CRASH DETECTION IN BICYCLE

A PROJECT REPORT

Submitted by

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Roll No. 12MAE09

in partial fulfillment for the award of the degree of

MASTER OF ENGINEERING

in

APPLIED ELECTRONICS

Department of Electronics and Communication Engineering

KUMARAGURU COLLEGE OF TECHNOLOGY
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APRIL 2014

BONAFIDE CERTIFICATE

Certified that this project report titled **“CRASH DETECTION IN BICYCLE”** is the bonafide work of **MAHALINGAM.S [Reg. No. 12MAE09]** who carried out the research under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other project or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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ACKNOWLEDGEMENT

I express my sincere thanks to the management of Kumaraguru College of Technology and Joint Correspondent **Mr. Shankar Vanavarayar** for the kind support and for providing necessary facilities to carry out the work.

I would like to express my sincere thanks to our beloved Principal **Dr.R.S.Kumar Ph.D.,** Kumaraguru College of Technology, who encouraged me in each and every steps of the project.

I would like to thank **Dr.Rajeswari Mariappan Ph.D.,** Head of the Department, Electronics and Communication Engineering, for her kind support and for providing necessary facilities to carry out the project work.

In particular, I wish to thank with everlasting gratitude to the project coordinator **Ms.G.Amritha Gowri M.E., Associate Professor,** Department of Electronics and Communication Engineering ,for her expert counselling and guidance to make this project to a great deal of success.

I am greatly privileged to express my heartfelt thanks to my project guide **Ms.K.Thilagavathi M.E, Assistant Professor(SRG),** Department of ECE**,** throughout the course of this project work and I wish to convey my deep sense of gratitude to all teaching and non-teaching staffs of ECE Department for their help and cooperation.

I would also like to thank co-guide **Mr. John Felix RBEI/EST6, Project Manager, Robert Bosch** for his motivation and guidance for this project.

Finally, I thank my parents and my family members for giving me the moral support and abundant blessings in all of my activities and my dear friends who helped me to endure my difficult times with their unfailing support and warm wishes.

ABSTRACT

With the increasing number of bicycle riders, there is an increased risk of Accidents between bicycles and automobiles.Intelligent transportation systems (ITS), which utilize information communication technology, which have been researched and developed recently. Most of them are designed for cars are not considered to be used for bicycles. One of the reasons why it is difficult for bicycle to use the conventional ITS is that mobility and motion of a bicycle are different from a car. The purpose of the system is to comprehend bicycle behavior by placing the smart phone containing sensor such as tri-axial accelerometer sensor and tri-axial gyroscope sensor on the bicycle.

Orientation angles such as pitch and roll were computed using accelerometer and gyroscope sensor data. Orientation angle obtained from both the sensor were combined or fused together using complementary filter. Several test such as normal, speedbrake, hit, slide test were carried out by placing smartphone at specific position on bicycle. Based upon the different behavior of bicycle, threshold values are set in order to detect the crash in the bicycle.

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CHAPTER 1

INTRODUCTION

1.1 Overview of the project

Recently, intelligent transportation systems (ITS) have attracted considerable notice. ITS utilizes information technology to realize safety. There are many research fields for ITS such as development of an advanced high technology car navigation system and optimization of traffic management. One of them is a safety driving system, and it has been researched actively.

HONDA has developed a system to prevent to drive erratically. This system is implemented into a car navigation system. It gets a value of the speed sensor and the gyro sensor and calculates the trajectory of the car with the obtained data. This system gives warning to the driver if the derived trajectory crosses over standard or Threshold value. Most of existing ITS services are designed for a car, and they are not considered to be used for bicycle. There are many differences between car and bicycle as shown in Table 1.

Compare	**Bicycle**	**Car**
How to turn	Lean the body	Turn the steering
Rooms for devices	Less	Enough
At an accident	A rider damages Directly	The cabin protects a Driver
Visibility	Low	High

Table 1 Characteristic of Car and Bicycle

The behaviors of bicycle are much different from that of car. For example, a bicycle can lean its body to turn a corner whereas a car does not lean. The differences between bicycle and car are classified into the four aspects: hardware, handling way, body behavior and mobility. From the stand point of hardware, a bicycle's body is smaller than that of a car, and a bicycle cannot stand on its own. The rider on a bicycle is in more dangerous than the driver on a car at an accident. A bicycle's body does not protect the rider whereas the cabin of a car protects the driver and passengers. Due to the small body, it is not easy for other drivers to notice the presence of a bicycle. In addition a bicycle has less space to equip ITS devices. As a result, it is difficult for a bicycle to equip with a system which implements a convenient ITS services designed for a car.

Since a bicycle cannot be self-standing, a rider must balance during riding it. To turn a corner, a rider needs to lean the bicycle's body. To ride a bicycle needs a different handling method comparing to driving a car. The behaviors of a bicycle are also different from that of a car. Since the body size is small, a bicycle can go through the traffic roads which a car cannot do and only bicycles can run through between neighboring cars. Such a bicycle's mobility makes it harder for other car drivers to find neighboring bicycles. This is one reason of traffic accidents with a bicycle due to escaping the attention of the bicycle.

Many ITS services have been developed so far, but most of them have not become common. One of the major reasons is that a vehicle needs to equip expensive devices to receive the benefit of services. A smartphone is becoming popular in the world and has a lot of sensors such as a GPS receiver, an acceleration sensor and a gyro sensor. Therefore sensors in a smartphone are used to comprehend a bicycle's behaviors without installing new devices. Also a smartphone can be used as a platform of ITS application.

To comprehend a bicycle’s behavior, we make our proposed system discriminate the following behaviors: going forward, stopping, turning left or right, running through neighboring vehicles from sensed values. First of all, we make our system to be able to discriminate the following primitive behaviors of bicycle. The primitive behaviors consist of the following four primitive motilities: speed up, slow down, constant velocity, and stopping and the following three primitive attitudes: uprightness, tilt to right, tilt to left. A variety of the behaviors can be expressed by combining these two types of primitives. Therefore, if it is possible that the system distinguishes from these primitives by the value of the sensor, the system becomes possible to comprehend the behavior.

In order to comprehend the vehicle state of a bicycle, we develop a system to detect the behavior of a bicycle. We utilize tri-axial acceleration sensor, tri-axial gyro sensor on a Smartphone to realize the system.

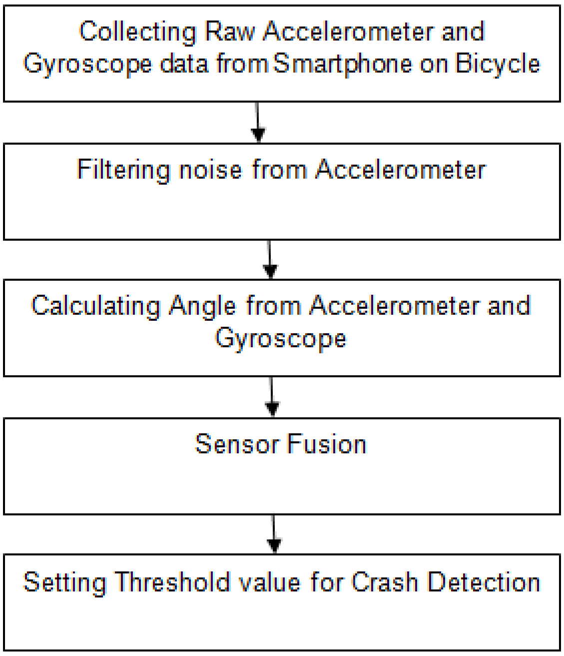

Fig 1.1 Overview of the project

1.2 Objective

The objective of the project is to determine the orientation/position of a bicycle using MEMS sensors placed on bicycle. Based on orientation, threshold values are set to determine crash.

The key features of this module are:

- Orientation using MEMS Accelerometer sensor.
- Orientation using MEMS Gyroscope sensor.

1.3 Organisation of the report

- Chapter 2 is about the sensors.
- Chapter 3 deals about the orientation.
- Chapter 4 deals about the data acquisition.
- Chapter 5 deals about the sensor fusion.
- Chapter 6 gives the results and analysis of the work.
- Chapter 7 gives the conclusion of the project.

CHAPTER 2

SENSORS

2.1 MEMS Technology

Micro-Electro-Mechanical Systems, or MEMS, is a technology that in its most general form can be defined as miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) that are made using the techniques of micro fabrication. The critical physical dimensions of MEMS devices can vary from well below one micron on the lower end of the dimensional spectrum, all the way to several millimeters. Likewise, the types of MEMS devices can vary from relatively simple structures having no moving elements, to extremely complex electromechanical systems with multiple moving elements under the control of integrated microelectronics. The one main criterion of MEMS is that there are at least some elements having some sort of mechanical functionality whether or not these elements can move. The term used to define MEMS varies in different parts of the world. In the United States they are predominantly called MEMS, while in some other parts of the world they are called “Microsystems Technology” or “micro machined devices”.

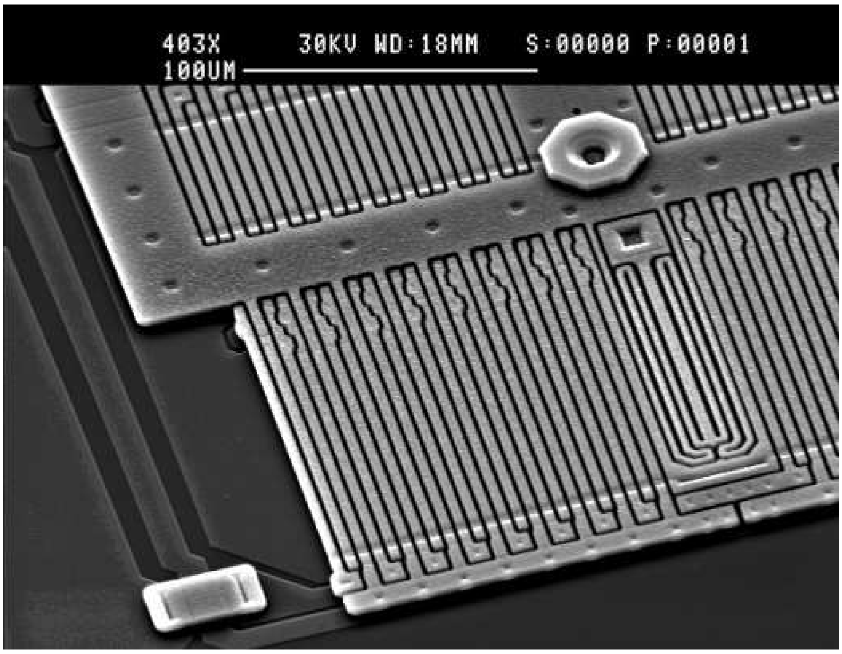

Fig. 2.1 MEMS Sensor

MEMS sensors are well recognized as the key building blocks for implementing disruptive applications in consumer devices. From game consoles to mobile phones and from laptops to white goods, consumer devices have already benefited in recent years from the use of low-g accelerometers for the implementation of motion-activated user interfaces and enhanced protection systems. It is now the turn of MEMS gyroscopes and geomagnetic sensors, as use of these sensors is propelling a new wave of compelling applications.

2.2 Accelerometer

One of the most common inertial sensors is the **accelerometer**, a dynamic sensor capable of a vast range of sensing. Accelerometers are available that can measure acceleration in one, two, or three orthogonal axes. Accelerometers are sensitive to both linear acceleration and the local gravitational field. The former provides information on taps and other handset motions allowing the development of 'gesture' user interfaces while the latter provides information on the accelerometer orientation which allows a smart phone or tablet display to automatically switch between portrait and landscape settings.

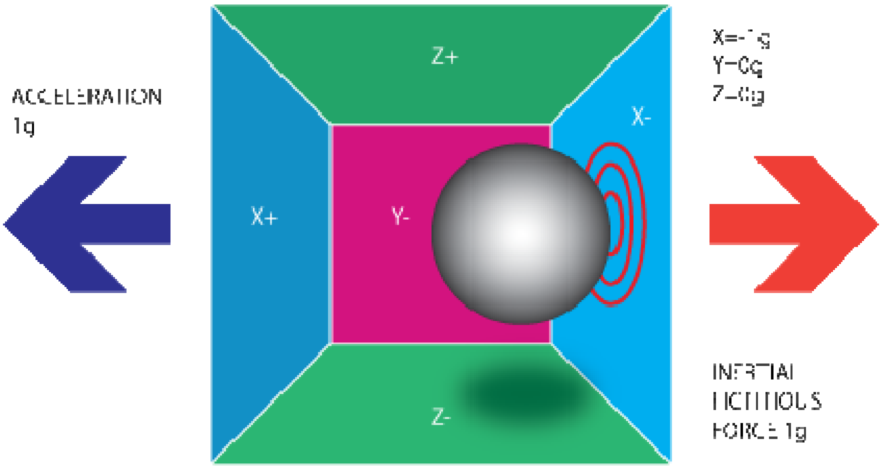

Fig. 2.2 Accelerometer sensor

This application note documents the mathematics of orientation determination using a three-axis accelerometer. The techniques are applicable to both digital accelerometers and, after signal digitization, to analog accelerometers. For convenience, it is assumed that the accelerometer is mounted in a smart phone or tablet but the arguments apply to any product with an embedded three-axis accelerometer. They are typically used in one of three modes:

- As an inertial measurement of velocity and position;
- As a sensor of inclination, tilt, or orientation in 2 or 3 dimensions, as referenced from the acceleration of gravity ($1 \text{ g} = 9.8 \text{m/s}^2$);
- As a vibration or impact (shock) sensor.

2.2.1 Principles of operation

Most accelerometers are Micro-Electro-Mechanical Sensors (MEMS). The basic principle of operation behind the MEMS accelerometer is the displacement of a small proof mass etched into the silicon surface of the integrated circuit and suspended by small beams. Consistent with Newton's second law of motion (**F = ma**), as an acceleration is applied to the device, a force develops which displaces the mass. The support beams act as a spring, and the fluid (usually air) trapped inside the IC acts as a damper, resulting in a second order lumped physical system. This is the source of the limited operational bandwidth and non-uniform frequency response of accelerometers.

An accelerometer measures proper acceleration, which is the acceleration it experiences relative to freefall and is the acceleration felt by people and objects. Put another way, at any point in space-time the equivalence principle guarantees the existence of a local inertial frame, and an accelerometer measures the acceleration relative to that frame. Such accelerations are popularly measured in terms of g-force. An accelerometer at rest relative to the Earth's surface will indicate approximately 1 g *upwards*, because any point on the Earth's surface is accelerating upwards relative to the local inertial frame (the frame of a freely falling object near the surface). To obtain the acceleration due to motion with respect to the Earth, this "gravity offset" must be subtracted and corrections made for effects caused by the Earth's rotation relative to the inertial frame.

The reason for the appearance of a gravitational offset is Einstein's equivalence principle, which states that the effects of gravity on an object are indistinguishable from acceleration. When held fixed in a gravitational field by, for example, applying a ground reaction force or an equivalent upward thrust, the reference frame for an accelerometer accelerates upwards with respect to a free-falling reference frame. The effects of this acceleration are indistinguishable from any other acceleration experienced by the instrument, so that an accelerometer cannot detect the difference between sitting in a rocket on the launch pad, and being in the same rocket in deep space while it uses its engines to accelerate at 1 g. For similar reasons, an accelerometer will read *zero* during any type of free fall. This includes use in a coasting spaceship in deep space far from any mass, a spaceship orbiting the Earth, an airplane in a parabolic "zero-g" arc, or any free-fall in vacuum. Another example is free-fall at a sufficiently high altitude that atmospheric effects can be neglected.

2.2.2 Purpose of the accelerometer

The application of accelerometers extends to multiple disciplines, both academic and consumer-driven. For example, accelerometers in laptops protect hard drives from damage. If the laptop were to suddenly drop while in use, the accelerometer would detect the sudden free fall and immediately turn off the hard drive to avoid hitting the reading heads into the hard drive platter. Without this, the two would strike and cause scratches to the platter for extensive file and reading damage. Accelerometers are likewise used in cars as the industry method way of detecting car crashes and deploying airbags almost instantaneously.

In another example, a dynamic accelerometer measures gravitational pull to determine the angle at which a device is tilted with respect to the Earth. By sensing the amount of acceleration, users analyze how the device is moving. The term ‘accelerometer’ is used to designate the entire transducer, normally comprising a mechanical sensing element and conversion of the signal from the mechanical to the electrical domain.

The acceleration measurement has a variety of uses. The sensor can be implemented in a system that detects velocity, position, shock, vibration, or the acceleration of gravity to determine orientation. A system consisting of two orthogonal sensors is capable of sensing pitch and roll. This is useful in capturing head movements. A third orthogonal sensor can be added to the network to obtain orientation in three dimensional space. This is appropriate for the detection of pen angles, etc. The sensing capabilities of this network can be furthered to six degrees of spatial measurement freedom by the addition of three orthogonal gyroscopes. As a shock detector, an accelerometer is looking for changes in acceleration. This jerk is sensed as an over damped vibration.

Accelerometer sensors measure the difference between any linear acceleration in the accelerometer’s reference frame and the earth's gravitational field vector. In the absence of linear acceleration, the accelerometer output is a measurement of the rotated gravitational field vector and can be used to determine the accelerometer pitch and roll orientation angles. The orientation angles are dependent on the order in which the rotations are applied. The most common order is the aerospace sequence of yaw then pitch and finally a roll rotation.

Accelerometer sensors are insensitive to rotation about the earth's gravitational field vector. The equations for the roll and pitch angles therefore have mathematical instabilities when rotation axes happen to become aligned with gravity and point upwards or downwards. A workaround is presented to prevent this instability occurring. Simple vector algebra expressions are derived for computing the tilt of the accelerometer from vertical or the rotation angle between any two accelerometer readings. The most common application of accelerometers in consumer electronics is switching between portrait or landscape display modes. An algorithm is presented for controlling a tablet PC’s display orientation.

2.2.3 Practical applications of accelerometers

By measuring the amount of static acceleration due to gravity, we can find out the angle the device is tilted at with respect to the earth. By sensing the amount of dynamic acceleration, we can analyze the way the device is moving. Accelerometers are very useful in the sensor world because they can sense such a wide range of motion. They are used in automobiles to control airbag release when there is a sudden stop. They are applied in the laptops to detect when the computer’s suddenly moved or tipped, so the hard drive can be locked up to prevent damage (If you accidentally drop the laptop, the accelerometer detects the sudden freefall, and switches the hard drive off so the heads don’t crash on the platters). They are used in cameras, to control image stabilization functions. They are used in pedometers, gait meters, and other exercise and physical therapy devices. They are used in self balancing robots, tilt-mode game controllers, collision detection, human motion monitoring, leveling sensor and inclinometer, model airplane auto pilot, space mission rocketry etc.

2.3 Gyroscope

Gyroscopes are physical sensors that detect and measure the angular motion of an object relative to an inertial frame of reference. The term "Gyroscope" is attributed to the mid-19th century French physicist Leon Foucault who named his experimental apparatus for Earth's rotation observation by joining two Greek roots: gyros - rotation and skopeein. Unlike rotary encoders or other sensors of relative angular motion, the unique feature of gyroscopes is the ability to measure the absolute motion of an object without any external infrastructure or reference signals. Gyroscopes allow untethered tracking of an object's angular motion and orientation and enable standalone Heading Reference Systems (AHRS). Combining 3 gyroscopes with 3 accelerometers in a complete 6-axis Inertial Measurement Unit (IMU) enables self-contained Inertial Navigation Systems (INS) for navigation, guidance, and dead reckoning.

All gyroscopes can be divided into two main categories, depending on whether the angular velocity or orientation is being measured. Rate gyroscopes measure the angular velocity, or the rate of rotation of an object. Angle gyroscopes, also called Whole Angl*e* or Rate Integrating gyroscopes, measure the angular position, or orientation of an object directly. While devices sensitive to the angular acceleration are used in some applications, these sensors are typically not referred to as gyroscopes, but rather as angular accelerometers. Essentially all existing Micro-Electro-Mechanical-Systems (MEMS) gyroscopes are of the rate measuring type and are typically employed for motion detection (for example, in consumer electronics and automotive safety devices) and motion stabilization and control (for example, in smart automotive steering and antenna/camera stabilization systems).

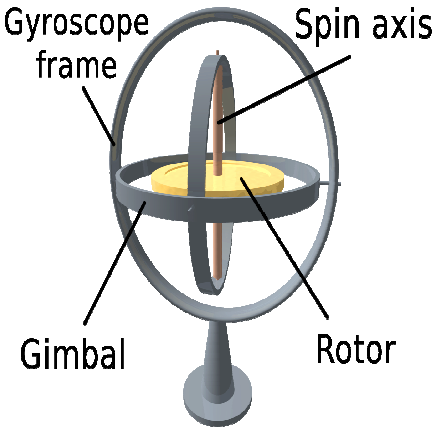

Fig. 2.3 Gyroscope sensor

A **gyroscope** is a device for measuring or maintaining orientation, based on the principles of angular momentum. Mechanically, a gyroscope is a spinning wheel or disc in which the axle is free to assume any orientation. Although this orientation does not remain fixed, it changes in response to an external torque much less and in a different direction than it would without the large angular momentum associated with the disc's high rate of spin and moment of inertia. The device's orientation remains nearly fixed, regardless of the mounting platform's motion, because mounting the device in a gimbal minimizes external torque.

Gyroscopes based on other operating principles also exist, such as the electronic, microchip-packaged MEMS gyroscope devices found in consumer electronic devices, solid-state ring lasers, fibre optic gyroscopes, and the extremely sensitive quantum gyroscope. Applications of gyroscopes include inertial navigation systems where magnetic compasses would not work (as in the Hubble telescope) or would not be precise enough (as in ICBMs), or for the stabilization of flying vehicles like radio-controlled helicopters or unmanned aerial vehicles. Due to their precision, gyroscopes are also used in gyrotheodolitres to maintain direction in tunnel mining.

2.3.1 Description and Diagram

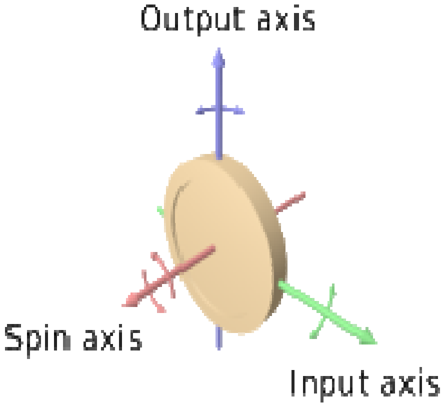

Fig. 2.4 Gyroscope Rotation

Diagram of a gyro wheel. Reaction arrows about the output axis (blue) correspond to forces applied about the input axis (green), and vice versa. Within mechanical systems or devices, a conventional gyroscope is a mechanism comprising a rotor journaled to spin about one axis, the journals of the rotor being mounted in an inner gimbal or ring; the inner gimbal is journaled for oscillation in an outer gimbal for a total of two gimbals.

The **outer gimbal** or ring, which is the gyroscope frame, is mounted so as to pivot about an axis in its own plane determined by the support. This outer gimbal possesses one degree of rotational freedom and its axis possesses none. The next **inner gimbal** is mounted in the gyroscope frame (outer gimbal) so as to pivot about an axis in its own plane that is always perpendicular to the pivotal axis of the gyroscope frame (outer gimbal). This inner gimbal has two degrees of rotational freedom.

The axle of the spinning wheel defines the spin axis. The rotor is journaled to spin about an axis, which is always perpendicular to the axis of the inner gimbal. So the rotor possesses three degrees of rotational freedom and its axis possesses two. The wheel responds to a force applied about the input axis by a reaction force about the output axis. The behavior of a gyroscope can be most easily appreciated by consideration of the front wheel of a bicycle. If the wheel is leaned away from the vertical so that the top of the wheel moves to the left, the forward rim of the wheel also turns to the left. In other words, rotation on one axis of the turning wheel produces rotation of the third axis.

A **gyroscope flywheel** will roll or resist about the output axis depending upon whether the output gimbals are of a free- or fixed- configuration. Examples of some free-output-gimbal devices would be the attitude reference gyroscopes used to sense or measure the pitch, roll and yaw attitude angles in a spacecraft or aircraft. The centre of gravity of the rotor can be in a fixed position. The rotor simultaneously spins about one axis and is capable of oscillating about the two other axes, and, thus, except for its inherent resistance due to rotor spin, it is free to turn in any direction about the fixed point. Some gyroscopes have mechanical equivalents substituted for one or more of the elements. For example, the spinning rotor may be suspended in a fluid, instead of being pivotally mounted in gimbals. A control moment gyroscope (CMG) is an example of a fixed-output-gimbal device that is used on spacecraft to hold or maintain a desired attitude angle or pointing direction using the gyroscopic resistance force.

In some special cases, the outer gimbal (or its equivalent) may be omitted so that the rotor has only two degrees of freedom. In other cases, the centre of gravity of the rotor may be offset from the axis of oscillation, and, thus, the centre of gravity of the rotor and the centre of suspension of the rotor may not coincide.

2.3.2 Gyroscope-enabled navigation

In strap down inertial navigation theory, a 3-axis accelerometer and 3-axis gyroscope are used as a 6D IMU. The purpose of the gyroscope is to construct the direct cosine matrix (DCM) between the handheld device body axes and the local horizontal frame. Then the accelerometer measurements on the body axes will be projected to the local horizontal plane from the DCM. Single integration of the projected acceleration will give the velocity of the handheld device and double integration will give the distance travelled for the handheld device. This section will discuss how to use gyroscope's measurements to construct the direct cosine matrix. Three Euler angles are referenced to the local horizontal plane which is perpendicular to the earth's gravity. Users can define the handheld body axes as forward-right-down b-frame.

CHAPTER 3

ORIENTATION

Inertial sensor can also be used to determine the orientation as a function of time. Without an absolute reference an IMU can only be used to track changes in orientation from some initial point in time. For absolute orientation tracking you will need to combine an IMU with an absolute reference sensor such as magnetometer, camera, or GPS. Combining an IMU with a magnetic sensor creates what is known as an Absolute Heading Reference System (AHRS). For this case we will look at the error caused by the accelerometer that influences the orientation estimate. An AHRS determines orientation by making the assumption that the measured acceleration vector minus the known inertial acceleration is equal to the gravity vector. For cases where the actual inertial acceleration is unknown the AHRS assumes that the measured acceleration on the accelerometer is the actual gravity vector. Due to this assumption any errors in the accelerometer will translate into errors in the estimated direction of the downward direction. The gyros will dampen out much of the time based disturbances in the acceleration, however any constant errors in the accelerometer calibration parameters will directly propagate into orientation errors.

Orientation Sensors combine information from accelerometers, rate gyros, and (in some cases) GPS to produce reliable attitude and heading measurements that are resistant to vibration and immune to long-term angular drift.

Part of what makes reliable orientation estimates possible is the complementary nature of the different kinds of sensors used for estimation. Rate gyros provide good short-term stability and resistance to vibration, accelerometers can provide attitude information that does not become less reliable over time, and magnetic sensors provide heading information in addition to limited attitude information (pitch and roll). By combining data from each type of sensor using a filter such as an Extended Kalman Filter, accurate orientation estimates can be computed.

3.1 Accelerometer in orientation detection

Accelerometer sensor is used to measure the linear acceleration along x-axis, y-axis and z-axis. In the reference frame, three axes are at right angles to each other. Accelerometer output gives x, y and z values, which represents the position in respective axes. By computing these values, the orientation angles are determined. Roll, Pitch and Yaw are the orientation angles of the accelerometer.

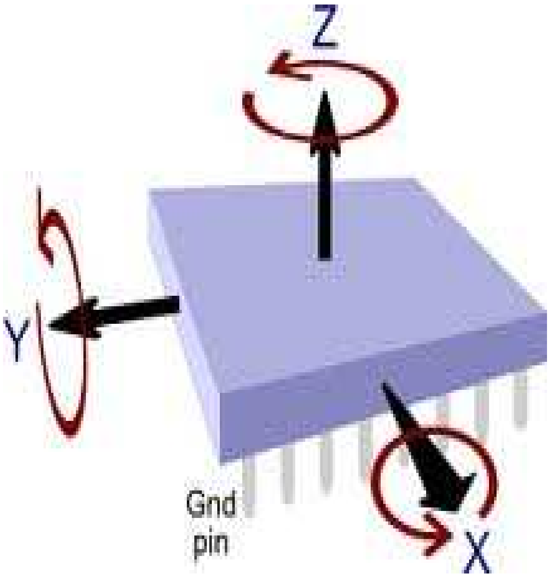

Fig. 3.1 3- axis representation

3.1.1 Roll, Pitch, Yaw

An aircraft in flight is free to rotate in three dimensions: *pitch*, nose up or down about an axis running from wing to wing, *yaw*, nose left or right about an axis running up and down; and *roll*, rotation about an axis running from nose to tail. The axes are alternatively designated as *lateral*, *vertical*, and *longitudinal*. These axes move with the vehicle, and rotate relative to the Earth along with the craft.

These rotations are produced by torques (or moments) about the principal axes. On an aircraft, these are produced by means of moving control surfaces, which vary the distribution of the net aerodynamic force about the vehicle's center of gravity. Elevators (moving flaps on the horizontal tail) produce pitch, a rudder on the vertical tail produces yaw, and ailerons (moving flaps on the wings) produce roll. On a spacecraft, the moments are usually produced by a reaction control system consisting of small rocket thrusters used to apply asymmetrical thrust on the vehicle.

- Normal axis, or yaw axis — an axis drawn from top to bottom, and perpendicular to the other two axes. Parallel to the fuselage station.
- Lateral axis, transverse axis, or pitch axis — an axis running from the pilot's left to right in piloted aircraft, and parallel to the wings of a winged aircraft. Parallel to the buttock line.
- Longitudinal axis, or roll axis — an axis drawn through the body of the vehicle from tail to nose in the normal direction of flight, or the direction the pilot faces. Parallel to the waterline.

Normally these axes are represented by the letters X, Y and Z in order to compare them with some reference frame, usually named x, y, z. Normally this is made in such a way that the X is used for the longitudinal axis, but there are other possibilities to do it.

Yaw

Yaw axis is a vertical axis through an aircraft, rocket, or similar body, about which the body yaws; it may be a body, wind, or stability axis. Also known as yawing axis.

The yaw axis is defined to be perpendicular to the body of the wings with its origin at the center of gravity and directed towards the bottom of the aircraft. A yaw motion is a movement of the nose of the aircraft from side to side. The pitch axis is perpendicular to the yaw axis and is parallel to the body of the wings with its origin at the center of gravity and directed towards the right wing tip. A pitch motion is an up or down movement of the nose of the aircraft. The roll axis is perpendicular to the other two axes with its origin at the center of gravity, and is directed towards the nose of the aircraft. A rolling motion is an up and down movement of the wing tips of the aircraft. The rudder is the primary control of yaw.

Pitch

The lateral axis (also called transverse axis) passes through the plane from wingtip to wingtips. Rotation about this axis is called **pitch**. Pitch changes the vertical direction the aircraft's nose is pointing. The elevators are the primary control of pitch.

Roll

The longitudinal axis passes through the plane from nose to tail. Rotation about this axis is called **bank** or **roll**. Bank changes the orientation of the aircraft's wings with respect to the downward force of gravity. The pilot changes bank angle by increasing the lift on one wing and decreasing it on the other. This differential lift causes bank rotation around the longitudinal axis. The ailerons are the primary control of bank. The rudder also has a secondary effect on bank.

As per the right hand rule,

-- x-axis refers to forward/ backward direction,
-- y-axis refers to left/right movement,
-- z-axis refers to up/down movement.

- Roll angle is the rotation along x-axis.
- Pitch angle is the rotation along y-axis.
- Yaw angle is the rotation along z-axis.

3.1.2 Yaw, Pitch, and Roll Rotations

A 3D body can be rotated about three orthogonal axes, as shown in Figure 3.1. Borrowing aviation terminology, these rotations will be referred to as yaw, pitch, and roll:

1. A yaw is a counterclockwise rotation of α about the z-axis. The rotation matrix is given by

$$R_z(\alpha) = \begin{pmatrix} \cos\alpha & -\sin\alpha & 0 \\ \sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix}.$$

2. A pitch is a counterclockwise rotation of β about the y-axis. The rotation matrix is given by

$$R_y(\beta) = \begin{pmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{pmatrix}.$$

3. A roll is a counterclockwise rotation of about the x-axis. The rotation matrix is given by

$$R_x(\gamma) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & -\sin\gamma \\ 0 & \sin\gamma & \cos\gamma \end{pmatrix}.$$

The yaw, pitch, and roll rotations can be used to place a 3D body in any orientation. A single rotation matrix can be formed by multiplying the yaw, pitch, and roll rotation matrices to obtain

$$R(\alpha,\beta,\gamma) = R_z(\alpha)\,R_y(\beta)\,R_x(\gamma) = \begin{pmatrix} \cos\alpha\cos\beta & \cos\alpha\sin\beta\sin\gamma - \sin\alpha\cos\gamma & \cos\alpha\sin\beta\cos\gamma + \sin\alpha\sin\gamma \\ \sin\alpha\cos\beta & \sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma & \sin\alpha\sin\beta\cos\gamma - \cos\alpha\sin\gamma \\ -\sin\beta & \cos\beta\sin\gamma & \cos\beta\cos\gamma \end{pmatrix}.$$

Roll angle(θ) is given as $\theta = \arctan(ay/az)$
Pitch angle(Φ) is given as $\Phi = \arctan(ax/\sqrt{(ay^2+az^2)})$
We cannot compute Yaw angle(ψ) for accelerometer data, because there is no variations in x and y-axes. $\psi = 0$(always).

3.2 Orientation angles in gyroscope

1. Yaw is defined as the angle between the Xb axis and the initial orientation of the object on the horizontal plane, measured in clockwise direction when viewing from the top of the device.

2. Pitch is defined as the angle between the Xb axis and the horizontal plane. When rotating the device around the Yb axis with the Xb axis moving upwards, pitch is positive and increasing.

3. Roll is defined as the angle between the Yb axis and the horizontal plane. When rotating the device around the Xb axis with the Yb axis moving downwards, roll is positive and increasing.

When the device having accelerometer sensor is said to be static, then Z = ±1g and X=Y=0. This is due to the gravitational force acting on the device. When the device is moved, then the 1g value is equally distributed along 3-axes. The computation of roll and pitch angles follows the aerospace rotation sequence used in aerospace industry. As per the aerospace rotation sequence, the roll angle ranges from -180º to +180º, the pitch angle ranges from -90º to +90º.

Users also can define a local horizontal n-frame with the X- and Y-axis leveled and the Z-axis pointing down. Assuming that at the beginning, the handheld device body axes' b-frame is the same as the local horizontal n-frame. When the handheld device is at any arbitrary position in 3D space, three rotations can be applied to rotate the local horizontal n-frame to the handheld body current axes as shown below.

Firstly, rotate the handheld device around the Zb axis clockwise at an angle with view from the origin to downwards. Then rotate the device around Yb at an angle with Xb moving upwards. Then rotate the device around Xb at an angle with Yb moving downwards. The new device body axes become X'b, Y'b and Z'b as shown in figure. As you probably remember from you physics class, position, velocity and acceleration are related to each other: deriving the position, gives us velocity:

$$\mathrm{d}\, x = v_x$$

with x being the position on the x-axis and v_x being the velocity along the x-axis. Maybe less obvious, the same holds for angles. While velocity is the speed at which the position is changing, *angular rate* is nothing more than the speed the angle is changing. That's right:

$$\mathrm{d}\ alpha = angular\ rate = gyroscope\ output$$

with *alpha* being the angle. It's starting to look pretty good! Knowing that the inverse of deriving (d) is integrating (∫), we change our formula's into:

$$\int angular\ rate = \int gyroscope\ output = alpha$$

The relation between angle (attitude) and our gyroscope's output is obtained by integrating the gyroscope's output, gives us our attitude-angle. Discrete integration is nothing more than summing up all the values. Basically, integration from 0 to the i'th value:

$$integration(i) = integration\ (i\text{-}1) + val_i$$

This is the simplest possible integrator. A more advanced one, which also flattens out possible jitter in the data, is the runge-kutta integrator:

$$integration(i) = integration(i\text{-}1) + \tfrac{1}{6}\ (\ val_{i-3} + 2\ val_{i-2} + 2\ val_{i-1} + val_i)$$

3.2.1 Drift problem

In reality, gyroscopes are suffering from an effect called *drift*. This means that over time, the value a gyroscope has when in steady position (called *bias*), drifts away from its initial steady value.

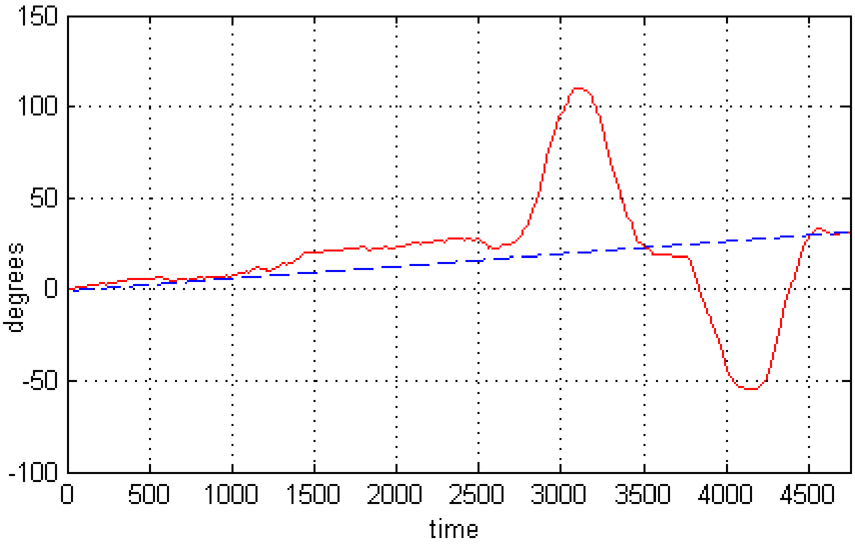

Fig. 3.2 Drift in Gyro

The blue line gives you an idea about the drift. During 4500 samples, the bias drifted about 30 degrees. Remember that we need the bias to normalize our data. We can integrate the drift about the correct bias and need to find a way to get the drift out. The drift problem is resolved when the gyro data is filtered through the appropriate filter. The filter characteristics should meet the gyro data signal properties in order to eliminate the drift from the signal. The orientation data is evaluated along with the time stamp when the data has acquired.

CHAPTER 4

DATA ACQUISITION

To detect the behaviors of bicycles, several motion sensors need to be considered as accessories attached to the bicycle. However, attaching and detaching such sensors on the bicycle may be inconvenient for daily use. Moreover, the use of specialized devices for this purpose has limitations in terms of distribution. For these reasons, we propose the use of a smartphone instead of a specialized sensor. Smartphones are commonly used in daily life, and several models already possess motion sensors such as accelerometers and gyrometers. Owing to the lightweight and high portability features of smartphones, it is easily attached to the body of the bicycle.

Even though smartphones have high portability, the method used to install the device on the bicycle is important because the usability of the system depends on the installation method, such as its mounting position and the instrument used. As expected, the device should collect sufficient motion data to precisely detect behaviors of bicycle. Therefore, satisfying the constraints of daily usability and precise data collection is crucial for the system.

Before implementing the system, we decided to investigate the conditions regarding the mounting position that would satisfy the above constraints. The detection of bicycle behavior is particularly difficult relative to motorcycle behavior owing to the instability caused by the pedaling action and lack of suspension mechanisms.

To determine the feasible mount position of the smartphone on a bicycle, several experiments were conducted. The purpose of these experiments was to examine the relationship between the mount position and acceleration data and to determine the best position for mounting.

The smart-phone is mounted on bicycle's handle to collect sensing data of the acceleration sensor, the gyro sensor on it. A tri-axial acceleration sensor gets three dimensional acceleration values (X, Y, Z). By this acceleration sensor, it will be possible to get back and forth, side to side and up and down acceleration. The smartphone are placed on a bicycle turning up the smartphone's display as shown in Fig 1, when the bicycle is speeding up, the acceleration sensor gets negative Y value, and when the bicycle is slowing down, the acceleration sensor gets positive Y value.

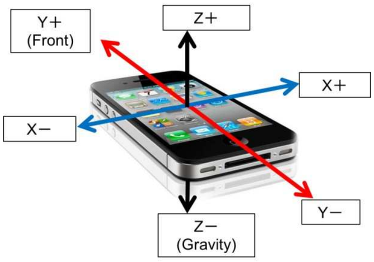

Fig 4 Axes of acceleration and gyro sensors

Similarly, a tri-axial gyro sensor gets three dimensional angular velocities (X, Y, Z) as shown in Fig 4. By this gyro sensor, it will be possible to get pitching, rolling and yawing motion. The pitching motion is obtained as change of X-axis value and clockwise rotation leads positive value. Also, the rolling motion and the yawing motion are obtained from Y-axis value and Z-axis value, respectively.

There are several researches such as recognizing human activity with acceleration sensors and driving analysis based on car mobility prediction. These method cannot directly used to bicycles because bicycles behaviors are some different from human or car. In order to comprehend a bicycle's behavior, developing a system to discriminate the following primitive behaviors of bicycle: going forward, stopping, turning left or right. The system should be able to discriminate the following primitive behaviors of bicycle. A variety of the behaviors can be expressed by combining these types of primitives. Therefore, if it is possible that the system distinguishes from these primitives by the value of the sensor, the system becomes possible to comprehend the behavior.

the tri-axial acceleration sensor, the tri-axial gyro sensor were utilized on a smartphone to realize the system.

In this research, Samsung Galaxy tab smartphone were used to collect outputs CSV-data with the acceleration sensor's value, the gyro sensor's value and time. Setting the sampling rate of 100Hz for stability. The application stores the data within Samsung Galaxy tab. After collecting data from smartphone, data were examined and analyzed.

4.1 Processing the data

In this section, Sensing data from the smartphone on a bicycle were analysed. Data collected by a smartphone includes the behaviors of riding operation as well as noise. A smartphone on a bicycle gets vibrations from the road during riding. These vibrations make large amounts of noise for the acceleration and gyro sensors values. It is difficult to comprehend the behavior of a bicycle with such noises. Therefore noise has to be removed to get the right signals of the behavior. Such noises consist of road noise and noise from wind. Road noise is from the vibration of tire hitting the road's bumps. The frequencies of road noise and wind noise are proportional to the speed of a bicycle. The frequencies of these noises are higher than the signal of the bicycle's behavior handled by human. Given the handling frequency of a bicycle as $H_{behavior}$ and the noise frequency as H_{noise}, the following equality holds $H_{noise} \gg H_{behavior}$.

Exponentially weighted moving average filter was used to remove the noises from the acquired sensing raw data. The exponential filter is a weighted combination of the previous estimate (output) with the newest input data, with the sum of the weights equal to 1 so that the output matches the input at steady state.

$$y(k) = a * y(k-1) + (1-a) * x(k)$$

where, x(k) is Raw input.

y(k) is filter output.

a is constant between 0 and 1.

CHAPTER 5

SENSOR FUSION

Several crash detection techniques were proposed for cars cannot be implemented for bicycle because of two reasons: (1) due to space complexity, it is impossible to place several accelerometer sensors. (2) Behavior of bicycle is different from that of the car. In car, several accelerometer sensors are placed in different position of car. Each sensor are capable of communicating with each other. In car, crash can be detected if the data from several accelerometer sensor placed in various position exceeds pre-determined threshold value. In car, accelerometer sensors are enough to determine whether crash has been occurred or not. But whereas in bicycle, crash cannot be detect using only accelerometer sensor. So both accelerometer and gyroscope sensors are combined or fused together to detect crash in bicycle.

Sensor fusion is the combining of sensory data or data derived from sensory data from disparate sources such that the resulting information is in some sense *better* than would be possible when these sources were used individually. The term *better* in this case can mean more accurate. Complementary filter is used in order to combine or fuse both the accelerometer and gyroscope angles.

The complementary filter obtain angle by filtering the signal through complementary network, Which means that if one of the signals is disturbed by high frequency noise, then it is appropriate to choose a low pass filter and consequently obtaining a high pass filter for the other signal.

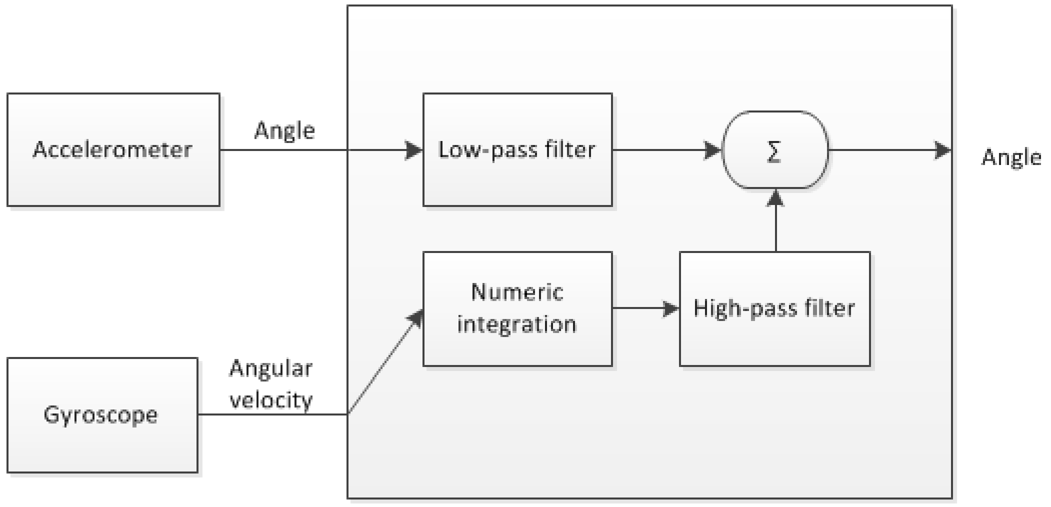

Fig 5 Complementary Filter

Accelerometer gives a good indicator of orientation in static conditions. Gyroscope gives a good indicator of tilt in dynamic conditions. So the idea behind complementary filter shown in Fig 5 is to pass the accelerometer signals through a low-pass filter and the gyroscope signals through a high-pass filter and combine them to give the final rate.

CHAPTER 6

RESULT AND ANALYSIS

In this section, the results for comprehending a bicycle behavior were presented and discussed. Several experiments were performed and investigated which sensor value is suitable to discriminate each behavior. Raw accelerometer data, filtered data and angle of a speed brake, hit, slide and normal readings are shown below. It is possible to discriminate slow down or speed up using y-axis acceleration value. The y and z-axis of gyroscope can be used to detect turns at a corner and direction left or right.

6.1 Speed Brake Readings

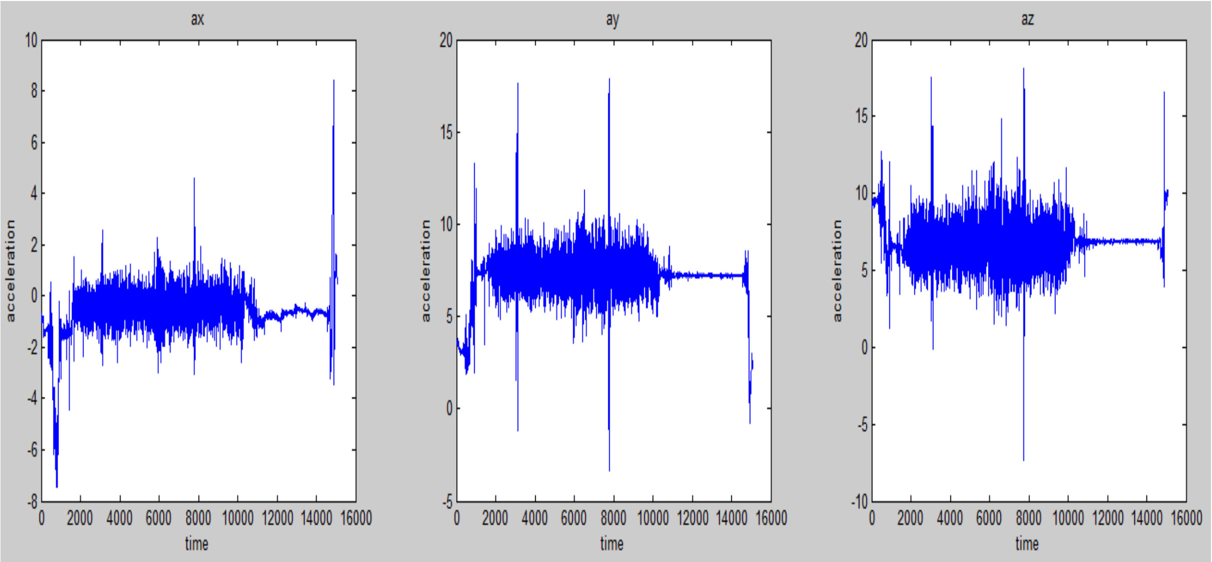

Fig 6.1.1 Raw Accelerometer

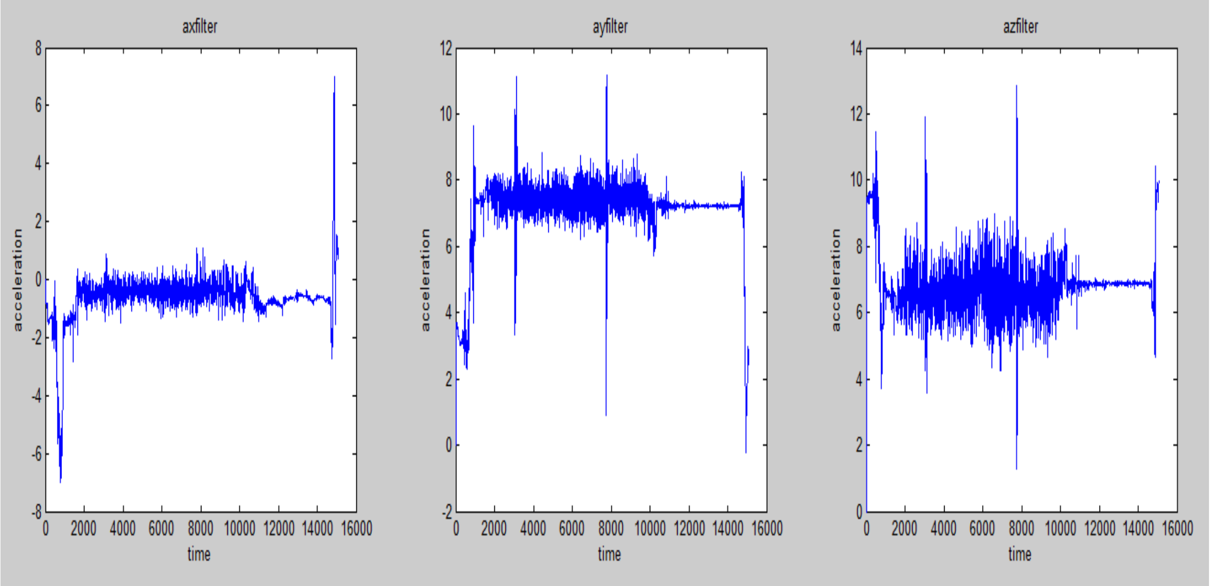

Fig 6.1.2 Filtered Accelerometer

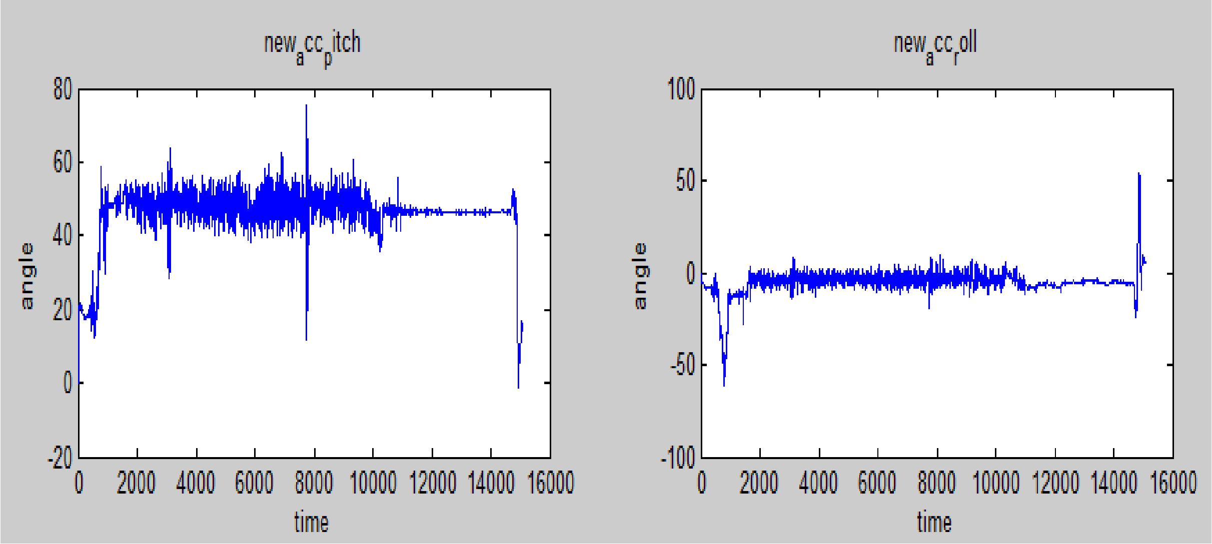

Fig 6.1.3 Accelerometer Angle

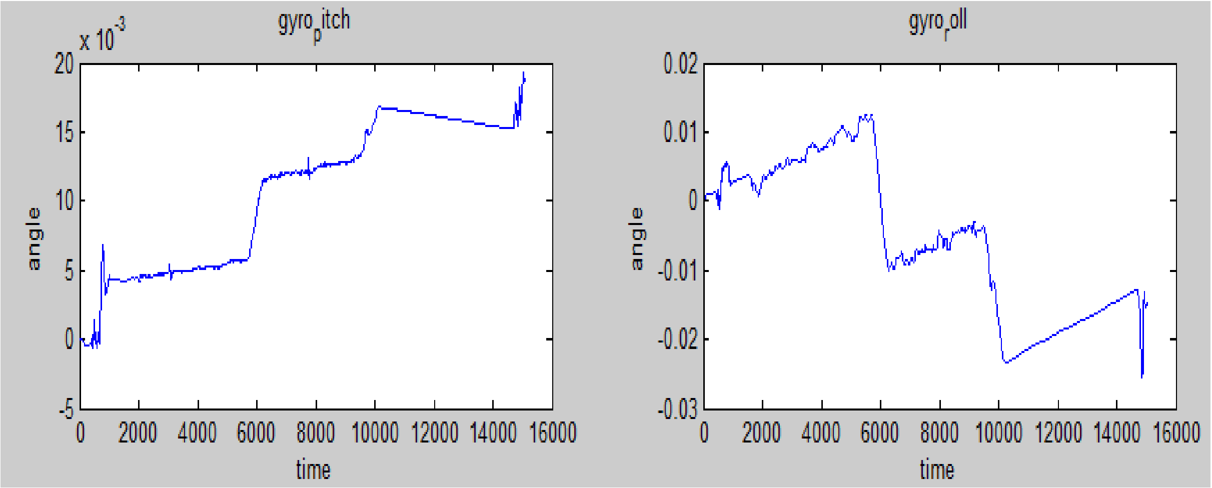

Fig 6.1.4 Gyroscope Angle

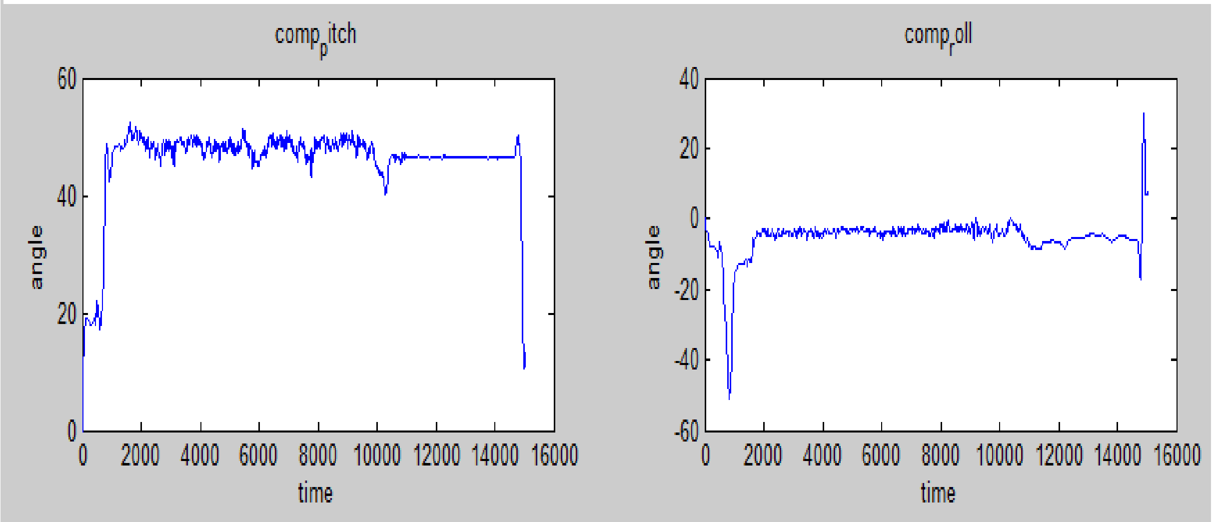

Fig 6.1.5 Complementary Angle

6.2 Hit Reading

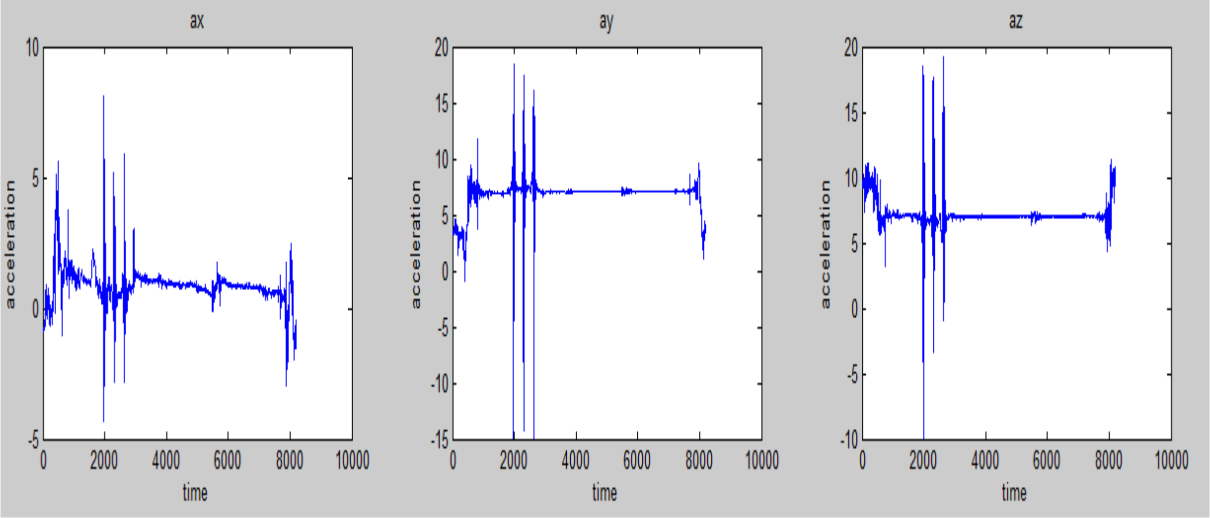

Fig 6.2.1 Raw Accelerometer

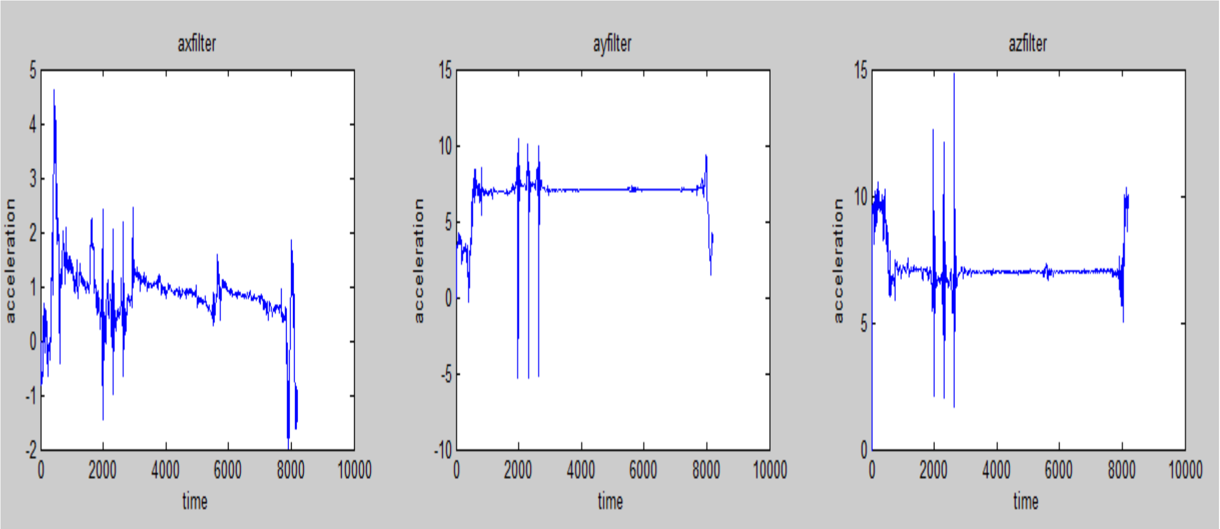

Fig 6.2.2 Filtered Accelerometer

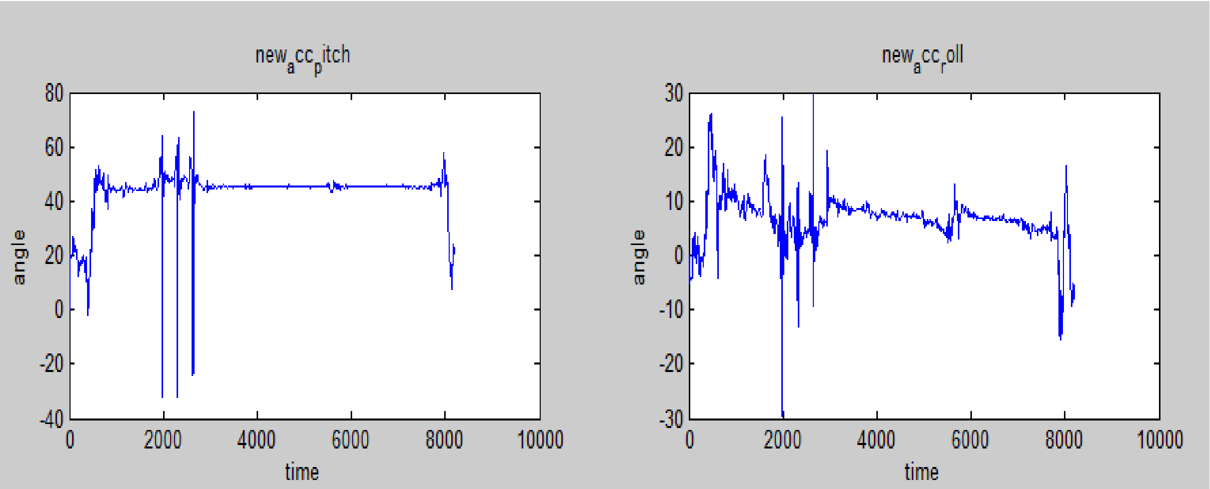

Fig 6.2.3 Accelerometer Angle

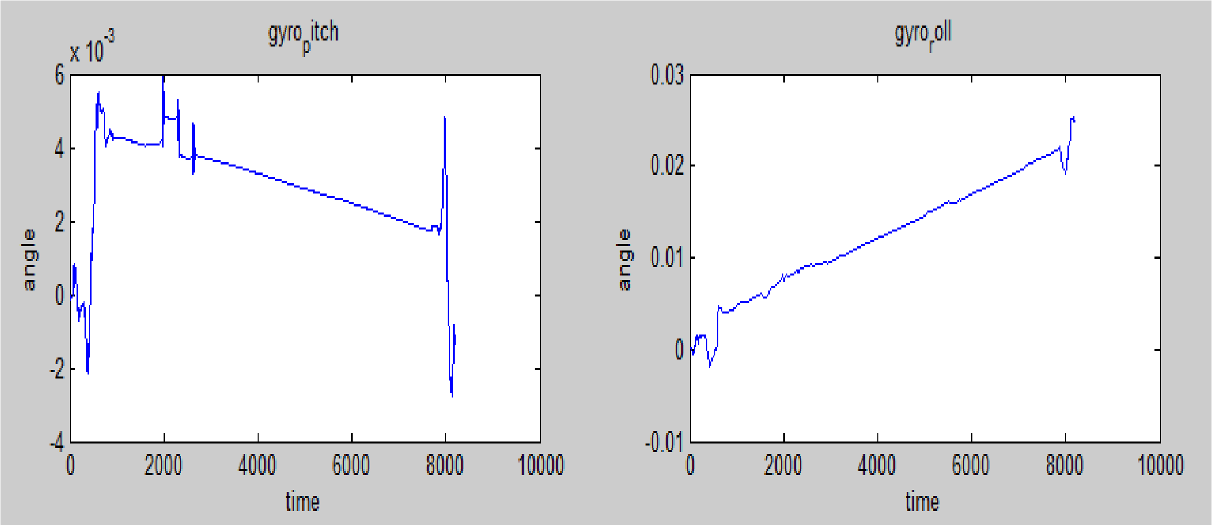

Fig 6.2.4 Gyroscope Angle

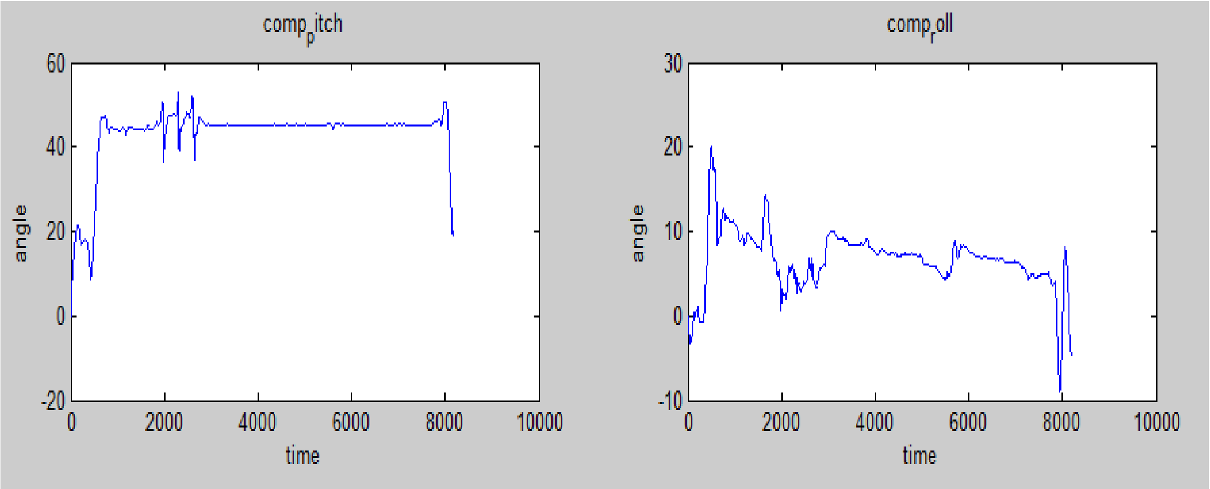

Fig 6.2.5 Complementary Angle

6.3 Slide Reading

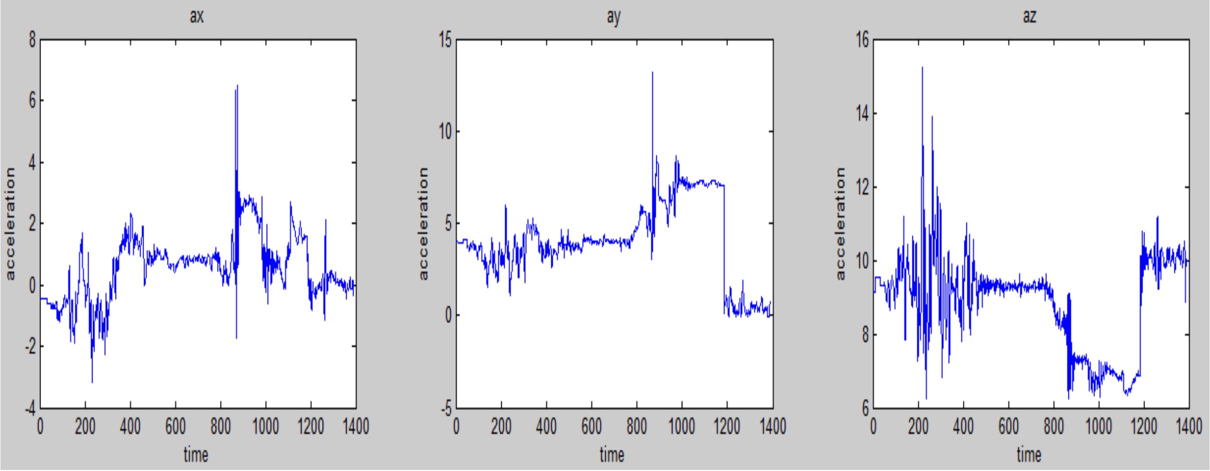

Fig 6.3.1 Raw Accelerometer

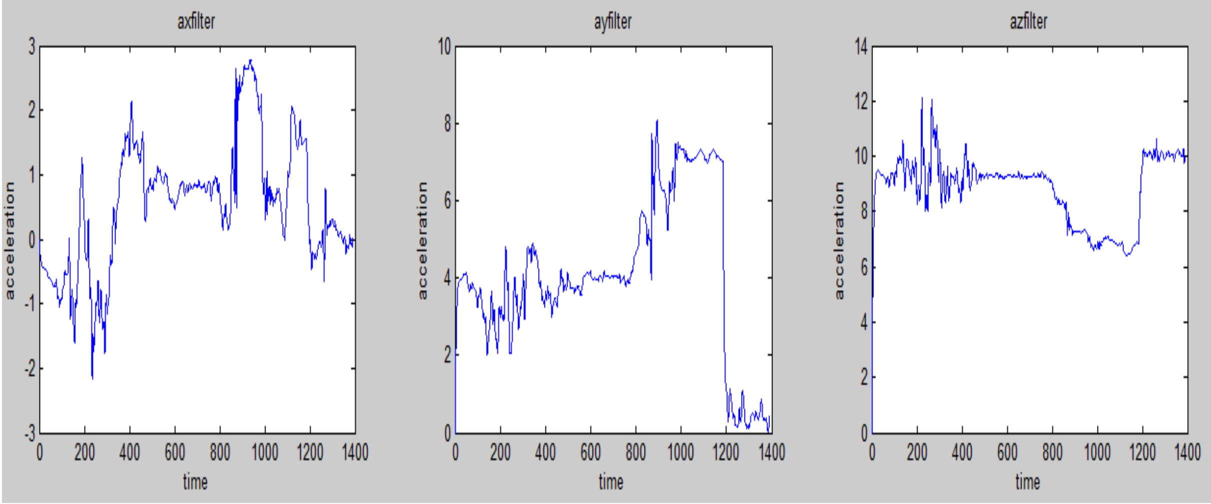

Fig 6.3.2 Filtered Accelerometer

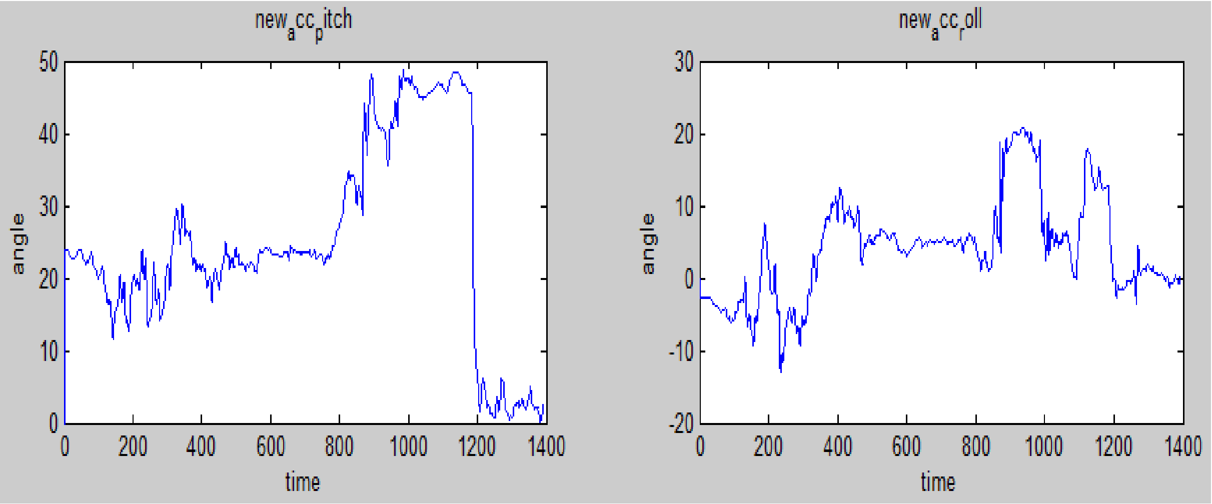

Fig 6.3.3 Accelerometer Angle

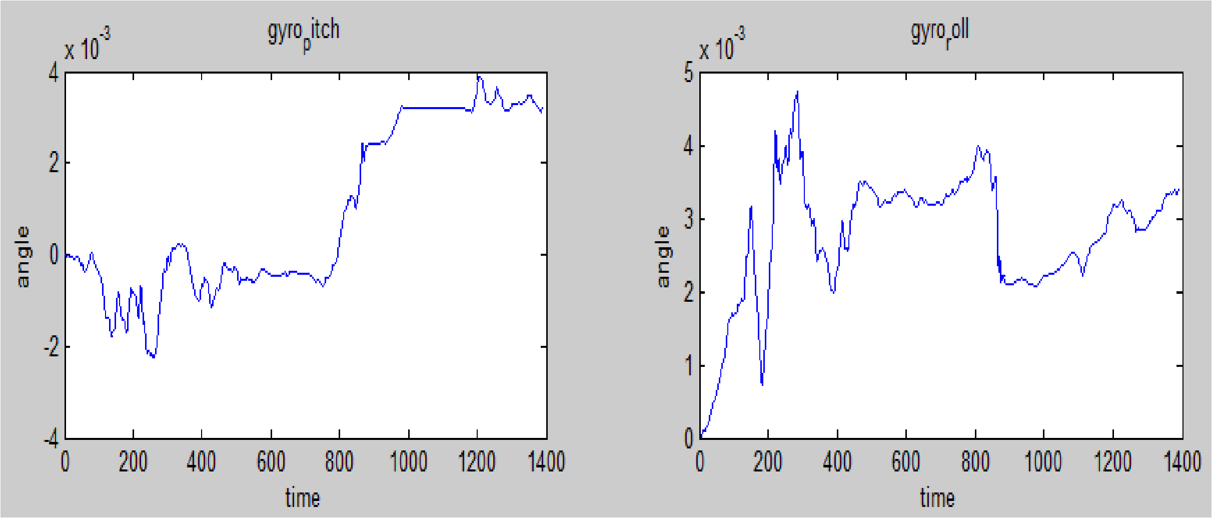

Fig 6.3.4 Gyroscope Angle

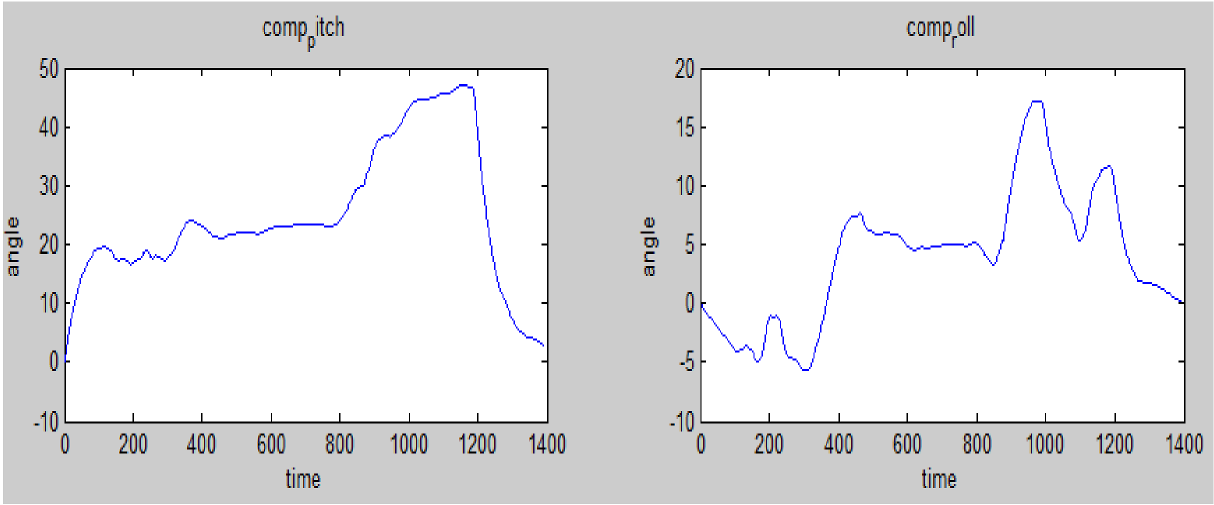

Fig 6.3.5 Complementary Angle

6.4 Normal Reading

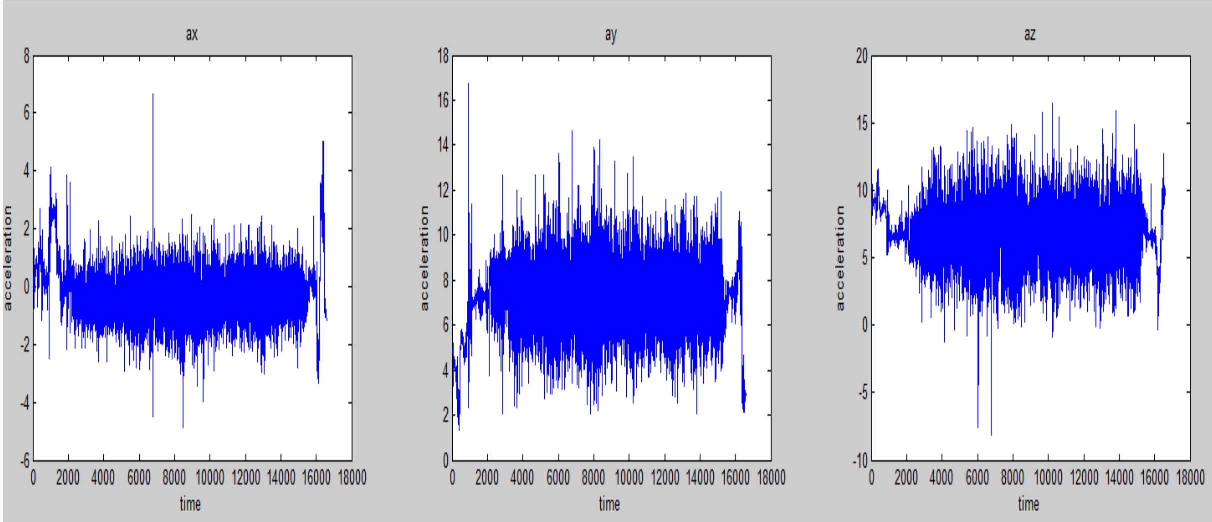

Fig 6.4.1 Raw Accelerometer

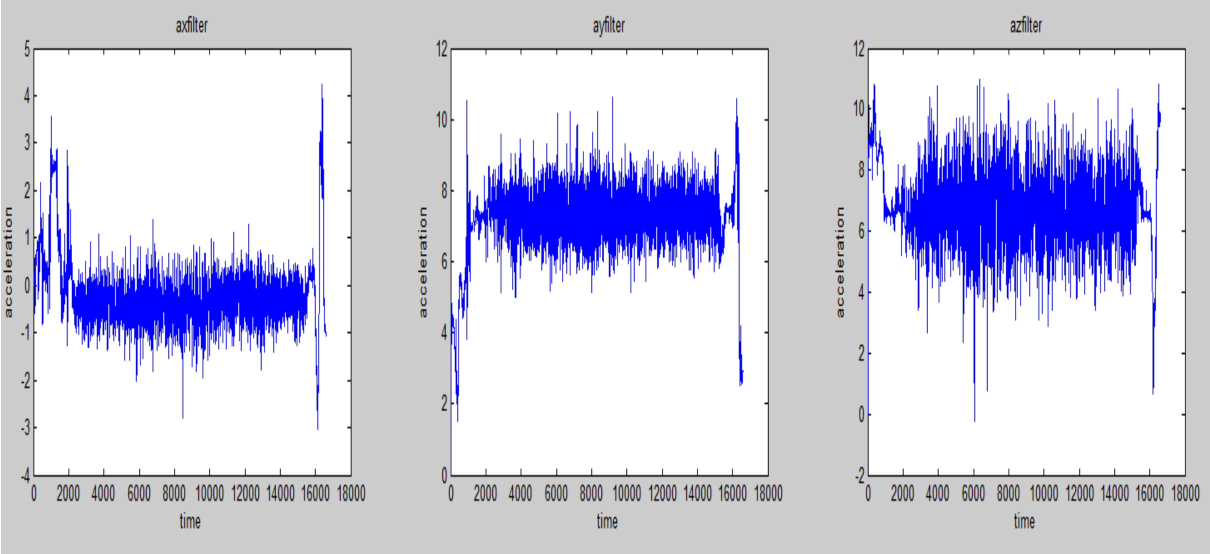

Fig 6.4.2 Filtered Accelerometer

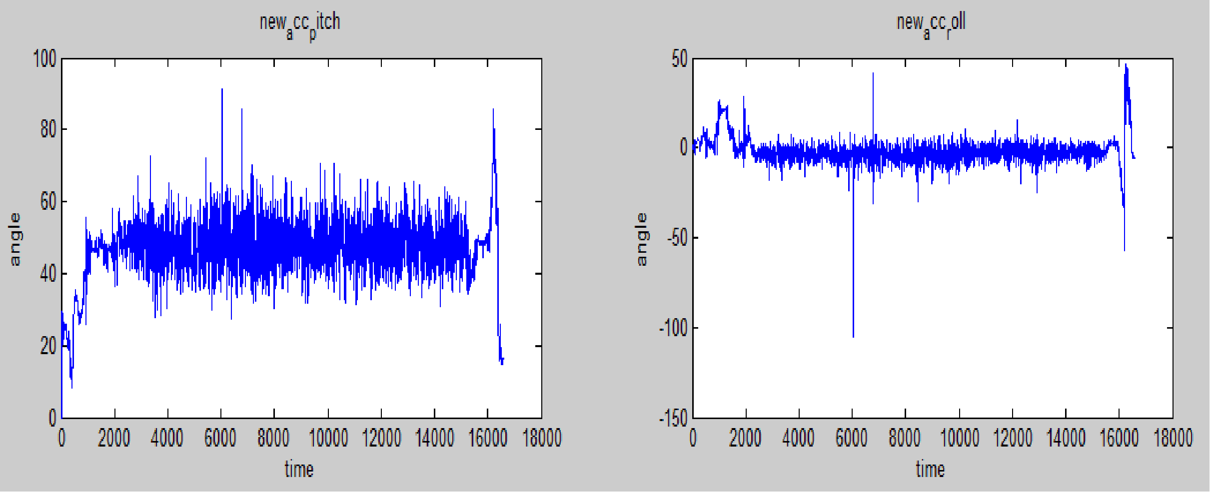

Fig 6.4.3 Accelerometer Angle

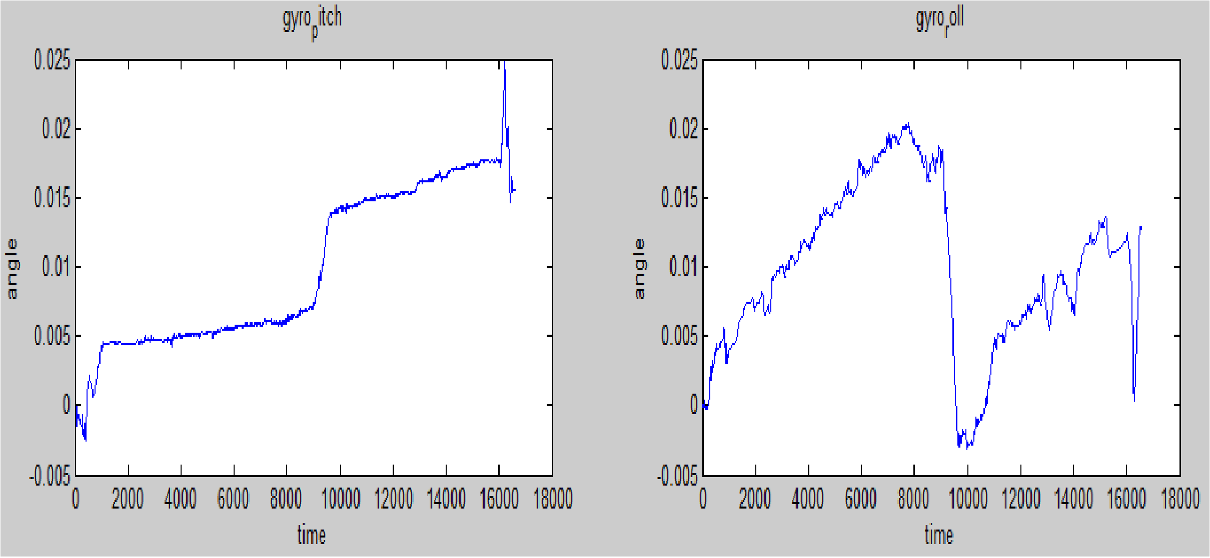

Fig 6.4.4 Gyroscope Angle

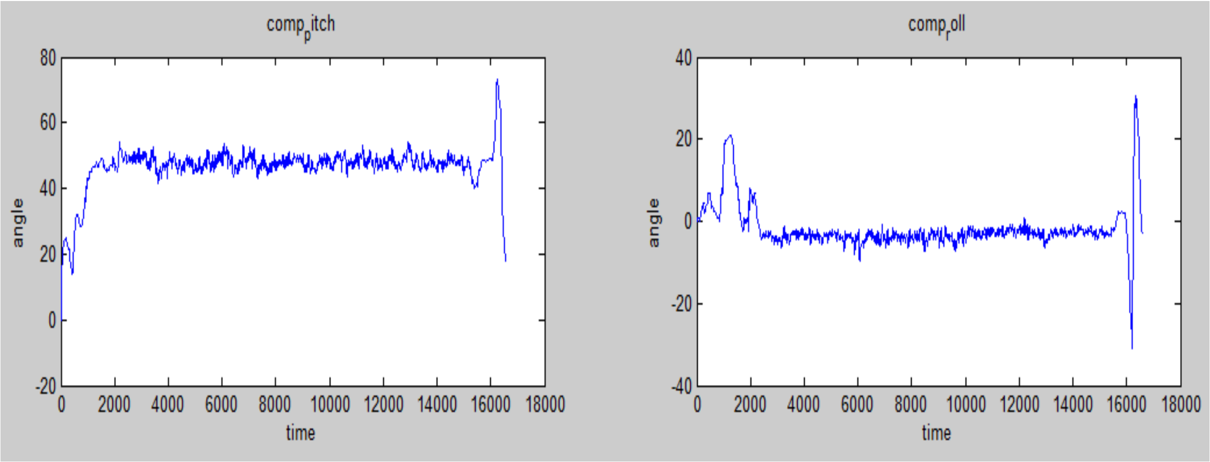

Fig 6.4.5 Complementary Angle

CHAPTER 7

CONCLUSION

The Accelerometer and Gyroscope data are acquired from the respective sensors. The noise and the drift in the sensor data are removed through some filtering techniques and the error-less data is obtained. The orientation angles roll, pitch are computed using mathematical equations involving trigonometry. Accelerometer is supposed to provide the roll and pitch angles but not yaw angle because the rotational movement about the z-axis determines no deviation in x and y-axis. Then the drift problem of gyroscope leads to incorrect data which in turn produce erroneous orientation angles. The accelerometer sensor and the gyroscope sensor are needs to be fused together to get the noise free sensor data.

Based upon analysis of various results obtained from accelerometer and gyroscope sensor. It is clear that, variation in filtered x-axis acceleration and complementary pitch angle are more during crash. So pre-defined threshold value were set for both filtered x-axis acceleration and complementary pitch angle in order to determine crash in bicycle. If the x-axis acceleration and complementary pitch angle exceeds predefined threshold value, then crash has been occurred.

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