direction axes, which can be seen in Table 4.2 below, when the three direction data can all meet the standards, which means those data are available data.
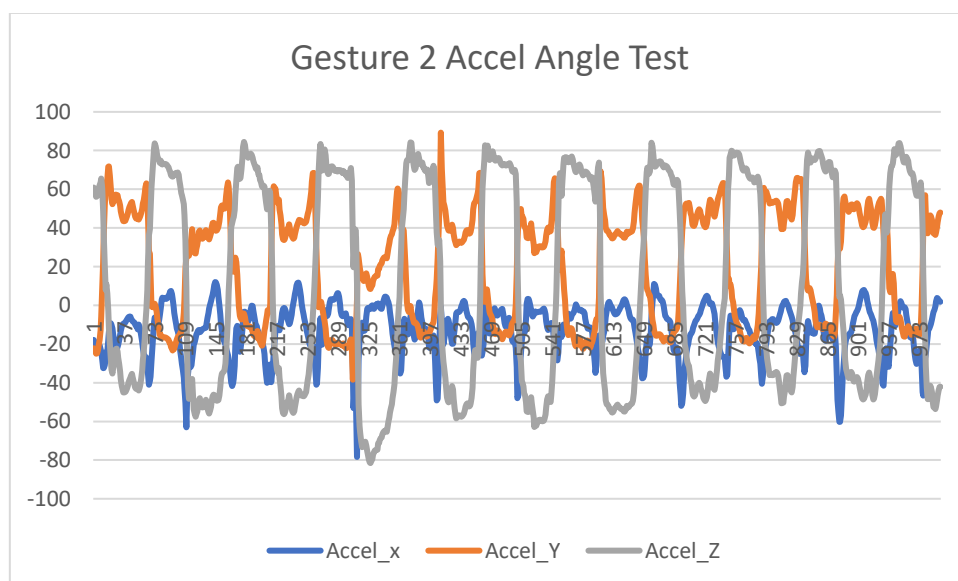

Gesture 2 Accel Angle Test

Figure 5-13: The Inclination angle change in Gesture 1

Table 5.2: Angles With The Gravity Restrictions In Action 1

Accelerometer Testing	Valid Range	Regulation
Inclination – Z-axis (Centre axis)	< -60° or >62°	For Gesture 1, first and foremost ,the inclination with Z axis should be in the valid range
Inclination – X-axis	-15° to 5°	And then, control the inclination swith X axis.
Inclination – Y-axis	-10° to 13°	Finally, control the inclination with Z axis.

There is a piece of code below realizes the judgement of the threshold data of the inclination in three axes. When `i == 0`, which means here using the threshold data of gesture 1, and this code if `(Accel.A_angle_z < action_123[i].accel_z[0] || Accel.A_angle_z >action_123[i].accel_z[1])` is used to restrict the inclination angle in Z-axis.

```
if (i == 0)
{
  if (Accel.A_angle_z <  action_123[i].accel_z[0] || Accel.A_angle_z >action_123[i].accel_z[1])
  if ((Accel.A_angle_y >action_123[i].accel_y[0] && Accel.A_angle_y< action_123[i].accel_y[1]))
  if (Accel.A_angle_x > action_123[i].accel_x[0] && Accel.A_angle_x < action_123[i].accel_x[1])
      flag[i] = true;
}
```

Gesture 2: shaking in the parallel plane to body, the glow stick should show the yellow colour.
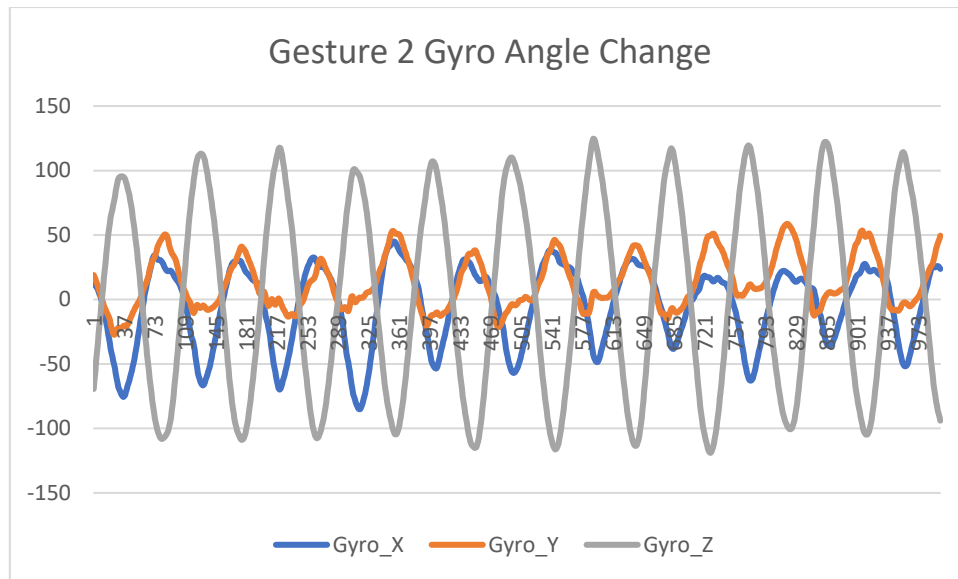
Figure 5-14: Spinning Angle Changes In Action 2

Table 5.3: Spinning Angle Restrictions In Action 2

Gyro testing angle	Minimum	Maximum
X-axis Spinning Angle	-50°	50°
Y-aixs Spinning Angle	-50°	50°
Z-aixs Spining Angle	-150°	150°

`action_123[1].gyro_x[0]` and `action_123[1].gyro_x[1]` represent the threshold data of spinning angle with X-axis.

`action_123[1].gyro_y[0]` and `action_123[1].gyro_y[1]` represent the threshold data of spinning angle with Y-axis.

`action_123[1].gyro_z[0]` and `action_123[1].gyro_z[1]` represent the threshold data of spinning angle with Z-axis.

```
if (Gyro.G_angle_x > action_123[0].gyro_x[1] || Gyro.G_angle_x <  action_123[0].gyro_x[0])
                    continue;
if (Gyro.G_angle_y > action_123[0].gyro_y[1] || Gyro.G_angle_y < action_123[0].gyro_y[0])
                    continue;
if (Gyro.G_angle_z > action_123[0].gyro_z[1] || Gyro.G_angle_z < action_123[0].gyro_z[0])
                    continue;
```
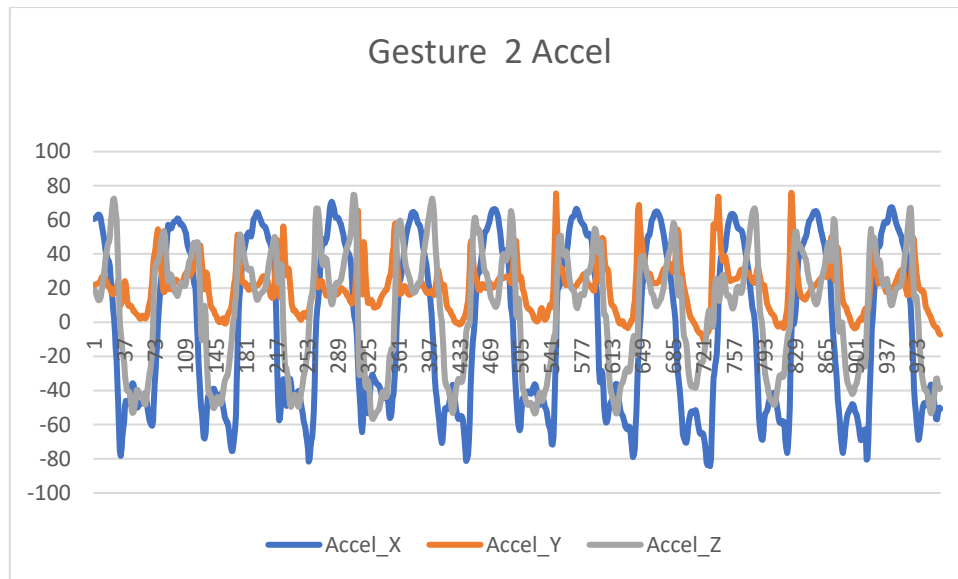
Figure 5-15: The Change of Inclination Angles in Gesture 2

Table 5.4: The Range of the Inclination Angle in Gesture 2

Accelerometer Testing	Valid Range
Inclination – X-axis (Centre axis)	<-63° or >63°
Inclination – Y-axis	-10° to 30°
Inclination – Z-axis	-10° to 30°

There is a piece of code below realizes this judgement of the inclination angle with three-axes. Here, firstly this line of code : `if (Accel.A_angle_x < action_123[i].accel_x[0] || Accel.A_angle_x >action_123[i].accel_x[1])`, it judges the inclination angle of X-axis as an initial condition, and then just the inclinations of Y-aixs and Z-axis, the same with judging gesture 1.

```
if (i == 1) {
  if (Accel.A_angle_x <  action_123[i].accel_x[0] || Accel.A_angle_x >action_123[i].accel_x[1])
  if (Accel.A_angle_y > action_123[i].accel_y[0] && Accel.A_angle_y < action_123[i].accel_y[1])
  if (Accel.A_angle_z > action_123[i].accel_z[0] && Accel.A_angle_z < action_123[i].accel_z[1])
      flag[i] = true;
}
```

In code, defining those threshold values in a structure below:

```
struct Action_angle_strict action_123[2] = {
      { -30, 30, -10, 10, -10, 10, -15, 15, -10, 13, -63, 63 },  // action1  control Z-axis
      { -10,  10,  -10,  10,  -30,  30,   -63,  63,   -10, 30,   -10, 30 }, // action2 X-aixs
```

51

```
};
```

5.3.4 Validating the Collection Data

After judging the data validity through the threshold values, there is other two algorithms to validate whether it is a valid gesture or not.

First: a valid gesture happened should be there are more than 4 continuous valid data of the inclination angle meet the standards; in this way, it can avoid some individual abnormal data affecting the result.

Second: In one time can only one gesture happen and there must be a module change, which means the data of Inclination angle must change from invalid range to an invalid range to prove this is a movement, not just a static condition.

There is a piece of code below realizing the function, for example. `aflag.last_times[0]` Gesture 1 flag variable and `aflag.last_times[1]` is Gesture 2 flag variable ,when there is a specific gesture happened it will become 1 from 0, and `aflag.previous_time` means how many times the data continually meet the condition, and `act` is a flag for marking a gesture happens or not, if `act == 1` means there is a correct gesture caught.

```
if (aflag.last_times[1] != 0)
{
        aflag.last_times[0] = 0;
        aflag.last_times[1] = 0;
        aflag.previous_time = 0;
        act = 0;
}
else {
        if (aflag.previous_time == 4)
                aflag.last_times[0]++;
        aflag.previous_time++;


        if (aflag.last_times[0] == 1) {
                aflag.last_times[0] = 0;
                act = 1;
        }
        else {
                act = 0;
        }
}
```

5.4 The Test Program of the Action Recognition

5.4.1 The Interface of the Program

The program interface below can run two files, Acceleration file and Gyroscope file from iPhone, to calculate how many times those three actions happens, so in this way, it can totally show the action recognition algorithm works and prove those kinds of products which will be created in near future market.
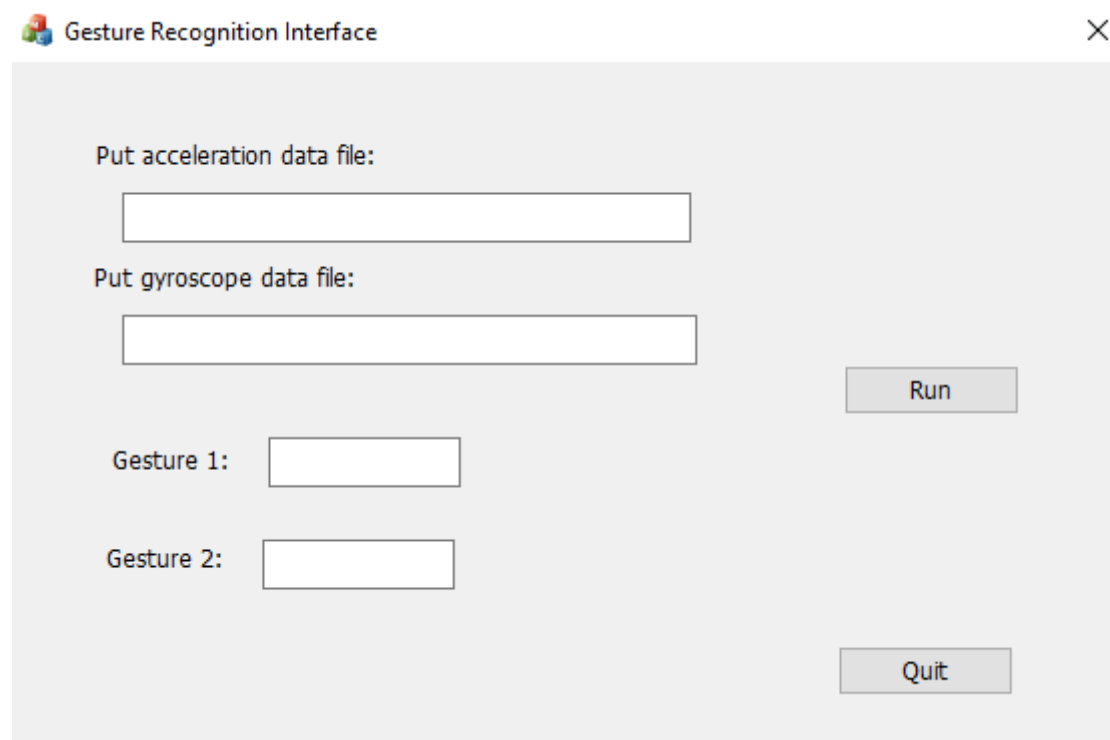

Figure 5-16 Action Report Interface

5.4.2 Gesture Recognition Accuracy Using This Tool

Gesture 1: There are two figures showing the data of accelerometer and gyroscope during the process of shaking the phone 20 times in gesture 1.

Figure 5-17 Gesture 1 Gyro Data

Figure 5-18 : Gesture 1 Acceleration Data

Figure 5-19 Action 1 Calculation Result

The accuracy of this gesture tool can be calculated below:

Gesture Number	Exact Shaking times	Testers tests	Accuracy
1	20	18	90%

Gesture 2: There are two figures showing the data of accelerometer and gyroscope during the process of shaking the phone 20 times in gesture 2.
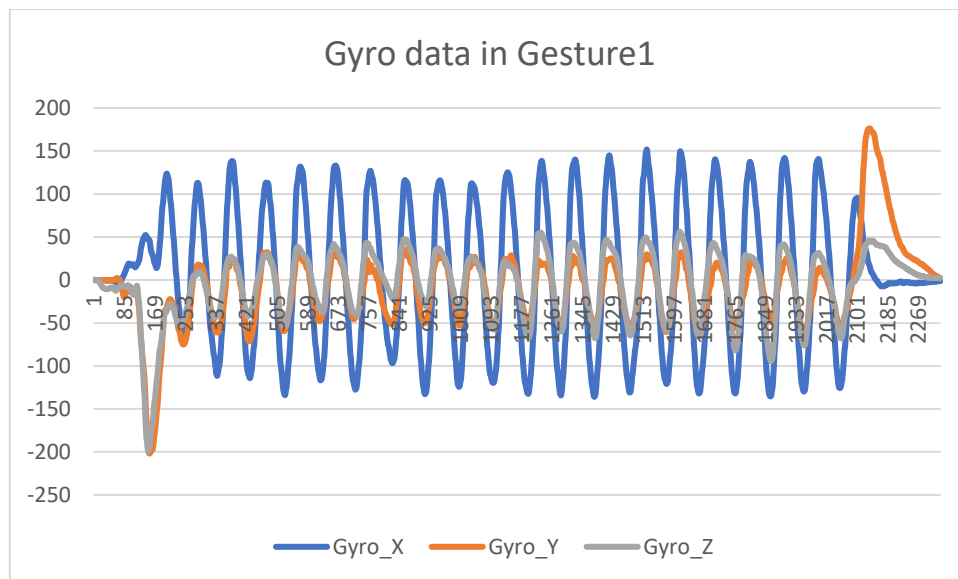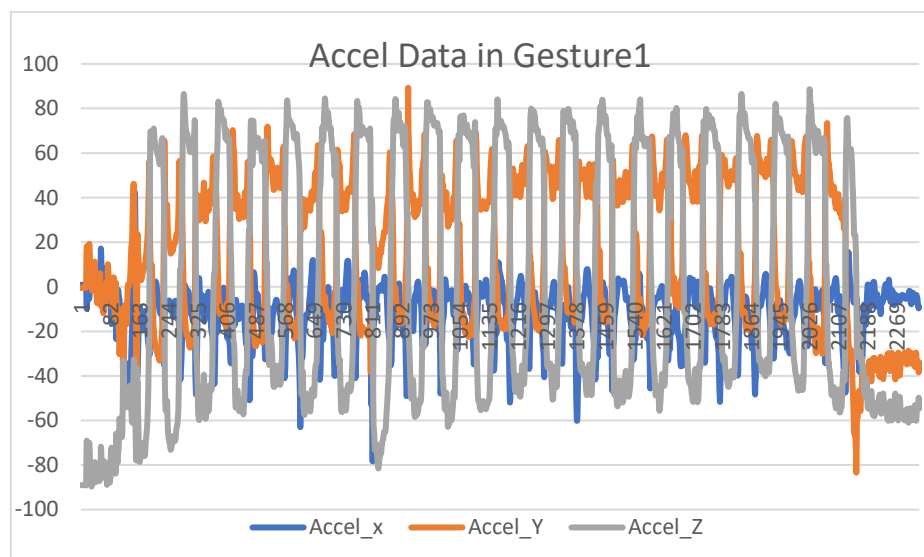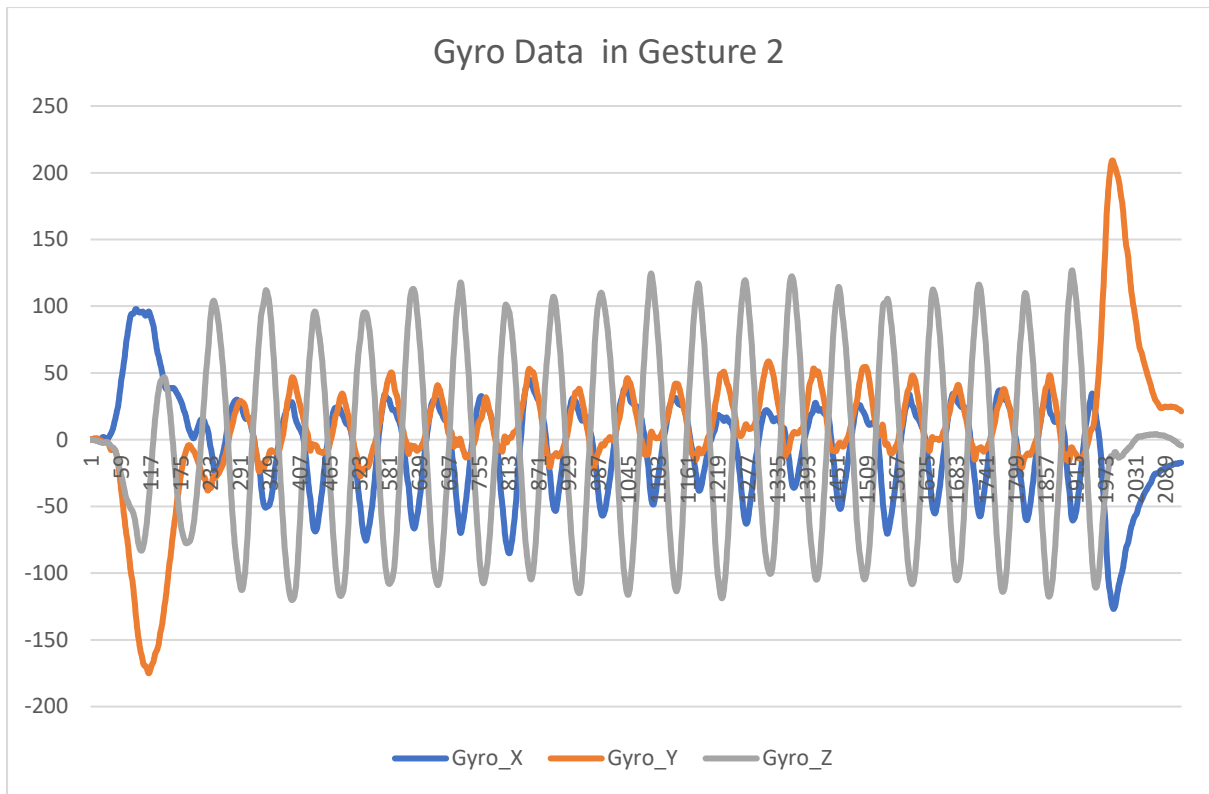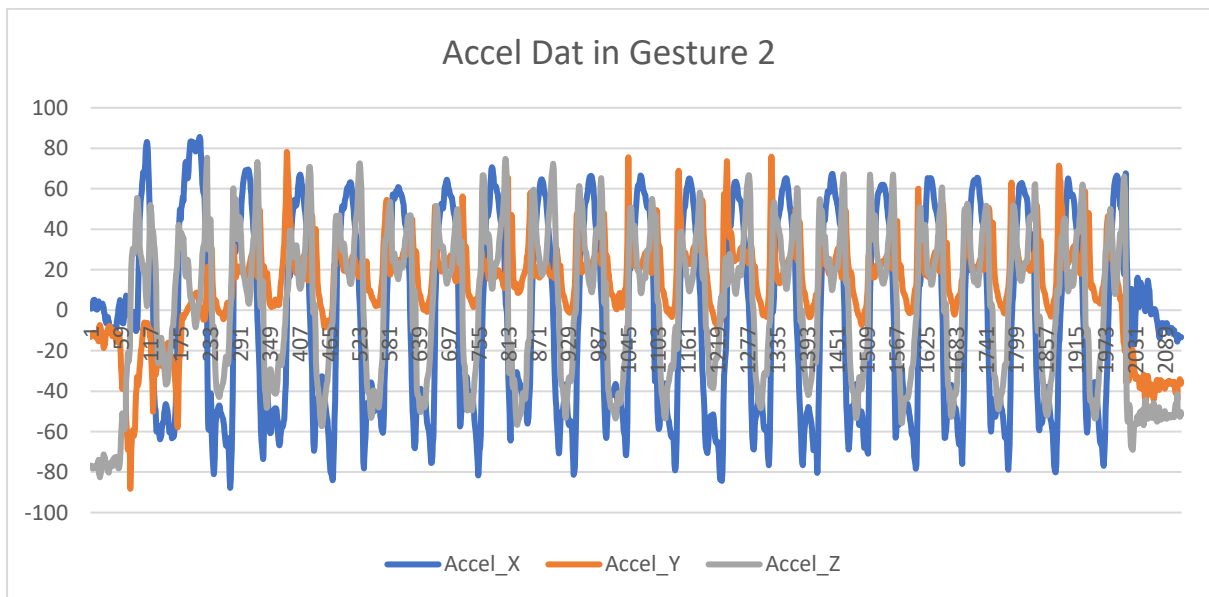
Figure 5-20 Gesture 2 Gyro Data

Figure 5-21 : Gesture 2 Acceleration Data
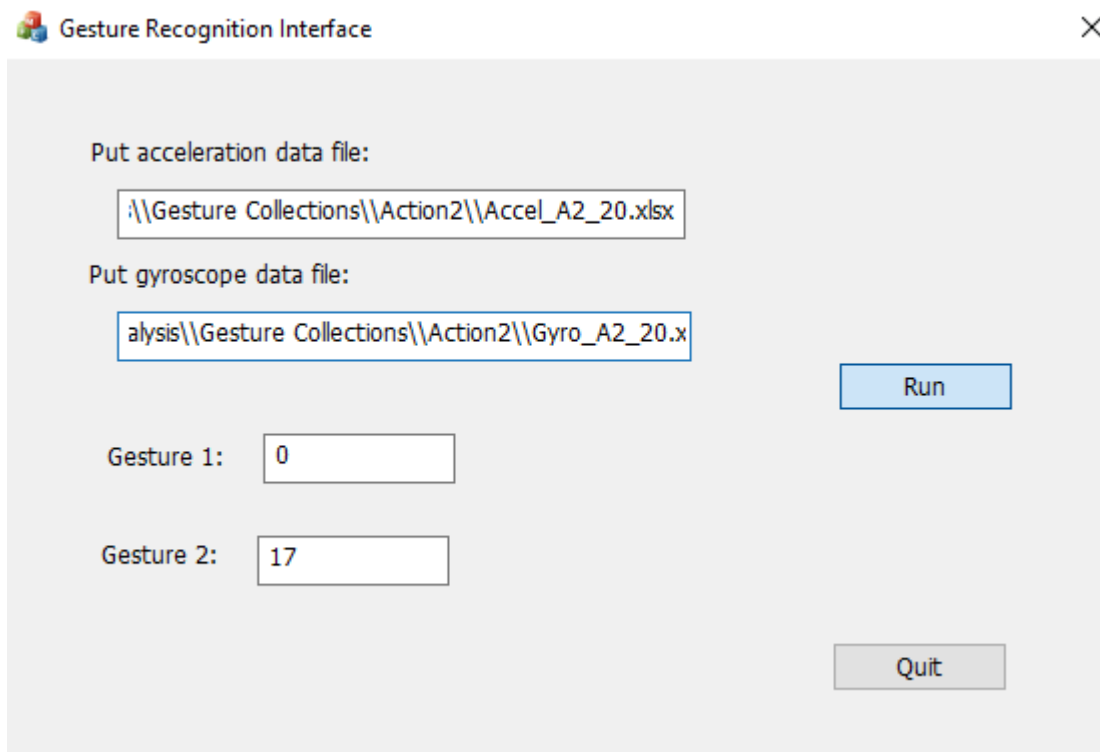
Figure 5-22 Action 2 Calculation Result

The accuracy of this gesture tool can be calculated below:

Gesture Number	Exact Shaking times	Testers tests	Accuracy
2	20	17	85%

5.5 Summary

This chapter shows how to Gyroscope and Accelerometer together to recognize two gestures and the times of shaking a glow-stick. After the basic understanding for the structures of Gyroscope and Accelerometer in previous chapters, continually analyze the data, and then get some suitable algorithms and strategies to make program for a judgement of the gestures. Finally, the accuracy of the program should be calculated through the experiments of data

analysis and what can be got is the accuracies of the recognition of the gesture1 and gesture2 are 90% and 85% respectively.

6 Conclusion and Future Work

In this chapter we provide a complete summary of all of the work in last four chapters. First of all, we go back to review the structure of the entire thesis and extract essences, at same time, summarize the key points, such as research strategies and algorithms.

6.1 Conclusion

First and foremost, we need to know three purposes of this thesis: the first is going to explain the principle of those two devices, so we know how it works and possibly can use it to do something after researching this thesis. The second one is to study some mature algorithms and strategies, basing on those algorithms and strategies, we should understand the principle and possibly program the code for Pedometer and Ricing Game. The last one is to research the gesture recognition algorithm based on the study in previous three chapters, and make a hypothesis for using the new researched algorithm on a glow-stick, when a glow-stick shaking in gesture 1 and gesture 2 maintained in the last chapter it can be recognized and also calculated for the number of shaking times.

After researching this thesis, we can use some mode

6.2 Future Work

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