INERTIAL TRACKING SYSTEM

Senior project

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DEDICATION

This thesis is dedicated to all my loving family who have supported me all the way throughout the process, and who taught me the value of hard work. Also, I dedicate it to all my annoying friends who stood by my side through bleak times.

Thank you for being the source of my strength and hope.

"If you're going to try, go all the way. Otherwise, don't even start. if you're going to try, go all the way. This could mean losing girlfriends, wives, relatives, jobs and maybe your mind. Go all the way. (...) you will ride life straight to perfect laughter, it's the only good fight there is." C. Bukowski, Roll the dice.

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Finally, I would like to take a moment to appreciate my parents' constant support, sacrifices, encouragement, ability to put up with me overstressing throughout the years, and for trusting me and providing me with the necessary facilities to get this job done.

After all, Gary Keller said:" Don't let small thinking cut your life down to size. Thinking big, aim high, act bold and see just how big you can blow up your life", a quote that inspired me and helped me get through it all.

ABSTRACT

The aim of this project is to be able to track a person in an indoor environment. For this purpose, an Inertial Tracking System (ITS) is proposed and the feasibility of its implementation is studied. The structure of the proposed ITS is in the form of hardware and software, excluding the use of GPS.

This project is focused on the position and orientation calculation. First, the raw acceleration signals are filtered by Kalman’s filter methods. Giving special emphasis to the Kalman’s filter, the position is obtained with great drift.

Finally, the orientation is calculated implementing Kalman’s filter to be able to subtract gravitational acceleration and to obtain gravity-free acceleration.

The acceleration and angular velocity is obtained through arduino UNO with and the six-axis sensor, MPU6050.

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LIST OF SYMBOLS AND ABBREVIATIONS

GPS: Global Positioning System

IMU: Inertial Measurement Unit

ITS: Inertial Tracking System

MEMS: Micro-electromechanical Systems

ZUPT: Zero Velocity Update

CHAPTER 1. INTRODUCTION

1.1. BACKGROUNG

Do you remember how life was before the new technologies took over, and transformed it into a whole new one?

As everyone knows that in the past there was no direction and no system, they used only to know the roads. Then, they started inventing new techniques to get directions; so they started to use the position of the sun and stars. After many years they have reached a very big invention that is The Compass. Then, several techniques have been invented until they have sent satellites to free space and this is where GPS technology has been invented. It is a very complicated system to know your specific location and your direction to all little details.

1.2. PROBLEM STATMENT

Nowadays, one of the trends in technology is the domain of autonomous vehicle where cars, submarines and airplanes are all some examples. One of the main challenges in autonomous vehicle is its localization and navigation. The vehicle needs to be located in a specific position and it should navigate to go from a position to another. Unfortunately, GPS does not work everywhere which causes a big issue in some applications. Indeed, GPS does not work in indoor environments, under the water, in some spaces where its signal is denied. For this reason, we need to switch to other methods to determine our position. One of the best method and easiest method is the use inertial measurement unit (IMU) or guidance system (INS) which is a system integrating an accelerometer (motion sensor), gyroscope (rotation sensor) and magnetometer (magnetic sensor) to reconstruct the state of the system and then determine the location. Such type of navigation is called inertial navigation. Using this technique, the system should know its initial position or location and the data of these sensors should be integrated to determine the speed, the position and the orientation of a moving object relative to its initial position. This system is used in vehicles like cars, ships, aircraft, submarines, radio-controlled missiles and craft. Sometimes, the inertial navigation is combined with GPS data in what is called Simultaneous Localization and Mapping (SLAM).

1.3. GENERAL OVERVIEW

The physical phenomenon chase system is like GPS but with the various methodology, by victimization cheap instrumentality you may reach a beautiful result once GPS turns OFF as during a tunnel or indoor. This methodology relies on MPU-6050, Arduino, Bluetooth, and pc. The general goal is to be ready to deliver a dependably calculable position, through the look associated implementation of an INS. beginning with the practicableness analysis of victimization Kalman filter as a noise filter for the raw values outputted by the measuring system.Then, the implementation of the Kalman filter as a device fusion algorithmic rule to be ready to acquire orientation exploitation of each value, from the measuring device and gyro.

1.4. OUTLINE

Finally, with this orientation, the practicableness analysis of subtracting the gravitational attraction that affects the measuring device and is in a position to calculate a free-gravity acceleration.

CHAPTER 2. LITTERATURE REVIEW

This section we will represent the literature review for inertial tracking system.

2.1. INERTIAL TRACKING SYSTEM OVERVIEW (ITS OVERVIEW)

An inertial guidance System could be a self-contained navigation technique within which accelerometers associated gyroscopes give measurements that are accustomed to track the position and orientation of an object relative to a far-famed start line, orientation, and rate, within the absence of external references like world positioning systems (GPS). This method makes use of a pc for a process the information given by the mechanical phenomenon measurements units that are electronic devices that ordinarily contain a 3-axis measuring instrument and 3-axis gyro, which measures linear acceleration and angular rate severally. The ITS is employed in an exceedingly big selection of applications, like craft navigation, steering in human spacefaring and target-hunting missiles among others.

For the needs of this project, attention is going to be targeted on the practicability of the primary half by proposing associate degree guidance System on that Kalman filter are going to be applied.

2.2. SCHEME OF AN ITS

Through the years there has been a rise of the need of knowing the position and orientation of various objects in many alternative fields. To be able to live the position of a body or device, it’s better to measure acceleration square measure additional convenient than the devices that square measure accustomed measure position directly. Thus, to get displacement from acceleration a double integration should be applied; however, this generates 2 necessary issues that cause major integration errors: drift associated to accelerometers and therefore the initial condition of the system square measure unknown.

For indoors tracking, some propose an answer by mounting the sensors on the pedestrian’s foot, victimization zero rate update (ZUPT), that is ready to deliver an honest accuracy of the pedestrian displacement by recognizing the walking pattern and shrewd the precise moment once there's no displacement of the foot and it will update rate to zero. Yet, within the context of this project, the employment of GPS isn't attainable because of attainable interference between the antennas signals of the observatory and it's not viable to implement a ZUPT as a result of the staff move from the initial check management during a vehicle and so walk to specific places, therefore its application wouldn't be of use during this case

As a start, AN already structured observation system is given wherever the concept behind it's that it will directly track the activity of employees in real time.

This is divided in three fundamental parts:

1. Inertial tracking subsystem

2. Communication subsystem

3. Platform development (data visualization).

Kalman filter is an algorithmic program-wide known because of its several applications in technology. Normally utilized in steering, navigation, and management of vehicles, maybe an algorithmic program, it is often enforced in real time exploitation solely the present mensuration, the antecedently calculated state, and an uncertainty matrix.

Finally, the positioning downside has been approached, however, most of the days the position estimation should be drained a controlled setting, between little periods of your time, notable patterns of behavior or not in real time.

2.3. PREVIOUS RESULT

There are many teams and universities that work on this navigation system and they reach approximate the same result as: [14] [15] [16] [17] [18]

Table 2.1: DISPLACEMENT AND ERRORS SUMMARY OF USED FILTERS

Filter	Displacement [m]	Error [m]
Kalman	0.784	0.416
Noise	0.833	0.367
SMA	1.225	0.025

They were able to achieve an error rate of 1.055%

CHAPTER 3. PROJECT SPECIFICATIONS'

In this chapter we will represent the component specification and the equation designed.

3.1. COMPONENT SPECIFICATION

As everyone know that the GPS turns OFF during tunnels, under water, military station… So we need to make a tracking system by using low cost equipment that is Arduino Uno, MPU-6050 and Bluetooth.

To design our project, we need a few and cheap component mpu6050 (3 axis accelerometer, 3 axis gyroscope), car, Bluetooth, Arduino-Uno and computer.

An Accelerometer is a device that measure the rate of change in the acceleration velocity, For example, an accelerometer at rest on the surface of the Earth will measure an acceleration due to Earth's gravity, straight upwards (by definition) of $g \approx 9.81\ m/s^2$. By contrast, accelerometers in free fall (falling toward the center of the Earth at a rate of about $9.81\ m/s^2$) will measure zero.

Basically, the functioning of the measuring device is often explained as a cube with a floating ball within, wherever associate axis is selected to the sensitive walls of the cube and while not an attraction field, as seen below.

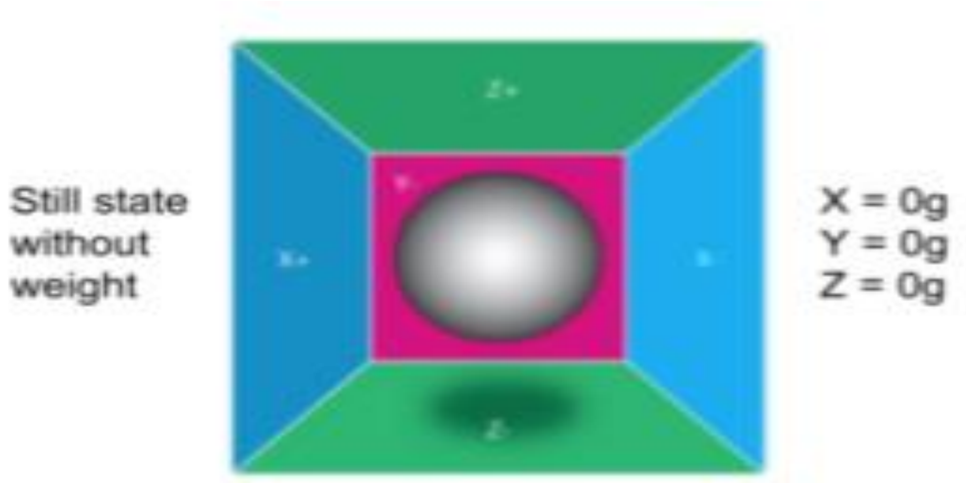

Figure 3.1: Practical illustration of the functioning of an accelerometer.

On the opposite hand, if the detector experiences an abrupt movement to the left, the within ball can bit the x wall with Associate in Nursing acceleration, as an example, 1g = 9.81m/s2 as it can be observed.

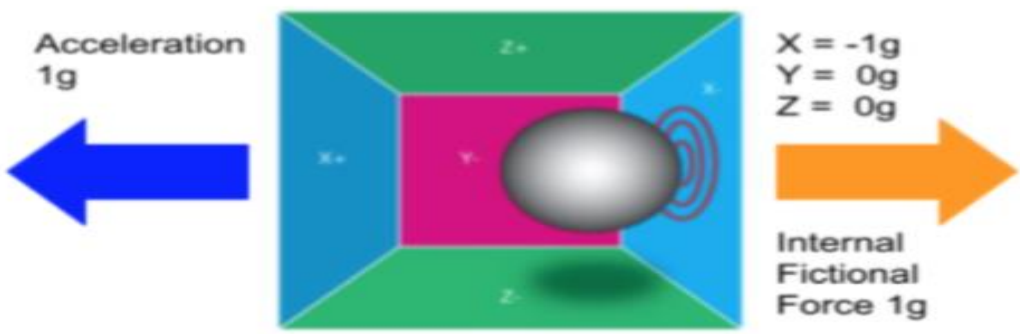

Figure 3.2: Practical illustration of the functioning of an accelerometer shifting left.

On Earth, the device experiences the gravity; therefore, the ball can break down the −Z wall and applied 1g as shown below

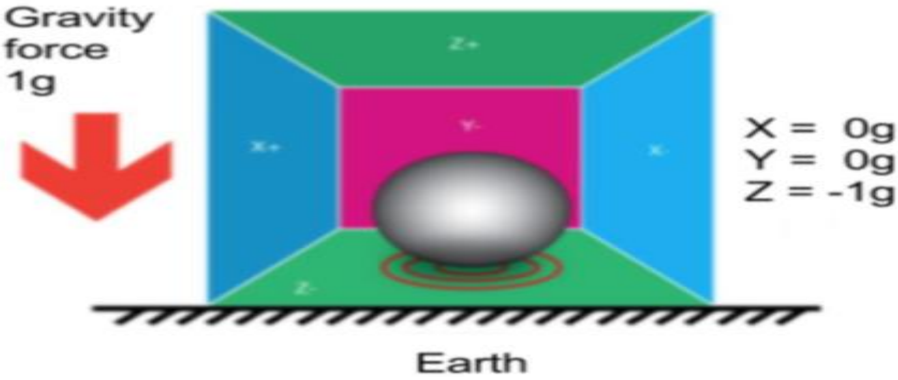

Figure 3.3: Practical illustration of the functioning of an accelerometer on a surface

A gyroscope is a device used for measuring or maintaining orientation and angular velocity. It is a spinning wheel or disc in which the axis of rotation is free to assume any orientation by it. When rotating, the orientation of this axis is unaffected by tilting or rotation of the mounting, according to the conservation of angular momentum.

MEMS gyroscopes area unit characterized by being tiny, low-priced and have smart performance. Once a MEMS-based rotating mechanism is turned, a little resonant mass placed inside it, shifts. This movement is reborn into tiny electrical signals that may be amplified and browse by a processing unit.

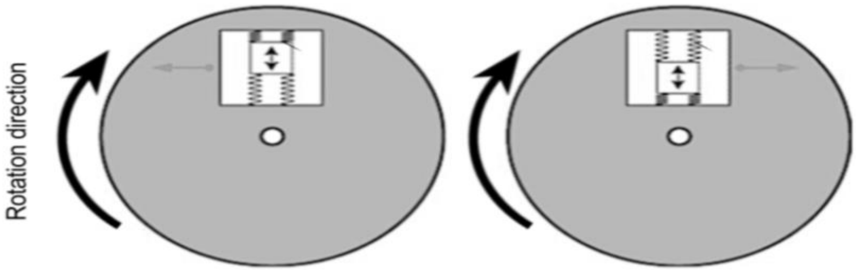

Figure 3.4: Principle of the inner operation of a MEMS-based gyroscope

A robot is a machine—especially one programmable by a computer—capable of carrying out a complex series of actions automatically. Robots can be guided by an external control device or the control may be embedded within. Robots may be constructed to take on human form but most robots are machines designed to perform a task with no regard to how they look.

Bluetooth is used to test this project and send data to a short distance.

Arduino is used a write the protocol for MPU-6050 to give data and to make interference by Bluetooth with the laptop. Also to make the mathematical the proper equation to get specific data we need.

3.2. MAIN EQUATIONS USED IN THIS REPORT

In this section, we will explain how the position and orientation are reconstructed form the accelerometer and gyroscope signals. For this purpose, we will first introduce the notion of Euler angle in 3D, then in 2D to reach finally, the equations needed to reconstruct the position and orientation.

Euler angle: using Euler angle, any rotation can be defined as three consecutive rotations around three axes in terms of so-called Euler angles. We use the convention (z, y, x) which first rotates an angle ψ around the z-axis, subsequently an angle θ around the y-axis and finally an angle φ around the x-axis. Assuming that the v-frame is rotated by (ψ, θ ,φ). The following figures illustrate the Euler angles.

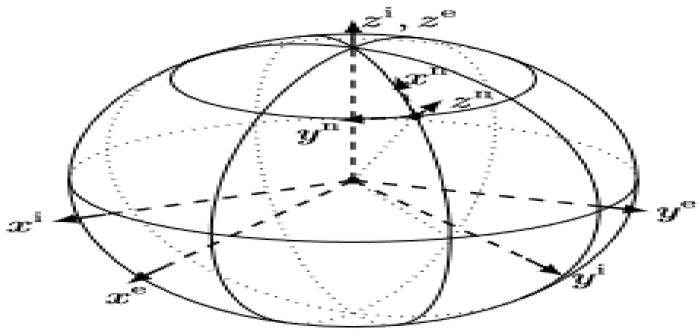

Figure 3.5: Three rotations around three axis combined together

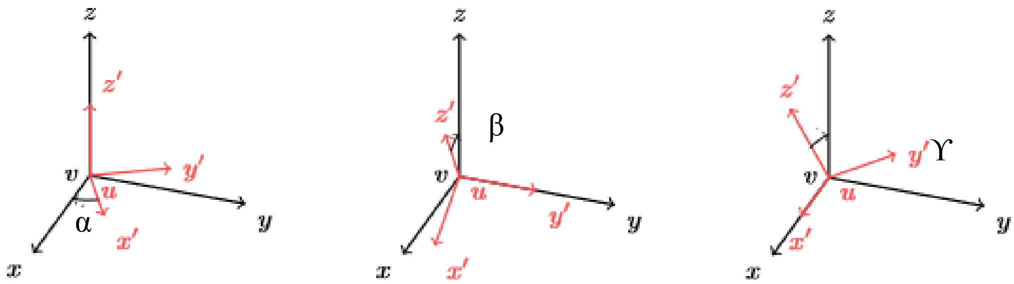

Figure 3.6: The three rotations around the three axes

Each rotation can be represented mathematically as a rotation matrix. Using rotation matrix, a coordinate of a vector in a frame can be transformed to another frame. A rotation matrix in three-dimensional space can be found by multiplying three rotation matrices around axes (z, y, x) by angles (ψ, θ ,φ) as shown below.

$$
\begin{aligned}
R &= R_{z''}(\gamma)\cdot R_{y'}(\beta)\cdot R_{z}(\alpha) \\
&= \begin{pmatrix} \cos\gamma & \sin\gamma & 0 \\ -\sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\beta & \sin\beta & 0 \\ -\sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix} \\
&= \begin{pmatrix} c\gamma c\beta c\alpha - s\gamma s\alpha & c\gamma c\beta c\alpha + s\gamma c\alpha & -c\gamma s\beta \\ -s\gamma c\beta c\alpha - c\gamma s\alpha & -s\gamma c\beta s\alpha + c\gamma c\alpha & s\gamma s\beta \\ s\beta c\alpha & s\beta s\alpha & c\beta \end{pmatrix}
\end{aligned}
$$

As it is known, the position is the double integral of the acceleration and the orientation is the integral of the angular velocity. (You need to write the equations to get the position and orientation from the acceleration and the angular positions)

$$\iint_R f(x,y)dA = \int_a^b \left[\int_c^d f(x,y)dy\right] dx$$

Equation for kalman filter shown in figure:3.7

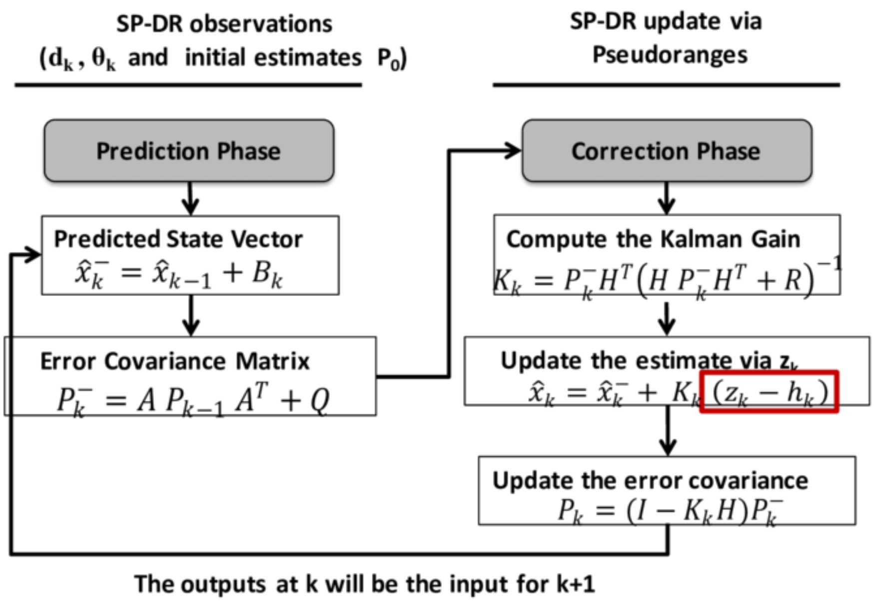

Figure 3.7: Mathematical Equations for kalman Filter

CHAPTER 4. DESIGN

In this chapter, we will present the design of our robot that answers the specifications presented in the previous section. For this reason, we will first present the components used and then, we will present the connections of the motors and sensors. Finally, we will move to present the algorithms and libraries used.

4.1. INTRODUCTION

An inertial navigation may be a self-contained navigation technique within which measurements provided by accelerometers and gyroscopes are wont to track the position and orientation of an object relative to a notable place to begin, orientation and speed. Mechanical phenomenon mensuration units (IMUs) usually contain 3 orthogonal rate-gyroscopes and 3 orthogonal accelerometers, activity angular speed and linear acceleration severally. By process signals from these devices, it's potential to trace the position and orientation of a tool.

4.2. HARDWARE IMPLEMENTATION

The MPU-6050 is a device that combines 3-axis of gyroscope and 3-axis accelerometer on the same silicon die, together with an onboard digital motion processor.

MPU-6050 is a chip that contains accelerometer and gyroscope and has a low price. We will use it to get the acceleration velocity and the angular velocity.

After getting this data we will transfer those from unfixed system to fixed system that lead to let as to use a single system since we can't work with two different systems. As shown in the table 4.1.

Table 4.1: MPU6050 features summary

Features summary:

I2C Digital-output of 6-axis MotionFusion data in rotation matrix, quaternion, Euler Angle, or raw data format	
Input Voltage	2.3 - 3.4V
Selectable Solder Jumpers	CLK, FSYNC and AD0
Tri-Axis angular rate sensor (gyro) a full-scale range	± 50, ± 500, ± 1000, and ± 2000dps
Tri-Axis accelerometer with a full scale range of	$\pm 2g$, $\pm 4g$, $\pm 8g$ and $\pm 16g$
Digital Motion Processing™ (DMP™) engine offloads complex MotionFusion, sensor timing synchronization and gesture detection	
Embedded algorithms for run-time bias and compass calibration. No user intervention required	
Digital-output temperature sensor	
Dimensions	25.5 x 15.2 x 2.48mm

This operation is done by working with Euler angle after that we need to get back all the data to the reference. This operation is done by multiplying the data with a matrix.

To this level we have the acceleration that is ax and ay (2D).

To get distance we need to make double integral to this data that give us new x and y, but need linearity to plot our data to get a tracking map so we need to sum for every point of the previous one.

Figure 4.1: mpu6050

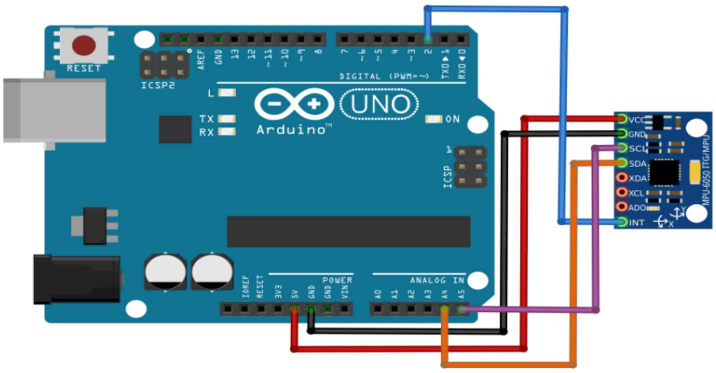

Figure 4.2: Connection between arduino UNO and MPU6050 sensor

Arduino-Uno is to make interference between MPU and send by Bluetooth to computer, also to write the codes that make MPU-6050 work properly, transmit and receive data.

Also we use Arduino to write the mathematical equation to get position for car.

Accelerometer is used to get the distance while Gyroscope to get angle.

4.3. CONCLUSION

Such system is so complex, by fragmenting it to parts we have simplified our design in order to get rid of expected problems and improve it to reach our goal.

Figure 4.3: robot to be tracked

CHAPTER 5. RESULTS

5.1. INTRODUCTION

At the instant of filtering the signal, it is often seen that the Kalman filter deals with success with the noise, filtering in line with the initial values set to alphabetic character and R. Still, it doesn't correct the constant bias that's made by the double integration method. This is often as a result at the instant of getting the orientation the filter uses 2 variables that consult with a similar data, however from different sources. One, by hard the quantitative relation of the different quantity of gravity is measured by the individual axis of the measuring system, and therefore the different direction from the gyroscope’s angular rates, that is that the price that drifts compares them to get one filtered price that's reliable and subjected to the activity and system noise. The difference between these 2 values, known as the bias, is being calculated and updated in each loop, to be then deducted from the screeching activity. This manner the values are complemented and therefore the drift is often corrected because it goes. This could be attainable due to the reliance on the measuring system within the long run, and therefore the short-run reliance on the rotating mechanism, so its measurements are combined to get a drift-free orientation of the device.

5.2. RESULT DISCUSSION

As for the comparison between the filters, it absolutely was shown that an easier filter might have sufficed. All the same, identical drawback is two-faced with the 3 filters that were applied. At the instant of mistreatment, the quadrilateral rule to get the speed, and not having the ability to own another reference instead of the acceleration itself, it provides a slope and when the second integration, it leads to associate degree mathematical function, delivering results that quickly diverge from reality, even with a low-pass filter applied when every integration to undertake to correct it. This was one amongst the foremost issues that were two-faced. As not having the ability to use the associate degree external relation to correct the drift conferred in displacement when the double integration method, the values obtained was unusable. all the same, because it was mentioned, a high-pass filter is employed in an exceedingly previous work, however, the results weren't satisfactory owing to the delay that the filter itself gave, therefore it absolutely was counseled an even bigger micro-controller for higher potential results. Another potential resolution might are rather than doing the calculations in real time, the info might are gathered till the displacement of a specific person is needed, wherever it might be potential to use alternative filters that can't be employed in real time, showing the displacement estimate while not the delay.

5.3. CONCLUSION

Finally, the orientation is well-calculated mistreatment the Kalman filter, delivering the expected values. Yet, at the instant of testing the idea behind of subtracting the gravity from the acceleration, because the universal gravitational constant is increased by a $\cos(\theta)$ or $\sin(\theta)$, it makes the worth oscillate a couple of times before really showing the important acceleration, and tends to destabilize quite quickly. Considering this, the combination of the important acceleration to get the rate and so the position wasn't created as a result of the position would grow exponentially, moving far-flung from the particular displacement.

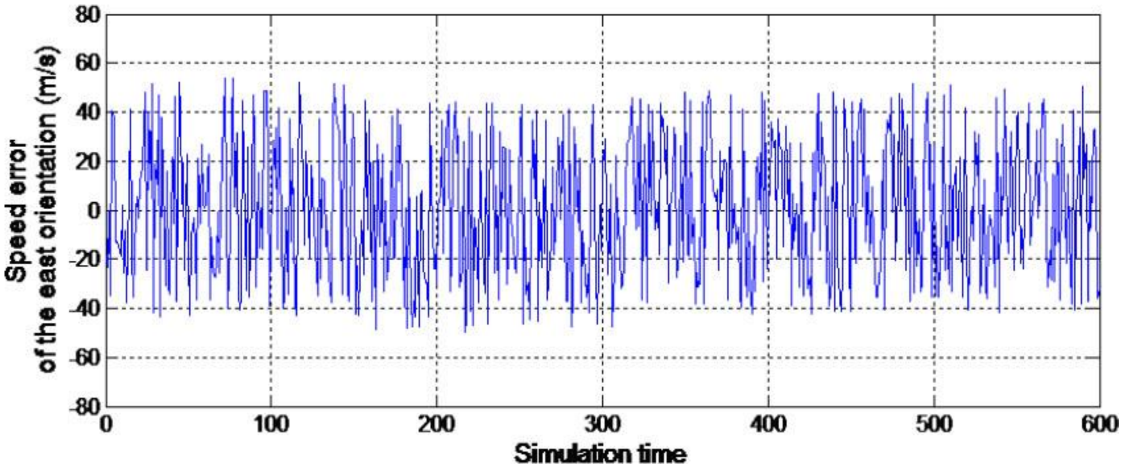

Figure 5.1: Data before kalman filter

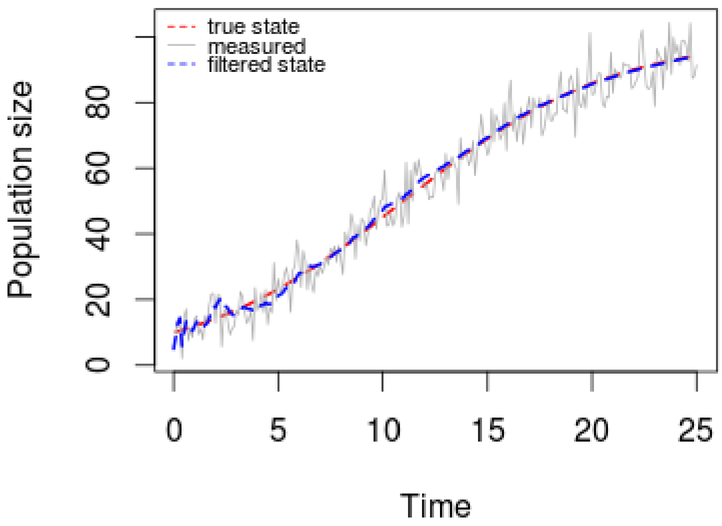

Figure 5.2: Smoothing results

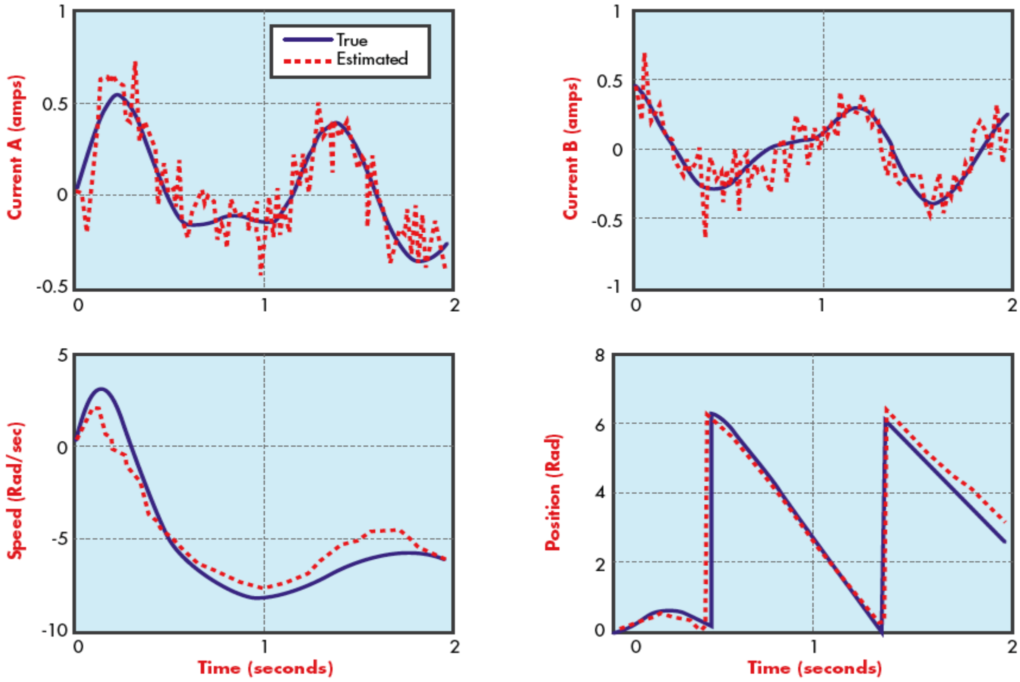

Figure 5.3: Data after filters implemented

CHAPTER 6. CONCLUSION

6.1. HARDWARE:

As the MPU-6050 presents a personality disorder known as offsets that comes with it from fabrication the standardization method is so an elementary step to be ready to acquire coherent results. Also, the MEMS by themselves square measure hardware that by their fabrication specifications brings associated errors, that makes the measurements less precise. However, for the context of this project, because the plan behind it absolutely was to trace someone in AN open area, a high accuracy wasn't necessary. Thus, the Arduino Uno beside the MPU-6050 used for this project was ready to deliver usable results

6.2. SIGNAL FILTERING

As it was expected, the signal that's two-handed out by the sensing element is very clanging. This is often explained by the affordable terrorist organization utilized in this project and also the micro-fabrication with that they're created. Even so, through the filters applied, it had been attainable to envision that this noise is so filtered out.

A filter will be chosen looking on the convenience of resources. For this project, one among the specific goals was to use the Kalman filter as a noise filter, which was with success done. The machine demand from Kalman wasn't as grand once it's used as a detector fusion formula, that means not a good difference within the temporal arrangement of the results obtained as compared with the opposite used filters, and the way it had been seen, neither within the double integration method.

Finally, every filter used handed out similar outputs. Notwithstanding, the important comparison take place at the instant of getting the displacement.

APPENDIX A. ARDUINO CODE

```
#include <Wire.h>
 #include <AFMotor.h>
unsigned long time;
double temp;
longaccelX, accelY;
floatgForceX, gForceY;
float gForceX1, gForceY1;
float gForceX2, gForceY2; // final value
longgyroZ;
floatrotZ, rotZ1, rotZ2; //gyroscope data(theta zero) , integration for gyroscope (delta
theta) , final value for theta (theta new)
unsigned long dt, dt1,d1=0,d2=0;
char c;
floatthetanew;
float ax, ay; // answer of matrix (acceleration)
int gForceX3, gForceY3;

void setup(){
Serial.begin(9600);
Wire.begin();
setupMPU();
}
```

```
void loop(){
  //writeData(data) tb3at data krmal  w lmpu6050
if(Serial.available()){
readData();
///l 2f wl else   control

}
do{
  // statement(s)
recordAccelRegisters();
recordGyroRegisters();
time = millis();



}
}
voidwriteData(String data)
{
Serial.print(data);
  }

voidreadData(){
    c=Serial.read();
}
```

```
voidsetupMPU(){
Wire.beginTransmission(0b1101000); //This is the I2C address of the MPU (b1101000/b1101001 for AC0 low/high datasheet sec. 9.2)
Wire.write(0x6B); //Accessing the register 6B - Power Management (Sec. 4.28)
Wire.write(0b00000000); //Setting SLEEP register to 0. (Required; see Note on p. 9)
Wire.endTransmission();
Wire.beginTransmission(0b1101000); //I2C address of the MPU
Wire.write(0x1B); //Accessing the register 1B - Gyroscope Configuration (Sec. 4.4)
Wire.write(0x00000000); //Setting the gyro to full scale +/- 250deg./s
Wire.endTransmission();
Wire.beginTransmission(0b1101000); //I2C address of the MPU
Wire.write(0x1C); //Accessing the register 1C - Acccelerometer Configuration (Sec. 4.5)
Wire.write(0b00000000); //Setting the accel to +/- 2g
Wire.endTransmission();
}

voidrecordAccelRegisters() {
Wire.beginTransmission(0b1101000); //I2C address of the MPU
Wire.write(0x3B); //Starting register for Accel Readings
Wire.endTransmission();
Wire.requestFrom(0b1101000,6); //Request Accel Registers (3B - 40)
while(Wire.available() < 6);
```

```
accelX = Wire.read()<<8|Wire.read(); //Store first two bytes into accelX
accelY = Wire.read()<<8|Wire.read(); //Store middle two bytes into accelY
processAccelData();
}

voidprocessAccelData(){
gForceX = accelX / 16384.0;
gForceY = accelY / 16384.0;
}

voidrecordGyroRegisters() {
Wire.beginTransmission(0b1101000); //I2C address of the MPU
Wire.write(0x43); //Starting register for Gyro Readings
Wire.endTransmission();
Wire.requestFrom(0b1101000,6); //Request Gyro Registers (43 - 48)
while(Wire.available() < 6);
gyroZ = Wire.read()<<8|Wire.read(); //Store last two bytes into accelZ
processGyroData();
}

voidprocessGyroData() {
rotZ = gyroZ / 131.0;
}
```

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