Autonomous Self Correcting Platform Using Accelerometer and Gyroscope

Submitted in partial fulfilment of the requirement

Of the degree of

Bachelor of Engineering in

Electronics and Telecommunication

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Certificate

This is to certify that the project entitled “Autonomous Self Correcting Platform using Accelerometer and Gyroscope” is a bonafide work of “Lehak Dharmani, Sanket Raut, Ronak Shah, and Suraj Thite” submitted to the University of Mumbai in partial fulfilment of the requirement for the award of “Bachelor” in “Electronics and Telecommunication”.

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Abstract

Self-Balancing technology is a field which has piqued interest of many people with the advent of Self Balancing Segway, Robots, etc. Our goal is to make a Self-Balancing Platform which would nullify the effect of movement on the platform and keep the platform surface parallel to the surface of the earth. We use an Inertial Measurement Unit which is a combination of accelerometer and gyroscope to measure the tilt of the body. The values obtained by the IMU is processed using Arduino board and the correspondingly equal and opposite motion is produced using servo motors to counter the effect of the tilt and keep platform stable.

Keywords: Self-Balancing, Inertial Measurement Unit, Servo Motor

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Chapter 1

Introduction

Self-balancing platform consists of an autonomous platform which is balanced by movement of servo motors in opposite direction to the movement of the platform. Microcontroller processes the tilt angles (pitch, roll, and yaw) obtained from IMU and program the respective servo motors to rotate by certain angle corresponding to its previous position to balance or control the platform. IMU consists of Accelerometer and Gyroscope whose outputs are calibrated properly by using KALMAN filter to give the precise raw data of pitch, roll and yaw. This angle is sent to PID or DCM algorithm which measures the error i.e. how far the current position of platform is from the desired set point (balancing point). The algorithm attempts to minimize the error by adjusting the process control inputs.[13]

1.1 Motivations

As a Group we were Fascinated with the self-balancing devices. With advent of self-balancing devices, be it Segway, DIY, or TIPI, we were fascinated with the futuristic scope that self-balancing devices hold, be it flying cars or compact car modules on two wheels, be itself stabilized and Bluetooth controlled cameras clicking in courteous moves of Hollywood stars or be it a simple self-stabilizing skateboard, controlled by your gestures, the idea of self-stabilizing skateboard controlled by our leg movements did take rounds in our fascinated team.[13]

As of delving deep into vast knowledge pool of self-controlled and stabilized devices, the team felt to get first-hand knowledge of various control mechanisms, IMUs, filters, robust mechanical system, and henceforth, concluded to engineer a manually controlled-cum-self stabilizing platform with three axis of freedom.

1.2 Objective and Goals

- To demonstrate the techniques involved in balancing a platform.
- To work on precise movements and accurate control of platform, with use of various algorithms and filtering process
- To understand the working of IMU. IMU work involves understanding the pin configurations of the IMU and configuring the correct libraries for the IMU.
- To identify the correct connections needed for all the peripheral hardware to communicate with the microcontroller.
- Establishing lines of communication with the correct hardware pin addresses will allow for easy identification on how each individual piece of hardware will transmit and process data to and from the IMU.
- To establish the power supply to each electronic components.[13]

1.3 INITIAL RESEARCH

Creating a balancing platform with the use of a gyroscope requires that the program keep track of the gyroscope's orientation and attempt to keep the gyroscope level.

The conventional motor control method for keeping sensor readings within a certain threshold is the proportional integral derivative, or PID, control loop. PID control typically provides smooth control with minimal overshoot on corrective action. Although there are easier control methods like bang-bang, proportional (P), and Proportional-Derivative (PD), taking the extra time to factor in a smooth integral will be the best payoff for a smooth and efficient system. DCM is very effective algorithm which has authentic calibration of filters and PID whose constants can be manipulated according to the project.

Analog output accelerometers and gyroscopes communicate with a Pulse-Width Modulation (PWM) signal, which most microcontrollers support. Digital output accelerometers and gyroscopes, such as the ones found on sparkfun.com, communicate using standard I2C protocol. There are a few different ways to communicate with motor controllers, which can be categorized by either analog or digital input. Analog input is done via PWM. Digital input can be done a couple ways. The first is by simulating an R/C signal that sets the speed and direction of the motor until specified at another time. The second is to use serial data to communicate the speed and direction of the motors.

The main advantage to using serial data is that the microcontroller can communicate with the motor controller with just one serial port. The shifting from control to stabilization mode is accomplished by using a switch between A0 pin of Arduino and a 9 V low current battery .Switching on implies change in Analog value at A0 pin which is used in our code to decide the respective mode. Arduino obtains tilt angle from IMU by using I2C Interface and then control servo motors using its PWM pins and the frequency of operation of servo motors can be made synonymous with that of IMU.[13]

Chapter 2

Literature Review

In the previous chapter we have focused on the implementation of various algorithms for the development of the self-balancing platform. In this chapter we will see with an in depth understanding of various components required for development of this platform.

2.1 Working of Accelerometer, Gyroscope and Servo Motor

2.1.1 Accelerometer

An accelerometer is an electromechanical device that is used to measure acceleration **a**nd the force producing it. Many types of accelerometers are available in the market today. They can be divided according to the force (static or dynamic) that is to be measured. Even today, one of the most commonly used one is the piezoelectric accelerometer. But, since they are bulky and cannot be used for all operations, a smaller and highly functional device like the MEMS accelerometer was developed. Though the first of its kind was developed years ago, it was not accepted until lately, when there was need for large volume industrial applications. Due to its small size and robust sensing feature, they are further developed to obtain multi-axis sensing.

One of the most commonly used MEMS (Micro-electro-mechanical Systems) accelerometer is the capacitive type. The capacitive MEMS accelerometer is famous for its high sensitivity and its accuracy at high temperatures. The device does not change values depending on the base materials used and depends only on the capacitive value that occurs due to the change in distance between the plates [2].

If two plates are kept parallel to each other and are separated by a distance‘d’, and if ‘E’ is the permittivity of the separating material, then capacitance produced can be written as

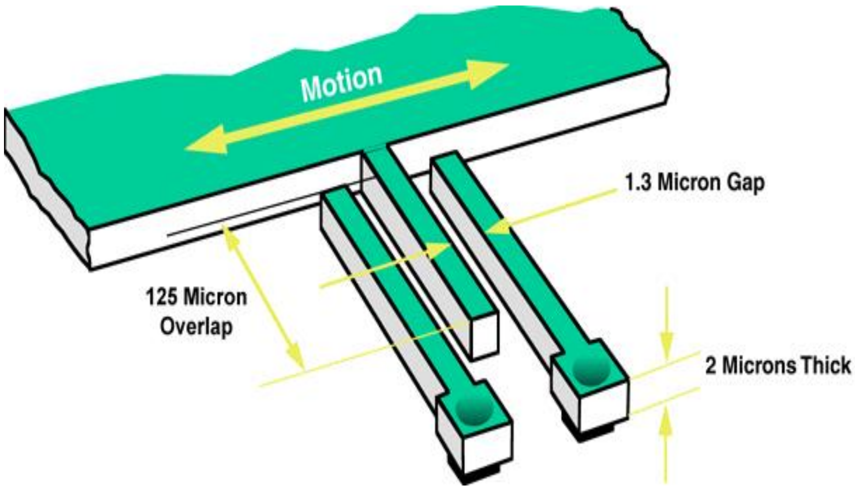
$$\mathbf{C_0 = E_0.E\ A/d = E_A/d}$$

$$\mathbf{E_A = E_0EA}$$

A – Area of the electrodes

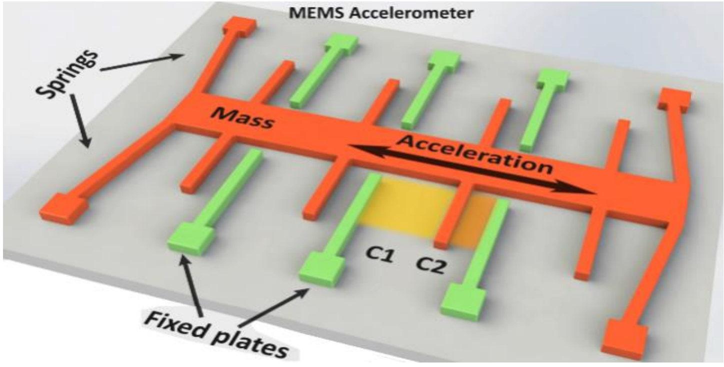
A change in the values of E, A or d will help in finding the change in capacitance and thus helps in the working of the MEMS transducer. Accelerometer values mainly depend on the change of values of d or A [2].

A typical MEMS accelerometer is shown in the figure below. It can also be called a simple one-axis accelerometer. If more sets of capacitors are kept in 90 degrees to each other you can design 2 or 3-axis accelerometer. A simple MEMS transducer mainly consists of a movable microstructure or a proof mass that is connected to a mechanical suspension system and thus on to a reference frame [2].



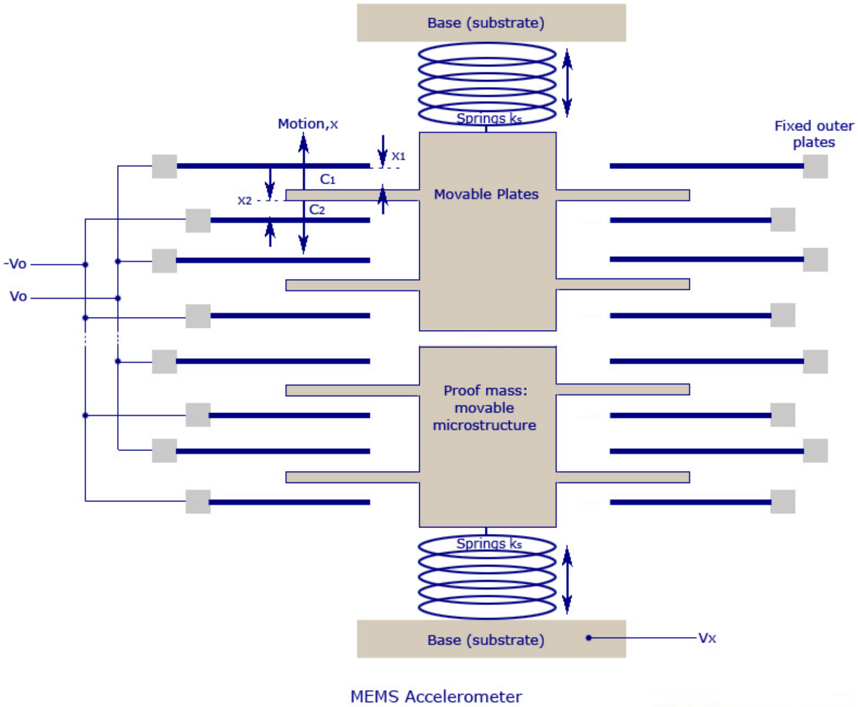
[1]

Figure 1 - Working of Accelerometer I



[3]

Figure 2 - Working of Accelerometer II



[2]

Figure 3 - Working of MEM Accelerometer

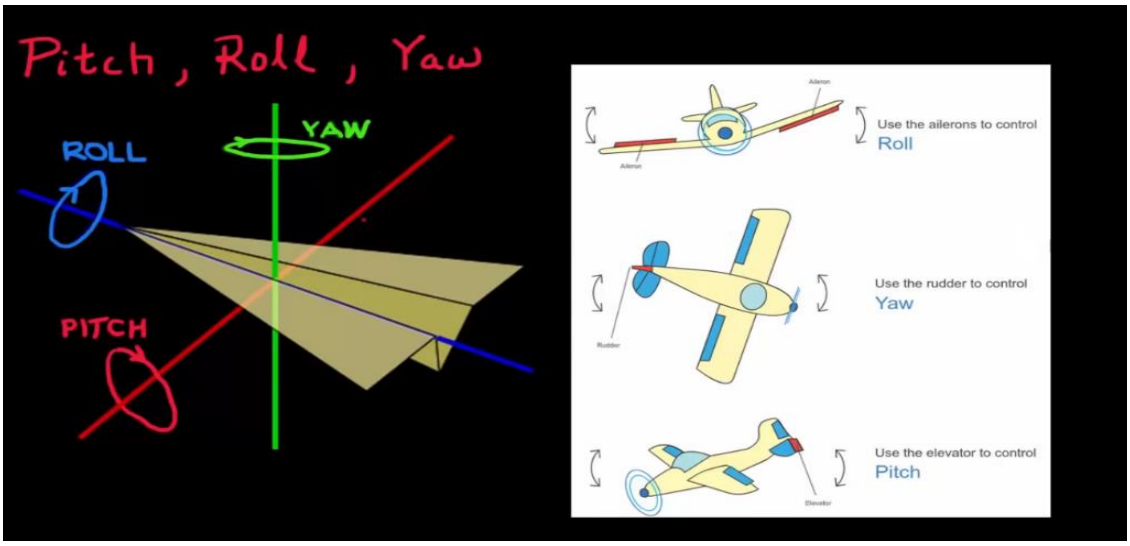
The movable plates and the fixed outer plates act as the capacitor plates. When acceleration is applied, the proof mass moves accordingly. This produces a capacitance between the movable and the fixed outer plates. When acceleration is applied, the distance between the two plates displace as X1 and X2, and they turn out to be a function of the capacitance produced. This difference in capacitance is detected and amplified to produce a voltage proportional to the acceleration. The dimensions of the structure are of the order of microns. The demodulator produces an output equal to the sign of the acceleration.

When no acceleration is given (a=0), the output voltage will also be zero. When acceleration is given, such as (a>0), the value of value of V_x changes in proportion to the value of V_0.When a deceleration is given, such as (a<0), the signals V_x and V_y become negative [2].

2.1.2 Gyroscope

A Gyroscope is a device for measuring or maintaining orientation. To understand Gyroscope we need to understand these three terms Pitch, Roll, Yaw and Coriolis Effect.

Pitch, Roll, Yaw represents the angular velocity along the x, y and z axes respectively as shown in the figure below.



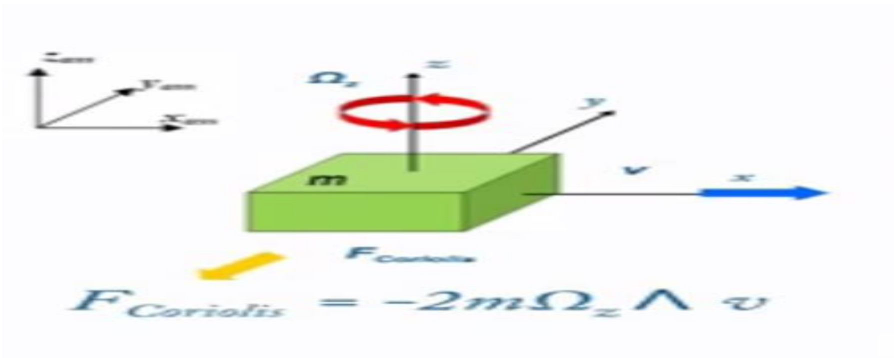
[5]

Figure 4 - YAW, PITCH, ROLL

2.1.2.1 Coriolis Effect

Consider a mass moving in direction v. When an Angular movement is applied (red arrow), the mass experiences a force in the yellow direction as a result of Coriolis Effect.

This resulting displacement is used in MEMS Gyroscope. This resulting displacement changes the effective capacitances between the fixed and the movable plates. This capacitance generated is directly proportional to the applied angular force. This capacitance is then converted into proportional electrical signal [4].



[4]

Figure 5 - Coriolis Effect

2.1.2.2 Tuning Fork Gyroscope

Practically though, Two masses are used vibrating in the opposite direction and the net displacement C between them is calculated and then the corresponding signal is produced. This arrangement is useful because it tends to eliminate the effect of acceleration on the body [5].

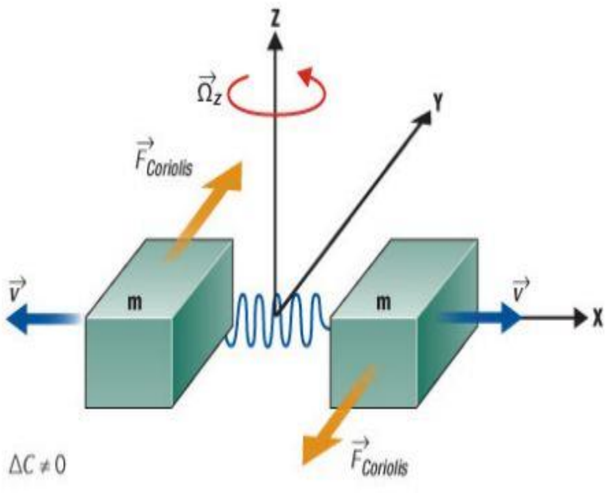
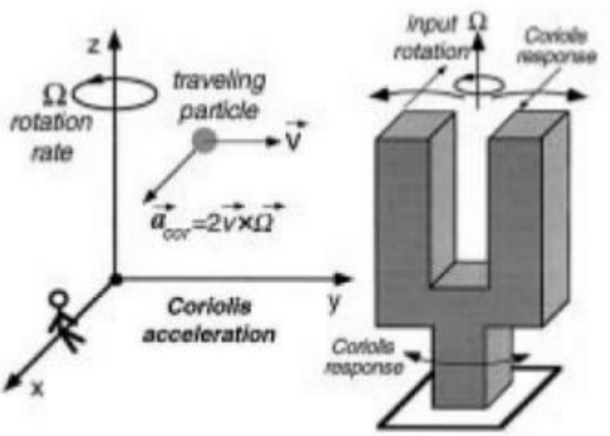


Figure 6 - Working of tuning fork I



[5]

Figure 7 - Working of tuning fork II

This capacitance is detected and amplified to produce a voltage proportional to the angular movement. The dimensions of the structure are of the order of microns. The demodulator produces an output equal to the sign of the applied force.

2.1.3 Servo Motors

This is nothing but a simple electrical motor, controlled with the help of servomechanism. If the motor as controlled device, associated with servomechanism is DC motor, then it is commonly known DC Servo Motor. If the controlled motor is operated by AC, it is called AC Servo Motor.

2.1.3.1 Servo Mechanism

A servo system mainly consists of three basic components - a controlled device, an output sensor, a feedback system. This is an automatic closed loop control system. Here instead of controlling a device by applying variable input signal, the device is controlled by a feedback signal generated by comparing output signal and reference input signal. When reference input signal or command signal is applied to the system, it is compared with output reference signal of the system produced by output sensor, and a third signal produced by feedback system. This third signal acts as input signal of controlled device. This input signal to the device presents as long as there is a logical difference between reference input signal and output signal of the system. After the device achieves its desired output, there will be no longer logical difference between reference input signal and reference output signal of the system. Then, third signal produced by comparing theses above said signals will not remain enough to operate the device further and to produce further output of the system until the next reference input signal or command signal is applied to the system. Hence the primary task of a servomechanism is to maintain the output of a system at the desired value in the presence of disturbances [11].

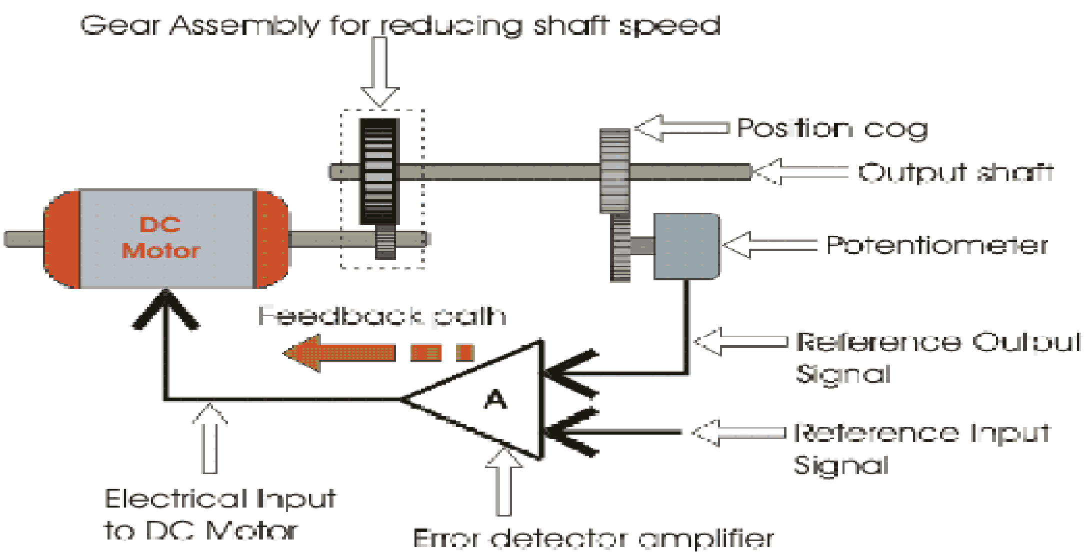


Figure 8 - Servo Control

The shaft of the servo is connected to a potentiometer. The circuitry inside the servo, to which the potentiometer is connected, knows the position of the servo. The current position will be compared with the desired position continuously with the help of an Error Detection Amplifier. If a mismatch is found, then an error signal is provided at the output of the error amplifier and the shaft will rotate to go the exact location required. Once the desired location is reached, it stops and waits.

2.2 Inertial Measurement Unit (IMU)

An inertial measurement unit (IMU) is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the magnetic field surrounding the body, using a combination of accelerometers and gyroscopes, sometimes also magnetometers. IMUs are typically used to manoeuvre aircraft, including unmanned aerial vehicles (UAVs), among many others, and spacecraft, including satellites and landers. Recent developments allow for the production of IMU-enabled GPS devices. An IMU allows a GPS receiver to work when GPS-signals are unavailable, such as in tunnels, inside buildings, or when electronic interference is present [12].

2.2.1 Working Principle

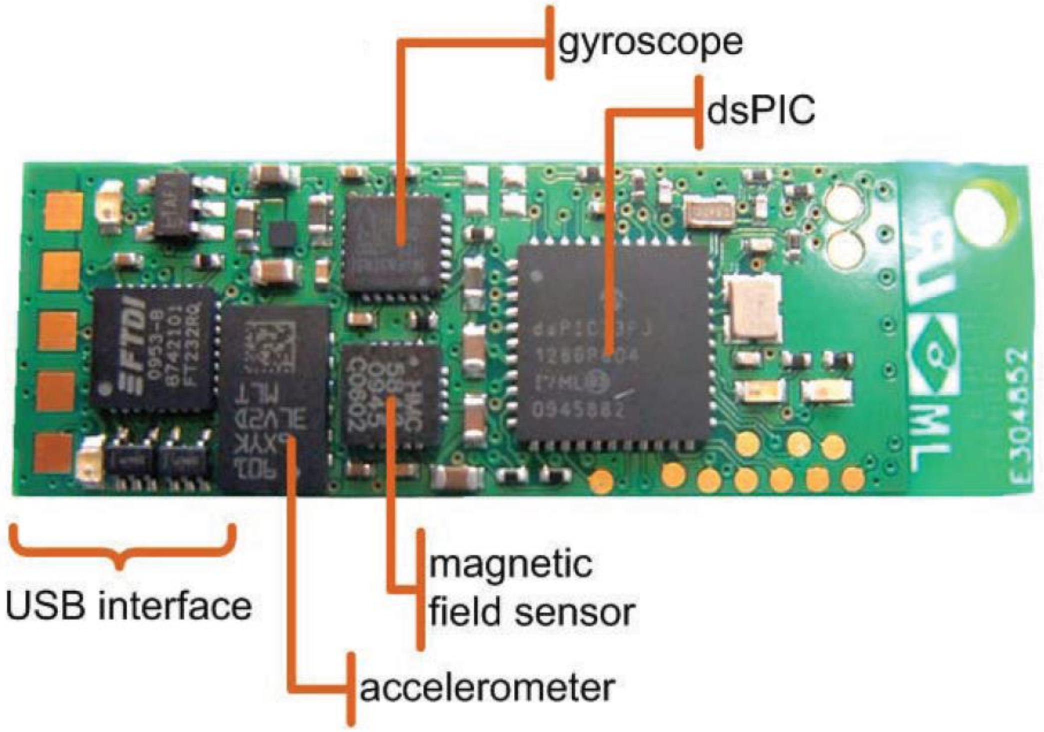
An inertial measurement unit works by detecting the current rate of acceleration using one or more accelerometers, and detects changes in rotational attributes like pitch, roll and yaw using one or more gyroscopes. And some also include a magnetometer, mostly to assist calibration against orientation drift. Inertial navigation systems contain IMUs which have angular and linear accelerometers (for changes in position); some IMUs include a gyroscopic element (for maintaining an absolute angular reference). Angular accelerometers measure how the vehicle is rotating in space. Generally, there is at least one sensor for each of the three axes: pitch (nose up and down), yaw (nose left and right) and roll (clockwise or counter-clockwise from the cockpit).

Linear accelerometers measure non-gravitational accelerations of the vehicle. Since it can move in three axes (up & down, left & right, forward & back), there is a linear accelerometer for each axis. A computer continually calculates the vehicle's current position. First, for each of the six degrees of freedom (x, y, z and θ_x, θ_y and θ_z), it integrates over time the sensed acceleration, together with an estimate of gravity, to calculate the current velocity. Then it integrates the velocity to calculate the current position. Inertial guidance is difficult without computers. The desire to use inertial guidance in the Minuteman missile and Project Apollo drove early attempts to miniaturize computers.

Inertial guidance systems are now usually combined with satellite navigation systems through a digital filtering system. The inertial system provides short term data, while the satellite system corrects accumulated errors of the inertial system. An inertial guidance system that will operate near the surface of the earth must incorporate Schuler tuning so that its platform will continue pointing towards the centre of the earth as a vehicle moves from place to place [12].

2.2.2 Construction

The term IMU is widely used to refer to a box containing three accelerometers and three gyroscopes and optionally three magnetometers. The accelerometers are placed such that their measuring axes are orthogonal to each other. They measure inertial acceleration, also known as G-forces. Three gyroscopes are placed in a similar orthogonal pattern, measuring rotational position in reference to an arbitrarily chosen coordinate system. Recently, more and more manufacturers also include three magnetometers in IMUs. This allows better performance for dynamic orientation calculation in Attitude and heading reference systems which base on IMUs.



[12]

Figure 9 - IMU

2.2.3 Uses

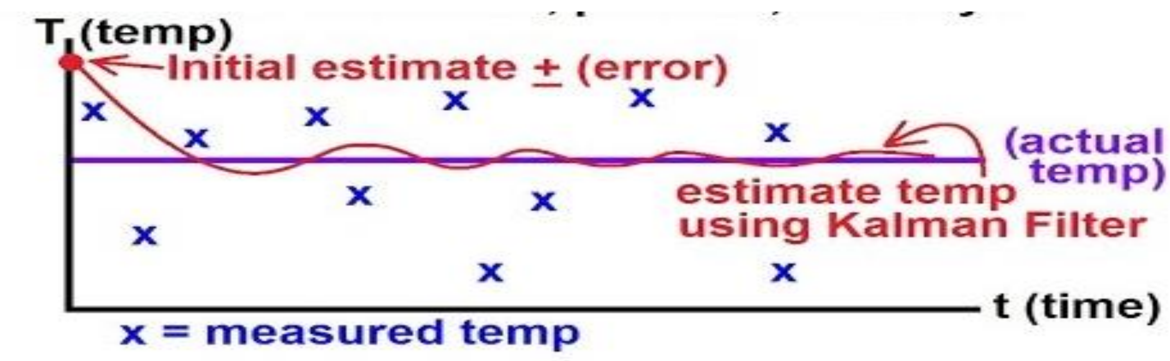
IMUs are used in vehicle-installed inertial guidance systems. Today almost every commercial or military water-going vessel has one. Most aircraft are also equipped with IMUs. IMUs are also used alone on air- and spacecraft, in order to report inertial measurements to a pilot (whether he is in the cockpit or piloting by remote control). They are critical during space missions to manoeuvre manned or unmanned landers and other craft. IMUs can, besides navigational purposes, serve as orientation sensors in the human field of motion. They are frequently used for sports technology (technique training) and animation applications. They are a competing technology for use in motion capture technology.

An IMU is at the heart of the balancing technology used in the Segway Personal Transporter. When used in orientation sensors, the term IMU is often (wrongly) used synonymously for Attitude and heading reference system. However, an Attitude and heading reference system includes an IMU but additionally -and that is the key difference- a processing system which calculates the relative orientation in space [12].

2.3 Implementation of Kalman Filter

The Kalman filter operates recursively on streams of noisy input data to produce statistically optimal estimate of the underlying system state. The algorithm works in the following process:

In the prediction step, the Kalman filter produces estimates of the current state variables, along with their uncertainties. Once the outcome of the next measurement (necessarily corrupted with some amount of error, including random noise) is observed, these estimates are updated using a weighted average, with more weight being given to estimates with higher certainty. Because of the algorithm's recursive nature, it can run in real time using only the present input measurements and the previously calculated state; no additional past information is required. The Kalman filter uses a system's dynamics model (e.g., physical laws of motion), known control inputs to that system, and multiple sequential measurements (such as from sensors) to form an estimate of the system's varying quantities (its state) that is better than the estimate obtained by using any one measurement alone. As such, it is a common sensor fusion and data fusion algorithm.



[13]

Figure 10 - Kalman Filter

2.4 Free IMU Libraries

IMU can be easily used on Arduino compatible boards using the Arduino Free IMU library which implements sensor fusion MARG orientation filter (a very efficient filter) enabling you to do easy and straightforward orientation sensing using tri axis accelerometer and gyroscope. It is very easy to implement and the functions used in this library is easily comprehended. We found it easily compatible with our 6DOF IMU. Yaw drift was also major issue which posed serious challenge as our yaw motor vibrated after almost every 0.5 seconds .The drift was reduced by using an algorithm described in next section.[13]

2.5 DCM ALGORITHM AND PID CONTROL

The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining u(t) as the controller output, the final form of the PID algorithm is:

$u(t) = MV(t) = K_p e(t) + K_i \int e(\iota) d\iota + K_d$

Where:

Kp: Proportional gain, a tuning parameter

Ki: Integral gain, a tuning parameter

Kd: Derivative gain, a tuning parameter

e: Error

t: Time or instantaneous time (the present)

We tune the PID controller by varying the constants Kp, Kd and Ki and optimizing them.

Process Variable (PV) vs time:

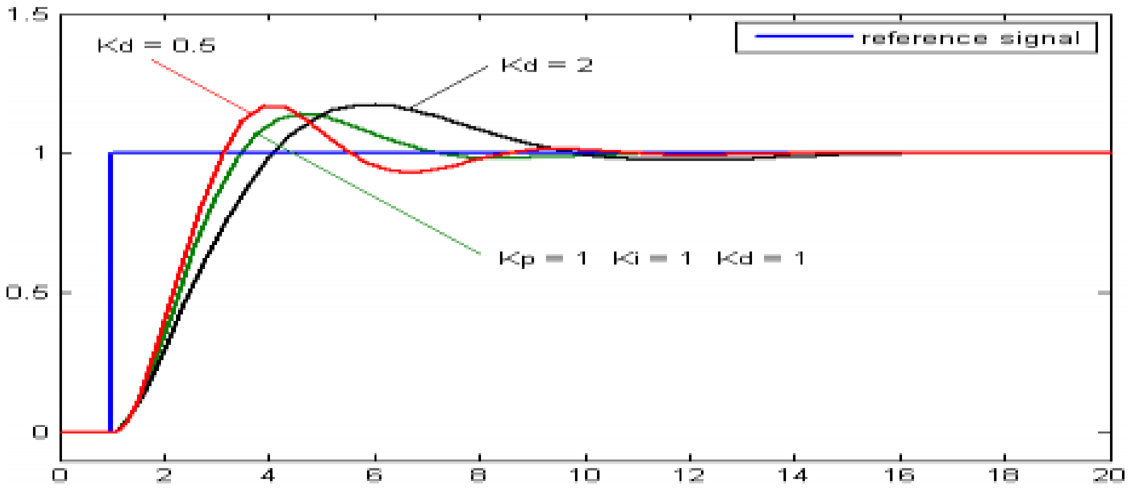
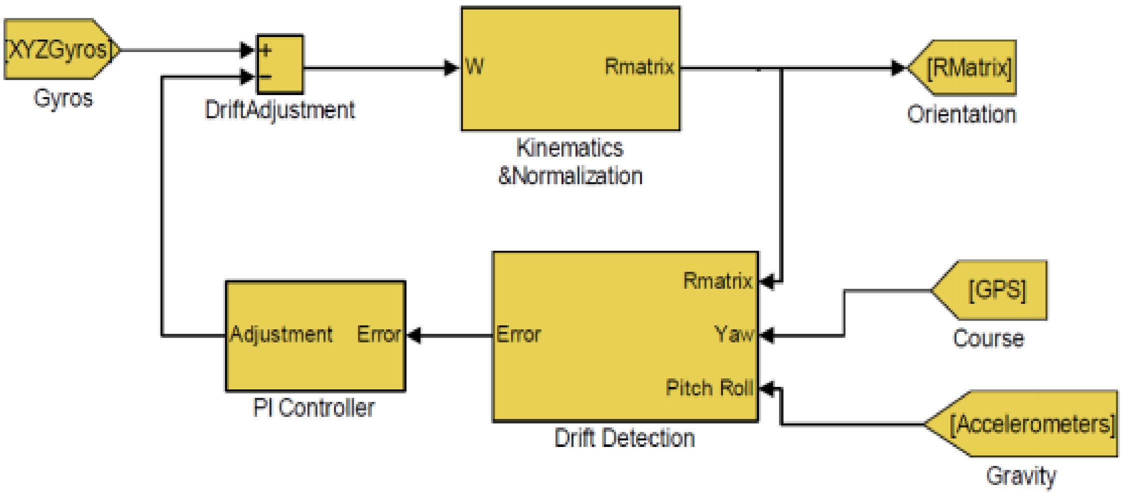


Figure 11 - PID control

DCM can be thought of a strong and robust algorithm for precise control of servo motors .It uses Euler angles, Direction Cosine Matrix (DCM) and Quaternion approaches. It has inbuilt Filters and Proportional – Integral Control Units which in turn is very effective in giving calibrated outputs.

The DCM algorithm uses Proportional – Integral Control units which are almost similar to PID except for the absence of Integral term. The tuning values, proportional constant (Kp) and derivative constant (Kd) changes in the code depending on how far the position of platform is from set point (balanced point). Recognizing that numerical errors, gyro drift, and gyro offset will gradually accumulate errors in the DCM elements, we use reference vectors to detect the errors, and a proportional plus integral (PI) negative feedback controller between the detected errors and the gyro inputs, to dissipate the errors faster than they can build up. GPS is used to detect yaw error, accelerometers are used to detect pitch and roll.



[13]

Figure 12 - Block diagram of PID control

Chapter 3

Problem Statement

3.1 System Implementation

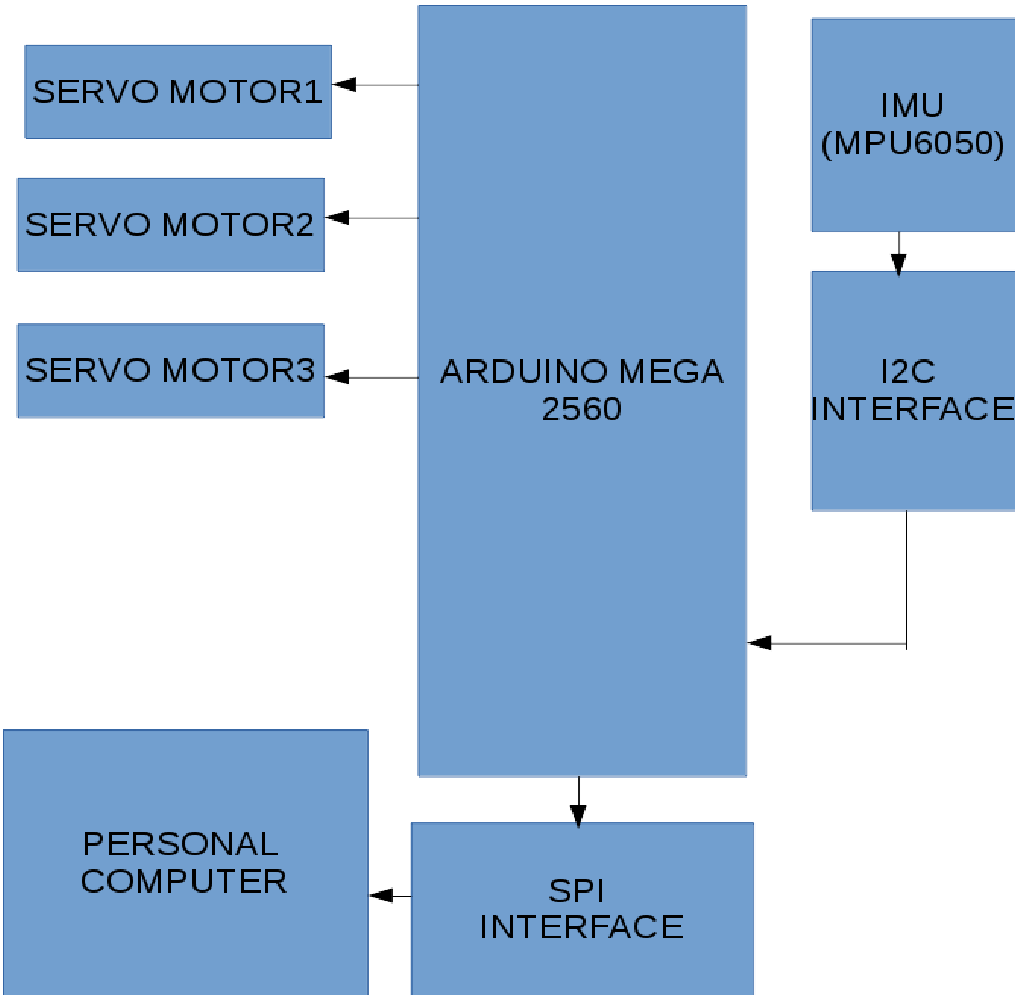
Sometimes we need to transport fragile objects from one place from another but due to irregularities in the travelling surfaces, there is a possibility of tilt in the surface carrying the material resulting in damage of the important object under consideration.

For example an Airplane carrying goods and stuff when it tries to take a turn, everything inside also tilts, this is wherein our project comes, it tries to compensate for the tilt and keep keeps parallel to the surface of the earth. It can also be implemented in Ships, Or to hold Video/Picture Camera to take Panoramic Videos/Pictures.

3.2 Block Diagram

An Accelerometer is used to measure the acceleration of the platform, and a gyroscope to measure the angular velocity along the x, y and z axes respectively. The data is transferred to microcontroller via I2C interface. These raw data values are then passed through KALMAN filter to remove irregularities and noise from the signals.

After analysing the output signal produced by the IMU module for 6 DOF (Degrees of Freedom), we compare the present values with the bygone values and program the servo motors proportional to the signal from IMU and try to negate the movement and stabilize the platform.



[13]

Figure 13 - Block Diagram of System

Chapter 4

Model Implementation

4.1 Hardware Model Design

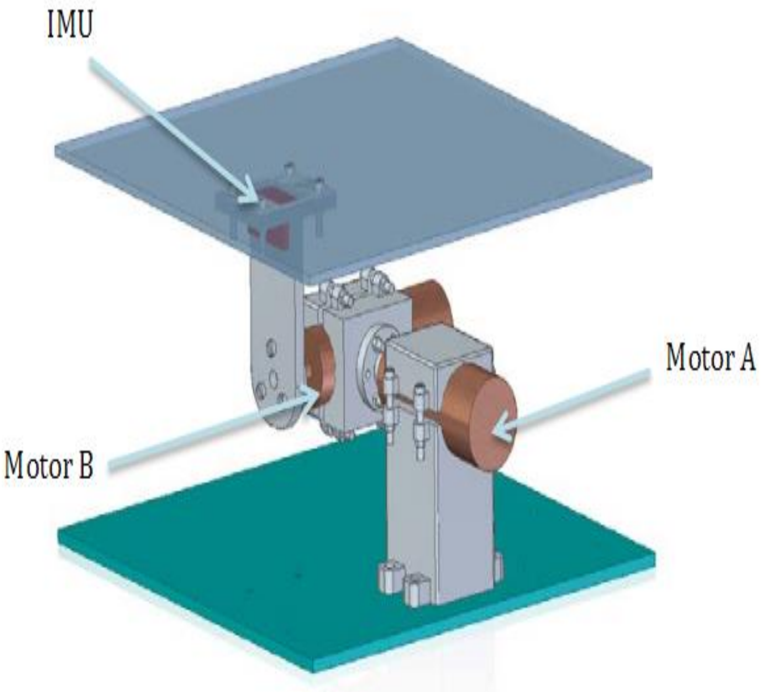


Figure 14 - Hardware Model I

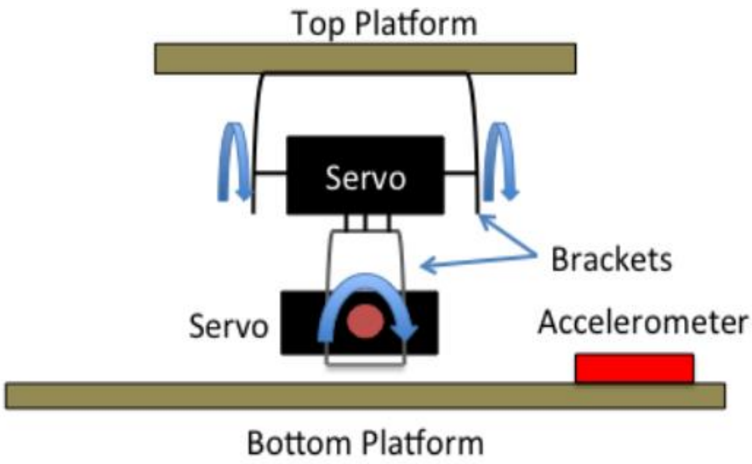


Figure 15 - Hardware Model II

The first motor is attached to the base and capable to rotate other two motors and the upper platform with camera about z direction. The other two motors gives the freedom to rotate the platform about x and y axis. Main base will consists of Arduino Mega, a battery and IMU circuit board that can be detached from the base to establish both control and stabilizing. While the IMU board is attached to the base, we can stabilize the upper platform with a camera or any other object placed on the platform. When we separate the IMU board we are able to control the camera holding platform about of the 3 axis, just by pressing a button.

When the Platform is tilted in x direction corresponding to that tilt an equivalent signal is measured by the Inertial Measurement Unit sensor, this sensor values are converted to proportional electrical signal which is given to the motor mounted in x direction to counter to movement and keep surface stable. Similarly in y direction also the same process happens and thus the simultaneous action of both with servo motors in x and y direction produces a super position effect on the platform to keep it balanced. We have used two Universal Servo Brackets to hold the servo motors and 2 C- Shaped brackets, 1st to connect both the servos with each other in a vertical orientation and 2nd C- Shaped bracket is used to connect the platform to the model.

4.2 Interfacing of IMU with Arduino

IMU sensors are most common type of sensors used today in all kinds of electronic gadgets. IMU sensors help in getting attitude of an object attached to the sensor in three-dimensional space. These values are usually in angles to help us to determine its attitude. They are used in smart phones to detect their orientation or in wearable gadgets like Fit Bit, which use IMU sensors to track movement.

IMU sensors have prolific number of applications. It is even considered inexorable component in quadcopters. Some of the sensors are:

- ADXL 345 accelerometer
- ITG 3200 gyroscope
- MPU 6050

MPU 6050 is the most reliable and accurate sensor from the above listed sensors. Apart from being cheap then other sensors it also performs better compared to others.

IMU sensors usually consist of two or more parts. Listing them by priority they are the accelerometer, gyroscope, magnetometer and altimeter. The MPU 6050 is a 6 DOF (degrees of freedom) or a six axis IMU sensor, which means it gives six values as outputs. Three values from accelerometer and three values from gyroscope. Both the accelerometer and gyroscope are embedded on a single chip. This chip use I2C (Inter integrated circuit) for communication.

The MPU 6050 communicates with the Arduino through the I2C protocol. The MPU 6050 is connected to Arduino as shown in the following diagram. If your MPU 6050 module has a 5V pin, then you can connect it to your Arduino’s 5V pin. If not, you will have to connect it to the 3.3V pin. Next, the GND of the Arduino is connected to the GND of the MPU 6050.

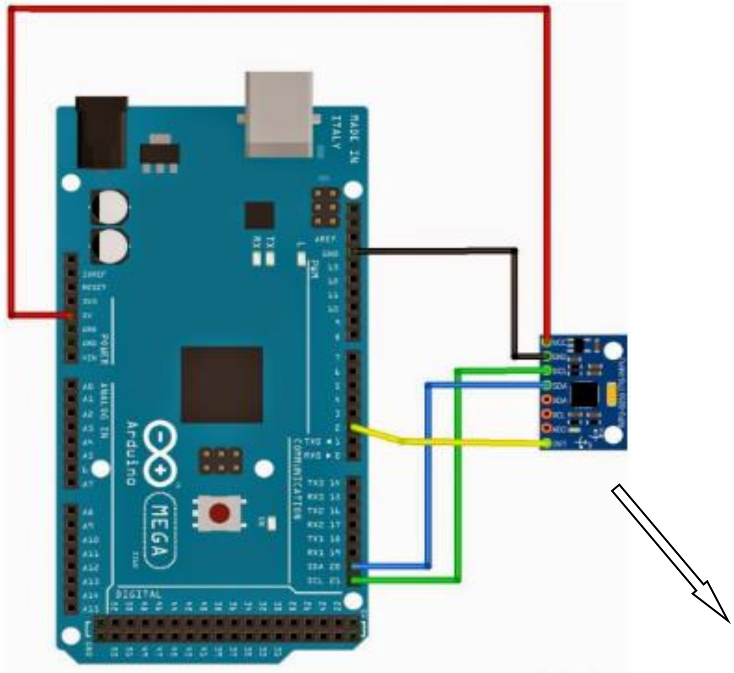


Figure 16 - Interfacing of IMU with Arduino

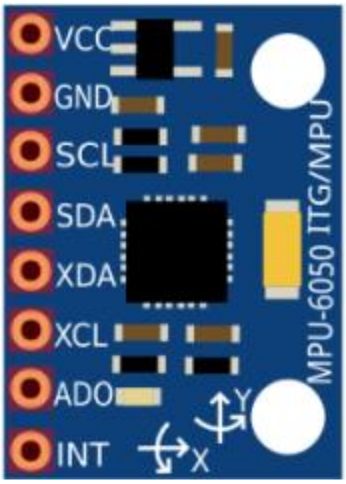


Figure 17 - MPU-6050

4.3 I2C Interfacing

The I2C communication bus is very popular and broadly used by many electronic devices because it can be easily implemented in many electronic designs which require communication between a master and multiple slave devices or even multiple master devices. The easy implementations comes with the fact that only two wires are required for communication between up to almost 128 (112) devices when using 7 bits addressing and up to almost 1024 (1008) devices when using 10 bits addressing.

I2C bus is used by many integrated circuits and is simple to implement. Any microcontroller can communicate with I2C devices even if it has no special I2C interface. I2C specifications are flexible - I2C bus can communicate with slow devices and can also use high speed modes to transfer large amounts of data. Because of many advantages, I2C bus will remain as one of the most popular serial interfaces to connect integrated circuits on the board.

I2C uses only two wires: SCL (serial clock) and SDA (serial data). Both need to be pulled up with a resistor to +Vdd. There are also I2C level shifters which can be used to connect to two I2C buses with different voltages.

The Serial Clock pin of the Arduino Board will be connected to the Serial Clock pins of the two breakout boards, the same goes for the Serial Data pins and we will power the boards with the Ground and the 5V pin from the Arduino Board.

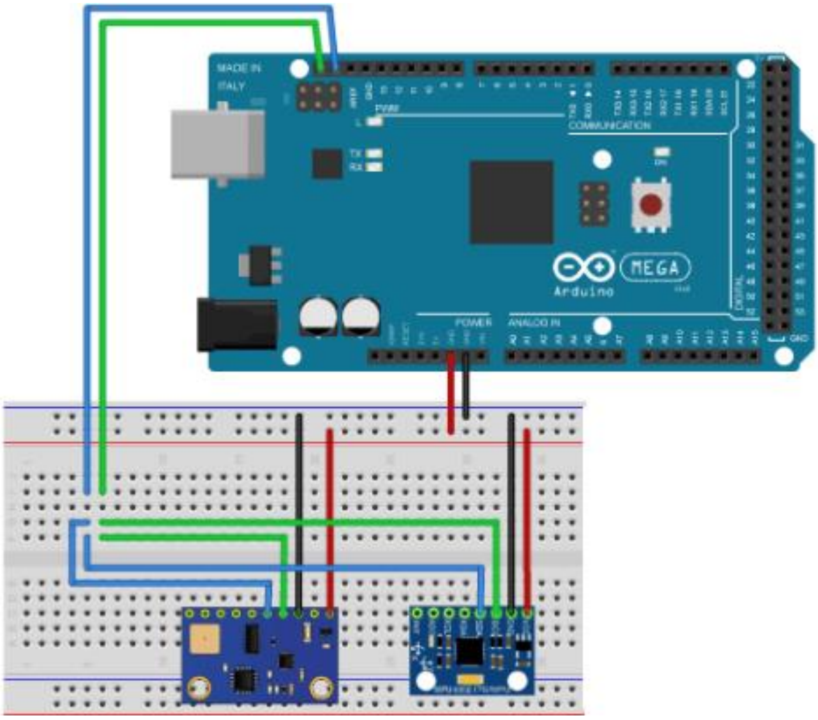


Figure 18 - I2C

Basic I2C communication is using transfers of 8 bits or bytes. Each I2C slave device has a 7-bit address that needs to be unique on the bus. Some devices have fixed I2C address while others have few address lines which determine lower bits of the I2C address. This makes it very easy to have all I2C devices on the bus with unique I2C address. There are also devices which have 10-bit address as allowed by the specification.

7-bit address represents bits 7 to 1 while bit 0 is used to signal reading from or writing to the device. If bit 0 (in the address byte) is set to 1 then the master device will read from the slave I2C device. Master device needs no address since it generates the clock (via SCL) and addresses individual I2C slave devices.

4.4 Interfacing of Servo Motor with Arduino

Servo motors can be directly connected to an Arduino to control the shaft position of the motor very precisely.

Because servo motors use feedback to determine the position of the shaft, you can control that position very precisely. As a result, servo motors are used to control position of objects, rotate objects, move legs, arms or hands of robots, move sensors etc. with high precision. Servo motors are small in size, and because they have built-in circuitry to control their movement, they can be connected directly to an Arduino.

Most servo motors have the following three connections:

- Black/Brown ground wire
- Red power wire (5V)
- Yellow/White PWM wire

The power and ground pins are connected directly to the Arduino 5V and GND pins. The PWM input will be connected to one of the Arduino's digital output pins as required.

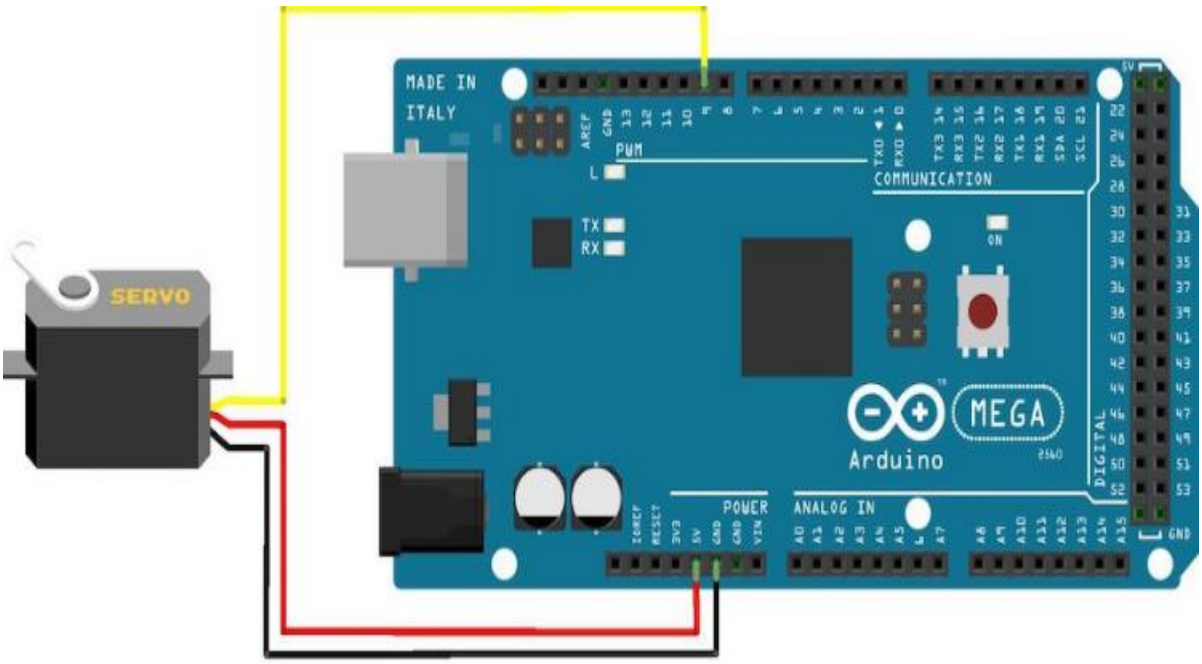


Figure 19 - Interfacing of Servo Motor with Arduino

A servo motor is a combination of DC motor, position control system, gears. The position of the shaft of the DC motor is adjusted by the control electronics in the servo, based on the duty ratio of the PWM signal the SIGNAL pin. Simply speaking the control electronics adjust shaft position by controlling DC motor. This data regarding position of shaft is sent through the SIGNAL pin. The position data to the control should be sent in the form of PWM signal through the Signal pin of servo motor.

The frequency of PWM (Pulse Width Modulated) signal can vary based on type of servo motor. The important thing here is the DUTY RATIO of the PWM signal. Based on this DUTY RATION the control electronics adjust the shaft.

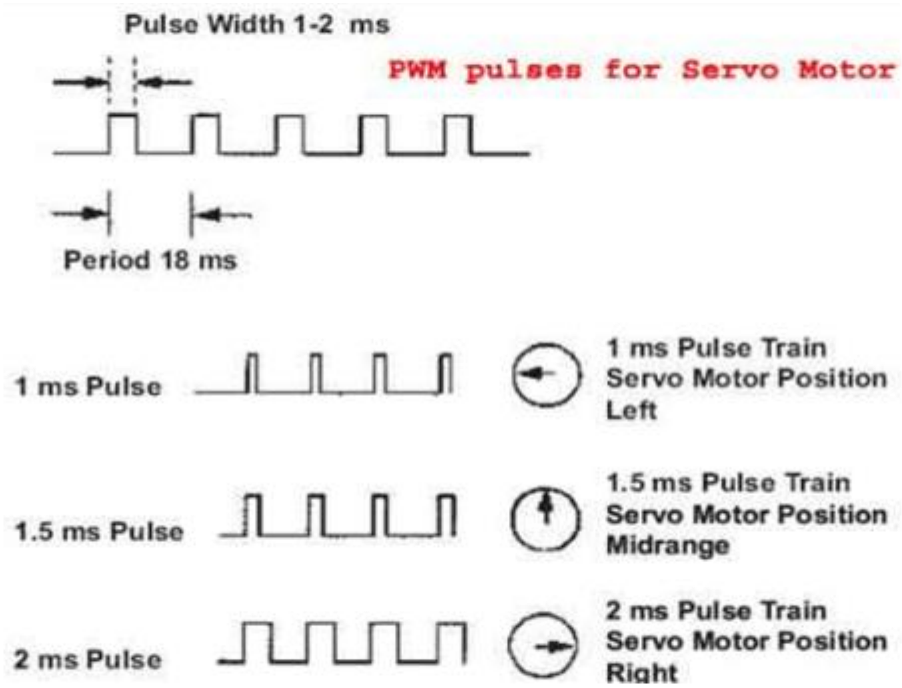


Figure 20 - PWM pulses for Servo Motor

For the shaft to be moved to 12o clock the ON time of signal must be 1.5ms and OFF time should be 16.5ms. This ratio is decoded by control system in servo and it adjusts the position based on it. This PWM in here is generated by using ARDUINO.

The things which we need to do for getting accurate position of servo are:

- #include <Servo.h>
- Servo sg90servo;

- Sg90.attach(servo_signal_pin_attached_to);

Sg90.write(needed_position_ angle);

4.5 Algorithm

1. Start
2. Include serial data, servo, i2c, FreeIMU libraries in the Arduino sketch.
3. Create array to store raw values of input data (ax, ay, az, gx, gy, gz)
4. Create another array to calculate values of yaw, pitch, roll from the input raw values
5. Create another two temporary arrays to store raw and calculated values in memory.
6. Declare flags to set the mode of operation
7. Declare servo objects servo1, servo2, servo3 and Free IMU Object
8. Begin the serial communication at 9600 baud and attach servo motors to port 8,9,10 respectively
9. Initialize the flags to one and all the memory elements to zero.
10. Continuously monitor the below steps under infinite loop
11. Get the calculated yaw, pitch, roll from the library using function getYawPitchRoll() under Free IMU class.
12. If value at A0 is less than 500 then set flag2 else reset flag two
13. If yaw _calculated – yaw_old is between -0.16 and 0.16 then print yaw into serial port and store same value in temporary register.
14. If the difference between calculated yaw value and old yaw value is between 90 and 0.16 and -90 and-0.16 then update the temporary register yaw value.
15. If this yaw value is between 90 and -90 and flag2 is set then update servo_value as 90+updated value.
16. If flag2 is reset then write data on servo motor 1 as 90-updated value.
17. If difference in yaw values is greater than 90 and less than -90 the do not change the servo motor values and print data on serial port.
18. Similarly if new_pitch_val - old_pitch_val is greater than 0.12 and less than -0.12 then update old pitch with new pitch.
19. If flag is set then write data to servo as 92.5-old_pitch_val otherwise 90 +old_pitch_val

20. If difference between new roll and old roll values is greater than 0.12 and less than -0.12 then update old value as old value = new value otherwise simply print roll value on serial port.
21. If flag2 is set than write data 87 + old roll value otherwise 87 – old roll value into servo motor.
22. Update old value to new value.
23. End

4.6 Power Supply

A LM7805 Voltage Regulator is a voltage regulator that outputs +5 volts.

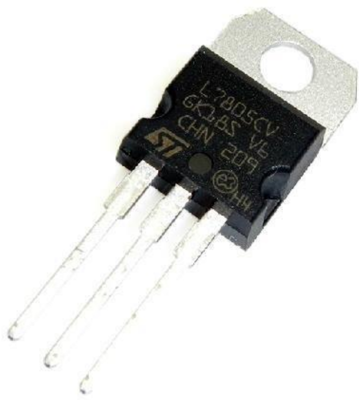


Figure 21 - LM78XX series

An easy way to remember the voltage output by a LM78XX series of voltage regulators is the last two digits of the number. A LM7805 ends with 05, thus it outputs 5 volts. The 78 part is just the convention that the chip makers use to denote the series of regulators that output voltage is positive. The other series of regulators, the LM79XX, is the series that output voltage is negative. [13]

The LM7805, like most other regulators, is a three-pin IC.

Pin 1(input pin): The input pin is the pin that accepts the incoming DC voltage, which the voltage regulator will eventually regulate down to 5volts.

Pin 2(ground): Ground pin establishes the ground for the regulator.

Pin3 (output Pin): The output pin is the regulated 5 volts DC.[13]

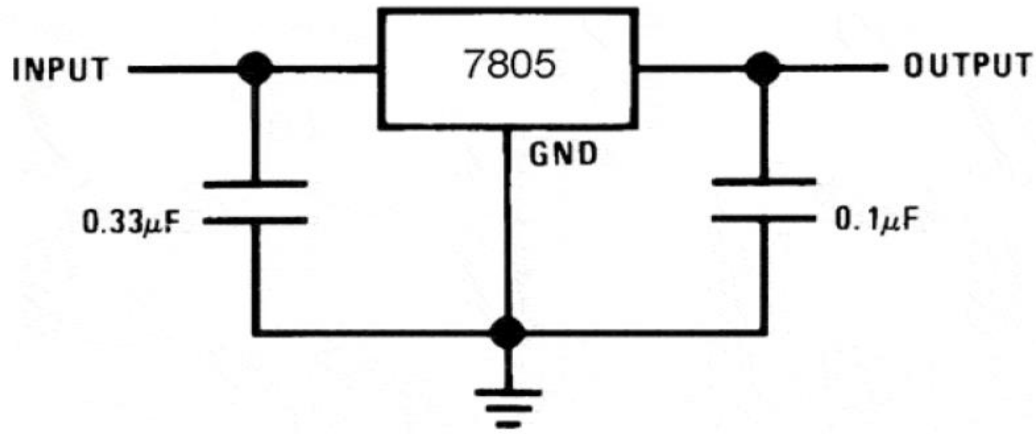


Figure 22 - Circuit Diagram

PCB Images

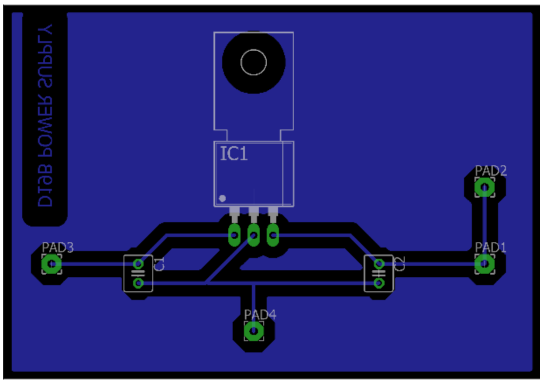


Figure 23 - Coloured Layout

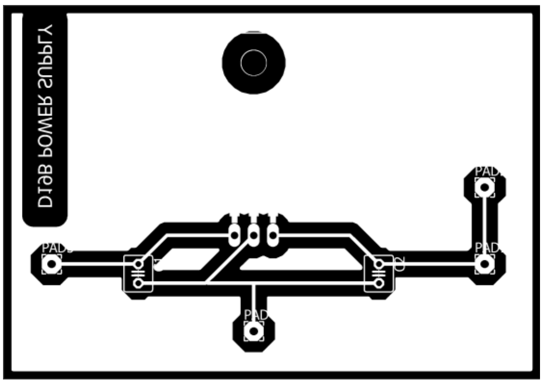


Figure 24 - Black and White Layout

Chapter 5

Results and Discussions

5.1 Simulation – 3D Model

For calibration of inertial measurement unit with the surface and determining the offset values of gyroscope and accelerometer, we have used the processing software which is java based Integrated Development environment which is useful for graphical and figurative analysis of the inertial measurement unit.

The converted values were send to the processing software via serial port and the separate components of accelerometer and gyroscope were shown as given below

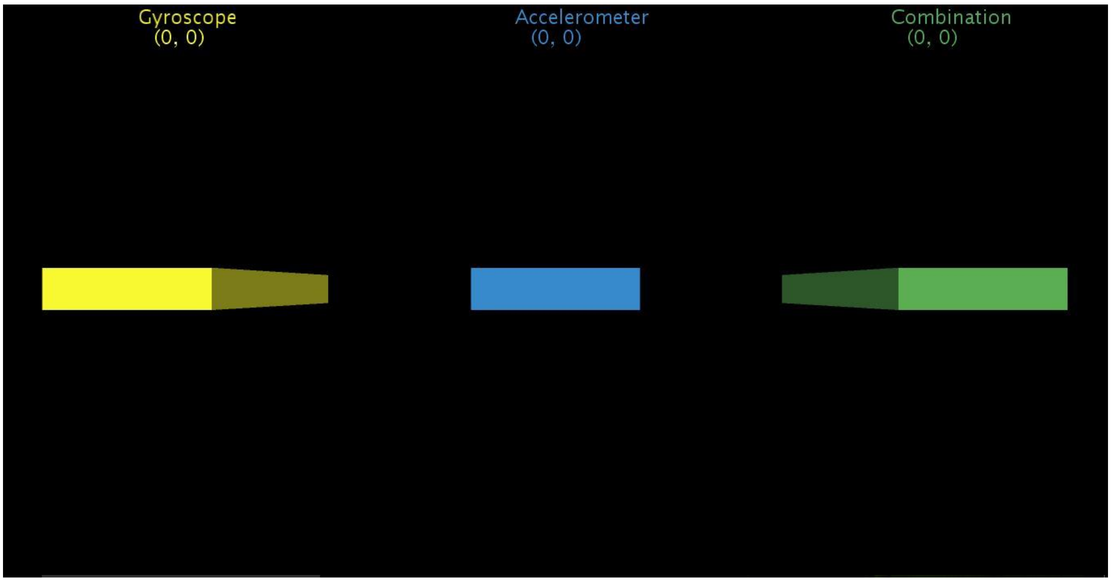


Figure 25 - 3D Model I

The sensor fusion of this data along with filtered output using Kalman filter was shown for Combination block. The figure above shows that the inertial measurement unit is in stable state and hence there is no movement in the blocks shown below. As the IMU is shifted by 60 degrees anti clockwise, the accelerometer values were found to be fluctuating but the fused filtered combination of gyroscope and accelerometer was completely smooth without any fluctuations with much robustness.

The diagram shows the changes in the component values and fused values of the inertial measurement unit.

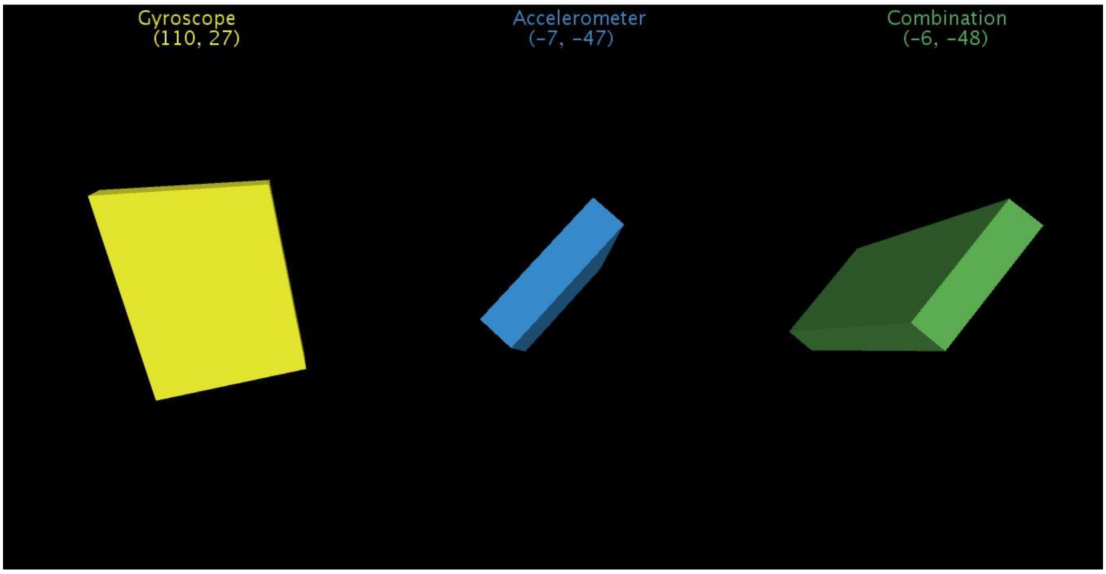


Figure 26 - 3D Model II

The inertial measurement unit was also tilted in the vertical direction and the response was found out to be perfect according to the need providing necessary smooth stabilization to the platform.

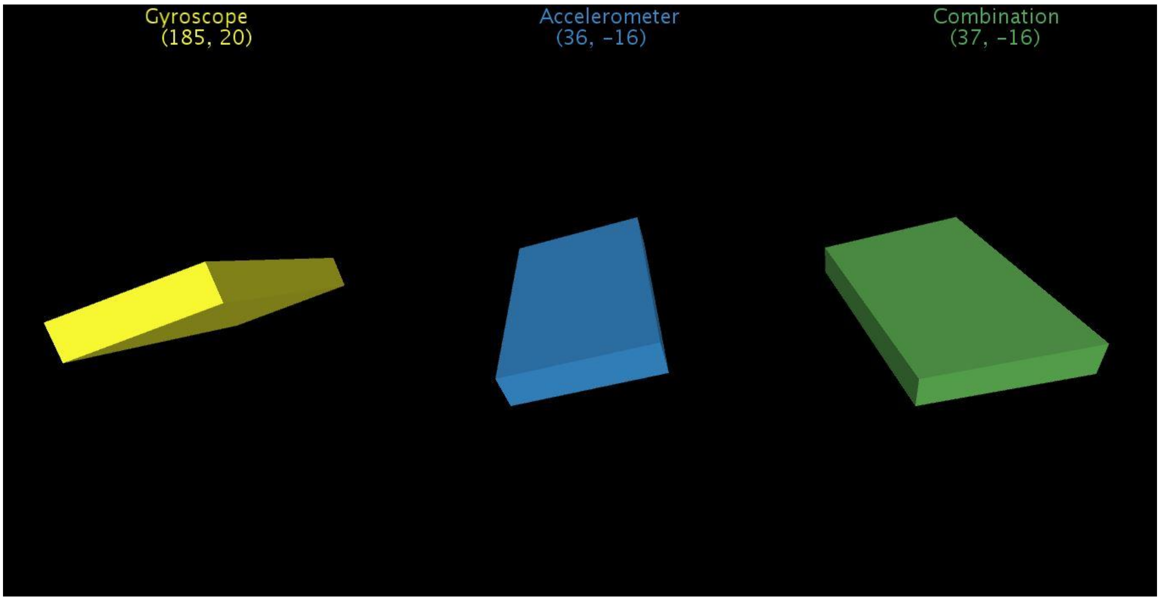


Figure 27 - 3D Model III

5.2 Simulation – Graph

The use of accelerometer and gyroscope to build little robots, such as the self-balancing, requires a math filter in order to merge the signals returned by the sensors. The gyroscope has a drift and in a few time the values returned are completely wrong. The accelerometer, from the other side, returns a true value when the acceleration is progressive but it suffers much the vibrations, returning values of the angle wrong usually a math filter is used to mix and merge the two values, in order to have a correct value: the Kalman filter. This is the best filter you can use, even from a theoretical point of view, since it is one that minimizes the errors from the true signal value.

In the hobby world, recently are emerging other filters, called complementary filters. In fact, they manage both high-pass and low-pass filters simultaneously. The low pass filter filters high frequency signals (such as the accelerometer in the case of vibration) and low pass filters that filter low frequency signals (such as the drift of the gyroscope). By combining these filters, you get a good signal, without the complications of the Kalman filter.

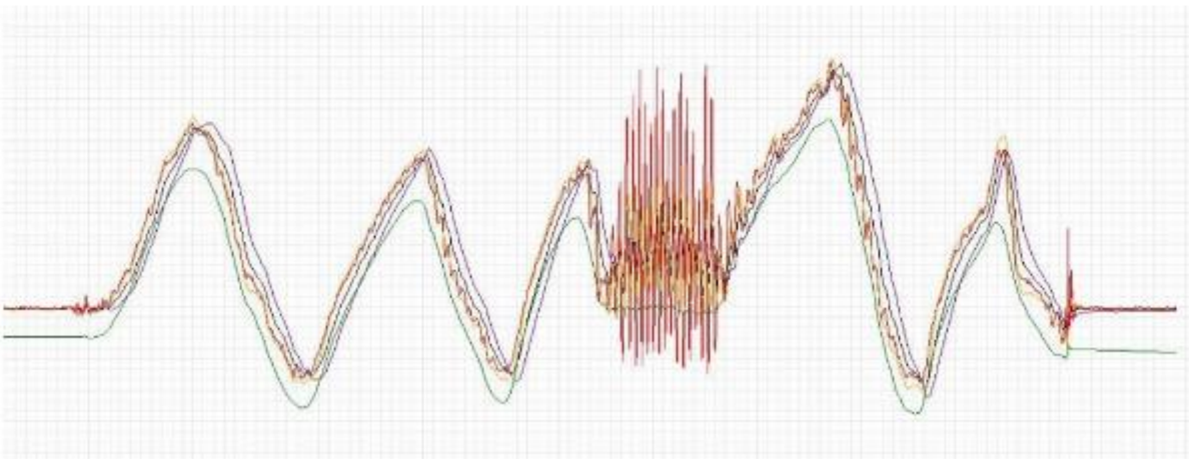


Figure 28 - Graph I

Colour lines:

- Red – accelerometer

- Green – Gyro
- Blue – Kalman filter
- Black – complementary filter
- Yellow – the second order complementary filter

Note that in the presence of vibrations, the accelerometer (red) generally go crazy. The gyro (green) has a very strong drift increasing in the time.

Now let's see a comparison only between a filtered signals. That kalman (green), complementary (black) and complementary second-order (yellow). You can see how the Kalman is a bit late vs complementary filters, but it is more responsive to the vibration. In this case the second order filter does not return an ideal curve. Hence for better stability to vibrations kalman filter is implemented in our project

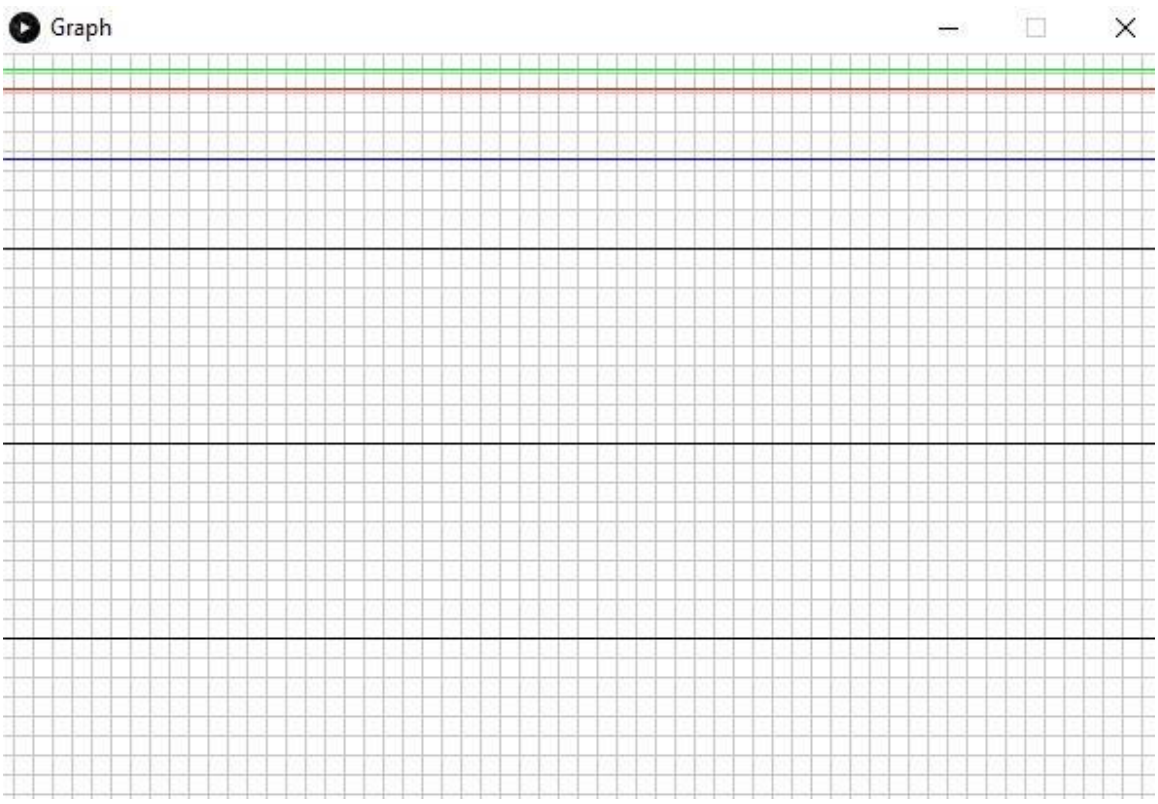


Figure 29 - Graph II

Graph for stable position of inertial measurement using

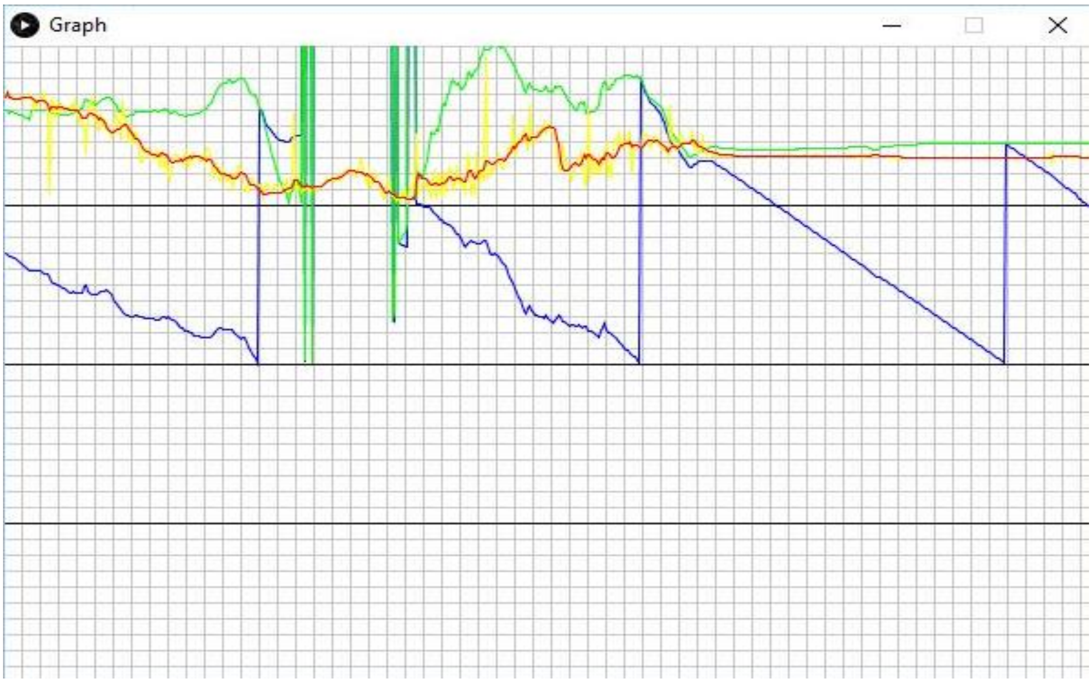


Figure 30 - Graph III

Graph for variations in inertial measurement unit values and filtered values.

We have designed a stabilizing platform in which the first motor is attached to the base and capable to rotate other two motors and the upper platform with camera about z direction. The other two motors gives the freedom to rotate the platform about x and y axis. Main base will consists of Arduino Mega, a battery and IMU circuit board that can be detached from the base to establish both control and stabilizing. While the IMU board is attached to the base, we can stabilize the upper platform with a camera or any other object placed on the platform.

We have also developed processing simulation model to display individual components and to illustrate the necessity of filtering required in the data acquisition process. The two filtering methods namely Kalman and Complementary were studied and their response were recorded graphically. The Kalman filter was found out to be more immune to vibrations but the code was bit big while the Complementary filter was small in size and robust but lacked stability. Hence Kalman filter was used in the design process.

The mechanical model of our setup is as below.

Figure 31 - Hardware I

Figure 32 - Hardware II

Chapter 6

Conclusion

The 3 axis stabilized platform is implemented using inertial measurement unit (MPU6050) and the raw values were found out to be fluctuating which were filtered using Kalman filter for stable data points. The serial data is sent to processing software and a simulation program was designed to show accelerometer and gyroscope components and stability of the acquired data points using serial port. The filtered output was also shown on the graphical window of the processing software drawing contrast between Complementary and Kalman filters for the stability of the data points.

The data points were found out to be more stable in Kalman filter approach and hence it was adopted in the process of filter designing. The servo motors counter the motion of the platform thus making it stationary w.r.t. a reference plane. The yaw pitch roll was displayed on the serial port and the power circuitry was designed using voltage regulator integrated circuit and the Arduino was powered using serial USB port.

The platform is found out quite stable and countering the vibrations faced by it by rotating the motor at a particular angle proportional to the values from the inertial measurement unit. The DCM algorithm is implemented for the error control which can be thought of a strong and robust algorithm for precise control of servo motors.

The DCM algorithm uses Proportional – Integral Control units which are almost similar to PID except for the absence of Integral term. The tuning values , proportional constant (Kp) and derivative constant (Kd) changes in the code depending on how far the position of platform is from setpoint (balanced point). Recognizing that numerical errors, gyro drift, and gyro offset will gradually accumulate errors in the DCM elements.

On using this algorithm, we came to realise that Yaw angle accumulate leading to a significant value after some time inspite of no change in orientation. We analysed the Yaw output and accordingly made a simple algorithm that is very effective in reducing drift. What we basically did was to ignore extremely small change of orientation angles in every cycle. These angles being in the order of .01 degrees are almost impossible to replicate by the physical motion of hands, leading to quite stable data without loss of much accuracy.

Chapter 7

Future Scope

Self-stabilizing platform "Ampelmann“, is used on the open sea. It automatically compensates all wave movements, so that safe work can be done on oil platforms from a ship base. For this purpose, the platform is supported by several hydraulic cylinders. Our Project can be applied at sea where a constant stable environment is required for proper functioning of processes.

The Self Stabilizing Platform is can be used in aircrafts and huge vehicles to protect the fragile objects from damage, which could occur due to speed and tilt angle of the vehicles. To measure and compensate for imbalance, it is essential for stabilizing mechanisms. The technique is applied in everything from self-stabilizing cameras to helicopters and noise reducing equipment.

These platforms can also be implemented on small size basis inside ships to prevent the tilt and other disturbances.

Appendix

Components

A.1 Specification of Components

A.1.1 Arduino

Arduino is an open-source platform used for building electronics projects. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on your computer, used to write and upload computer code to the physical board.

The Arduino platform has become quite popular with people just starting out with electronics, and for good reason. Unlike most previous programmable circuit boards, the Arduino does not need a separate piece of hardware (called a programmer) in order to load new code onto the board – you can simply use a USB cable. Additionally, the Arduino IDE uses a simplified version of C++, making it easier to learn to program. Finally, Arduino provides a standard form factor that breaks out the functions of the micro-controller into a more accessible package.

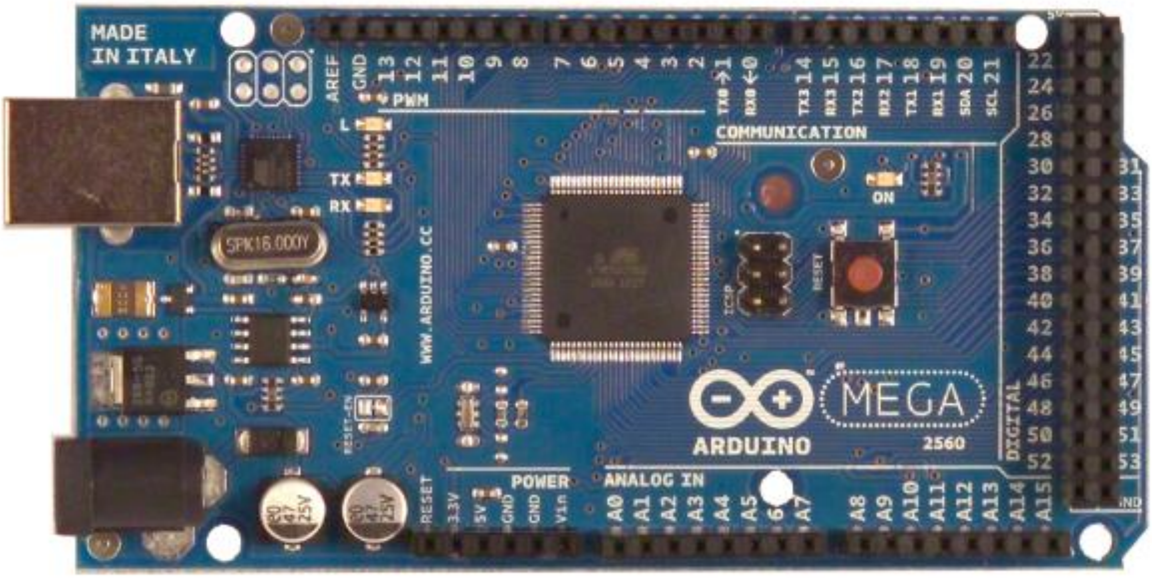


Figure 33 - ATmega2560

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8KB used by boot-loader
SRAM	8 KB
EEPROM	4 KB
Clock Speed	16 MHz

Table 1 - Specification of Arduino Board

A.1.2 Servo Motor

These servo motors would provide the proper amount of power required to maintain its own weight as well as the weight of all the electrical and physical hardware while at the same time still maintaining balanced equilibrium. The shaft can be easily angled between 0 to 180 degrees. This wire is given a pulse application for a specified duration, which in turn controls the angle of the shaft in a particular position for a certain point of time. This modulation is famously referred to as the PWM (Pulse Width Modulation). The servomotor expects a coded signal every few seconds. The duration of the pulse determines the angular degree of the shaft.

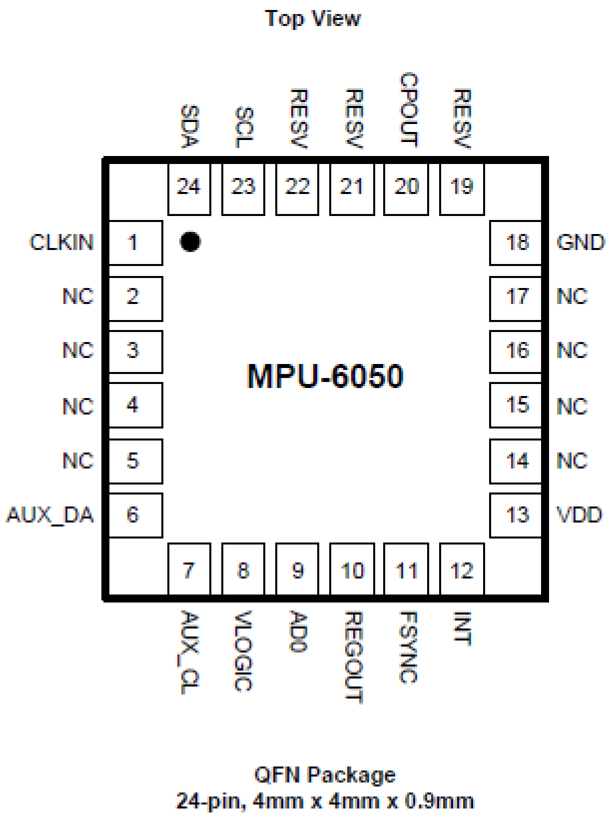
Servo motor that we have selected has torque of 15kg/cm, operating voltage of 4.8 V to 6 V, speed of 60degree/0.20sec, dimensions: length-49.3mm, width-25.4mm, height-42.9mm and weight about 80 g.

Figure 34 - Futaba Servo Motor

Control System	+Pulse Width Control 1520usec Neutral
Required Pulse	3-5 Volt Peak to Peak Square Wave
Operating Voltage	4.8-6.0 Volts
Direction	Counter Clockwise/Pulse Traveling 1520-1900usec
Operating Speed (4.8V)	0.23sec/60 degrees at no load
Operating Speed (6.0V)	0.19sec/60 degrees at no load
Gear Type	All Nylon Gears
Potentiometer Drive	Indirect Drive

Table 2 - Specification of Servo Motor

A.1.3 MPU-6050



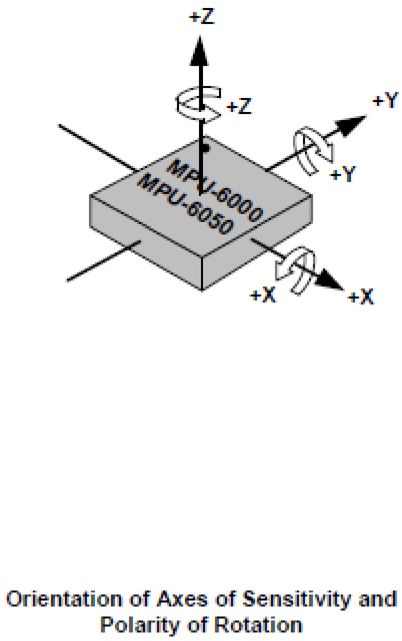


Figure 35 - MPU 6050

PART	MPU 6050
VDD	2.375V-3.46V
VLOGIC	1.71V to VDD
Serial Interfaces Supported	I2C
Pin 8	VLOGIC
Pin 9	AD0
Pin 23	SCL
Pin 24	SDA

Table 3 - Specification of MPU6050

Features:

- Tiny!
- Two mounting holes
- ADXL345 Accelerometer
- ITG-3200 gyro
- 3.3V input
- I2C interface

A.2 Components Cost

Component	Quantity	Cost	Total
Futaba Servo Motor	2	400	800
Servo C Bracket	2	90	180
Servo Universal Bracket	2	100	200
Arduino Mega	1	800	800
IMU 6050	1	300	300
Voltage Regulator 7805	1	20	20
Capacitors	-	5	5
Battery	1	20	20
Servo Connectors	-	20	20
Male to Male Connectors	-	20	20
Male to Female Connectors	-	20	20
Acrylic Sheet	1	100	100
TOTAL			2485

Table 4 - Cost of Components

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