Project Report On

INERTIAL MEASURING SYSTEM

SUBMITTED IN PARTIAL FULFILLMENT FOR THE AWARD OF THE DEGREE
OF

BACHELOR OF ENGINEERING
IN
ELECTRONICS ENGINEERING

BY
VISHNU NAIR (27)
SHIVAM SINGH (49)
PRATIK WALAWALKAR (60)

UNDER THE GUIDANCE OF
MS. ARCHANA BELGE
ASSISTANT PROFESSOR
AND
DR. JONATHAN JOSHI

ELECTRONICS DEPARTMENT
YEAR: 2017-2018

UNIVERSITY OF MUMBAI
DEPARTMENT OF ELECTRONICS ENGINEERING

THAKUR TRUSTS
Zagdu Singh Charitable Trust's (Regd.)
THAKUR COLLEGE OF ENGINEERING & TECHNOLOGY
(Approved by AICTE, Govt. of Maharashtra & Affiliated to University of Mumbai*)
Institute Accredited by National Assessment and Accreditation Council (NAAC), Bangalore#
Programmes Accredited by National Board of Accreditation (NBA), New Delhi**

A - Block, Thakur Educational Campus,
Shyamnarayan Thakur Marg, Thakur Village,
Kandivali (East), Mumbai - 400 101.
Tel.: 6730 8000 / 8106 / 8107
Fax : 2846 1890
Email : tcet@thakureducation.org
Website : www.tcetmumbai.in • www.thakureducation.org

ISO 9001:2015 Certified

*Permanent Affiliated UG Programmes : • Computer Engineering • Electronics & Telecommunication Engineering • Information Technology (w.e.f. A.Y. 2015-16) • Electronics Engineering (w.e.f. A.Y. 2017-18)
**1st time Accredited UG Programmes : • Computer Engineering • Electronics & Telecommunication Engineering • Information Technology (3 years w.e.f. 16-09-2011)
**2nd time Accredited UG Programmes : • Computer Engineering • Electronics & Telecommunication Engineering • Information Technology • Electronics Engineering (3 years w.e.f. 01-07-2016)
1st cycle of Accreditation : • "A" Grade for 5 years (w.e.f. 30-10-2017)

THAKUR TRUSTS
Zagdu Singh Charitable Trust's (Regd.)
THAKUR COLLEGE OF ENGINEERING & TECHNOLOGY
(Approved by AICTE, Govt. of Maharashtra & Affiliated to University of Mumbai*)
Institute Accredited by National Assessment and Accreditation Council (NAAC), Bangalore#
Programmes Accredited by National Board of Accreditation (NBA), New Delhi**
A - Block, Thakur Educational Campus, Shyamnarayan Thakur Marg, Thakur Village, Kandivali (East), Mumbai - 400 101.
Tel.: 6730 8000 / 8106 / 8107
Fax : 2846 1890
Email : tcet@thakureducation.org
Website : www.tcetmumbai.in • www.thakureducation.org
tcet
ISO 9001:2015 Certified
*Permanent Affiliated UG Programmes : • Computer Engineering • Electronics & Telecommunication Engineering • Information Technology (w.e.f. A.Y. 2015-16) • Electronics Engineering (w.e.f. A.Y. 2017-18)
**1st time Accredited UG Programmes : • Computer Engineering • Electronics & Telecommunication Engineering • Information Technology (3 years w.e.f. 16-09-2011)
**2nd time Accredited UG Programmes : • Computer Engineering • Electronics & Telecommunication Engineering • Information Technology • Electronics Engineering (3 years w.e.f. 01-07-2016)
1st cycle of Accreditation : • "A" Grade for 5 years (w.e.f. 30-10-2017)

CERTIFICATE

This is to certify that Vishnu Nair, Shivam Singh, Pratik Walawalkar are bonafide students of Thakur College of Engineering and Technology, Mumbai. They have satisfactorily completed the requirements of the B.E project as prescribed by University of Mumbai while working on **"Inertial Measuring System".**

Signature **Ms. Archana Belge** **(Guide)**	**Signature** **Dr. Sandhya Save** **(HOD ETRX)**
Internal Examiner **(Name and Signature with Date)**	**External Examiner** **(Name and Signature with Date)**

Dr. Kamal Shah **(Dean R&D)**	**Dr. Deven Shah** **(Vice Principal)**	**Dr. B.K.Mishra** **(Principal)**

Thakur College of Engineering and Technology
Kandivali(E), Mumbai-400101.

PLACE: Mumbai
DATE: (College seal)

ACKNOWLEDGEMENT

This project cannot be entirely created by an individual. The timely completion of this project on **'Inertial Measuring System'** has been possible because of my teacher and project guide **Ms.Archana Belge** and **Dr. Jonathan Joshi** who provided us with guidance and motivation throughout its making. We also thank them for giving us an opportunity to create this project.

We are also thankful to **Dr. Sandhya Save** (Electronics Department, HOD) for their guidance and to our parents for providing all possible resources to gain best possible knowledge.

Finally we would like to thank **Dr. B .K., Mishra** (Principal) , **Dr. Kamal Shah** (Dean R&D) and our college **Thakur College of Engineering and Technology** management for providing us with a platform and the necessary facilities to make this project.

SIGNATURE & NAME OF STUDENTS:

Vishnu Nair
(BE-ETRX 27)

Shivam Singh
(BE-ETRX 49)

Pratik Walawalkar
(BE-ETRX 60)

ABSTRACT

The present study is a proposition of a novel suspension system which is intended to be of great use in the field of autonomous or manned exploration primarily on extra-terrestrial planets. This new approach to suspension systems is totally electronic and uses negative feedback to stabilize the chassis. This research article attempts to let the reader go through the design process for the whole suspension system, including link design, dimensioning, electronic component selection and finally the embedded C code to attain the desired result.

The reasons for choosing these parameters are well addressed in the work. Multiple tests were performed on a prototype that was built during the course of this project on a track which simulated undulating surfaces for the robot to move on. Kinematic and structural analysis were carried out to ensure the prototype could perform as desired. These tests were constantly monitored using the open-source software, Processing, which gave real-time readings for the attitude of the chassis. The chassis model was drawn on OpenGL for easy visualization of the rolling, pitching and yawing of the chassis. Multiple tests resulting in lots of code tweaks has ultimately resulted in the fulfilment of the objective.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1

Introduction

1.1 Background

With planetary exploration becoming a major aim of India's 2020 goal, newer innovative and effective designs are wanted to travel on unknown terrains with safety assured. Unseen and unexplored terrains pose a great threat to vehicles movement and its components. Sensitive scientific equipment and astronauts will require a jerk free and tilt free ride. Suspension systems for highly uneven terrains are yet to reach a perfect solution. Although, there are many designs which are currently being researched upon and many simple yet very effective solutions like the "Rocker-Bogie Mechanism"[7], installed on the Mars Curiosity Rover, have surpassed all complications and have become the almost ideal solution for planetary exploration, there still exists the dream of a fluid-like movement on rough terrains. The introduction of computers and electronics has created a revolution in the automobile industry resulting in smarter, lighter, effective and economical solutions for a larger spectrum of systems. We have decided to go with an independent, centrally controlled suspension system.

This results in individual tire movements to avoid the roll instability. A centrally controlled suspension means that the "brain" i.e. the microcontroller installed controls the movements of the wheels depending upon the input parameters. New propositions for linkages from the tire to the chassis will be discussed. We have created a simple yet effective robotic suspension system by modifying a 4 bar link mechanism which can maintain a nearly horizontal chassis over a considerable forms of undulating terrains. The terrain should be in proportion with the robot for the suspension system to be properly effective. The suspension system can also be used for sharp obstacle climbing operations. The suspension movement is controlled by an IMU (Inertial Measurement Unit) which relays attitude information to the microcontroller which processes this data and relays instructions to the system of servo motors, which helps in controlling and moving the link mechanism to attain a perfectly horizontal chassis.

Due to the dramatic rise in space exploration, nuclear power plants and desert warfare and other defense related operations, there is a need for a new kind of suspension system. Most suspension systems can absorb shock and protect a robot from most terrains but what they can't do is maintain a horizontal chassis for a variety of terrains. There are certain suspension systems which use modern techniques such as M.R. fluids, however, these suspension systems are very expensive and not so effective on highly undulating terrains. Thus, there is a dire need of a new kind of suspension system which can be both effective and relatively inexpensive.

This design is intended to revolutionize the of robotic suspension systems as it results in perfect stabilization and is relatively cheaper when compared to its competitors which include monitored hydraulics[1], MR fluids [2] etc. This can help reduce costs in space exploration missions, defense missions and nuclear waste disposal operations etc. suspension systems can absorb shock and protect a robot from most terrains but what they can’t do is maintain a horizontal chassis for a variety of terrains. There are certain suspension systems which use modern techniques such as M.R. fluids, however, these suspension systems are very expensive and not so effective on highly undulating terrains. Thus, there is a dire need of a new kind of suspension system which can be both effective and relatively inexpensive.
This design is intended to revolutionize the of robotic suspension systems as it results in perfect stabilization and is relatively cheaper when compared to its competitors which include monitored hydraulics[1], MR fluids [2] etc. This can help reduce costs in space exploration missions, defense missions and nuclear waste disposal operations etc.

1.2 Project Objective & Accomplishment

Our main purpose is to develop an innovative and smart electronically controlled suspension system which always stabilizes the chassis to make it almost horizontal, with a very small degree of error. The robot must be able to go over both smooth undulating surfaces and sharp obstacles. In order to accomplish that, we designed various link mechanisms and then selected the most appropriate or optimum design for more load transfer & response. The robot also has two additional linkages which could also aid in sharp obstacle climbing. Algorithms which can provide real time stability solutions were developed and coded. The prototyping of the design was a crucial part of the eventual project plan. Through rigorous testing and experimentation, we achieved a near perfect suspension system.

1.3 Scope of Project

The new suspension system can be a real breakthrough in the field of robotic suspension systems. It would be a modification and an improvement on previously existing suspension systems and hence be more effective. The suspension will help improve mobility on difficult terrains for military and space exploration activities. This suspension system can be implemented on various kinds of wheeled bots like the ones which have robotic arms or other modifications and can result in an even more versatile robot vehicle. This can help in bringing relief to people stuck in earthquakes or war zones.

The current near perfect solutions like the BMW's dynamic drive [7] work well for really small vibrations and bumps. The suspension systems which can overcome large bumps are not precise enough which gives us our problem statement. :-

i. We need to come up with a high precision system that can overcome large bumps.
ii. The suspension system must have "auto-stabilization" which means it must be able to recover from all sorts of unprecedented actuations due to rough terrain.

Chapter 2

Proposed Work

and

Literature Review

2.1 Problem Definition

Our main purpose is to develop an innovative and smart electronically controlled suspension system which always stabilizes the chassis to make it almost horizontal, with a very small degree of error. The robot must be able to go over both smooth undulating surfaces and sharp obstacles. In order to accomplish that, we designed various link mechanisms and then selected the most appropriate or optimum design for more load transfer & response. The robot also has two additional linkages which could also aid in sharp obstacle climbing. Algorithms which can provide real time stability solutions were developed and coded. The prototyping of the design was a crucial part of the eventual project plan. Through rigorous testing and experimentation, we achieved a near perfect suspension system.

2.2 Literature Review

There are 2 kinds of suspension systems - Active and Passive. While passive suspension systems are purely mechanical, active suspension systems are interfaced with a great deal of sensors and electronics for higher precision. Since our suspension system has a lot of electronics involved (for higher accuracy), it falls under active suspension systems. Most of the active suspension systems are very expensive and require a lot of processing power. The suspension systems involving hydraulics, pneumatics and linear actuators are very expensive as the components are very costly. Purely kinematic based suspension systems are not precise enough, therefore a controlled kinematic suspension system would be perfect.

The current near perfect solutions like the BMW's dynamic drive [7] work well for really small vibrations and bumps. The suspension systems which can overcome large bumps are not precise enough which gives us our problem statement. We need to come up with a high precision system that can overcome large bumps. The suspension system must have "auto-stabilization" which means it must be able to recover from all sorts of unprecedented actuations due to rough terrain

2.2.1 Summary

An innovation in any field requires a proper study of existing technologies which is why a major portion of the time of this project was dedicated to the literature survey. This helped us in understanding various current technologies, the precision, advantages and disadvantages. The following is a list of relevant published, patented and unpublished research around the world.

i. Yuxin Zhanga (2011), proposed a study on a novel hydraulic pumping regenerative suspension for vehicles. From this paper, Hydraulic actuators were chosen as a way to absorb shock but ruled out due its cost. Also, the paper took a more energy oriented view which was not really relevant to our topic.
ii. Sy Dzung Nguyena (2015) wrote a paper on a hybrid clustering based fuzzy structure for vibration control - An application to semi-active vehicle seat-suspension system. The algorithms for neuro-fuzzy controller are important as they provide the backbone for the structure of the code to be implemented (in case neural networks are considered). However, serious modification is required as they are for MR.
iii. Flu Panshuo Li (2014) proposed a multi-objective control for active vehicle suspension with wheelbase preview. Front wheel movements were used as inputs to stabilize. This paper gave us an insight and a possibility of adding pseudo wheels whose movements we can track.
iv. John H. Crews(2011) wrote a paper on Multi-objective control optimization for semi-active vehicle suspensions. A similar approach as the previous one but for a semi-active suspension. Control algorithms are tested and hence reliable. The iROBOT from DARPA for Advanced Suspensions for Improved Mobility is a very intelligent, simple and effective design. Use of a chain couple with spring allows us to develop a mechanism which has better response to sharper angles and higher impact resistance.
v. E.C. Kern, called Tigger Bot II Robot is an electronically controlled chain locomotion without springs which provided the architecture for the microcontroller and other connections. These insightful diagrams helped us explore into microcontrollers.
vi. Researching on commercially available active suspensions led us to the famous car company BMW which has the Dynamic Drive[3], which is a highly sophisticated system in production. Employ's the use of sensors to detect movement of wheels and creates counter forces. But an adaptation or improvisation of this idea was ruled out because of its high cost.
vii. Karl Iagnemma (2013) developed the Control of Robotic Vehicles with Actively Articulated Suspensions in Rough Terrain. This new mechanism to overcome roll stability made us think about a simple

approach. Shifting of center of mass was also a new possible way to achieve our objective.

viii. Kazuo Tani (2011) worked on Wheeled Robots to Overcome Ground Unevenness in Construction Areas. A multi-functioning bot with 3 different mechanisms was a big inspiration in the mechanisms which we added perform multiple tasks including climbing stairs.

ix. Adibi Asl, H. (2010) used lead vehicle response to generate preview functions for active suspension of convoy vehicles. Similar approach to Panshuo Li et al, except a whole convoy was mathematically modelled and deflections in tire of one was reading for the other. Can be implemented when we use COBOTS or swarms.

2.3. Block Diagram:

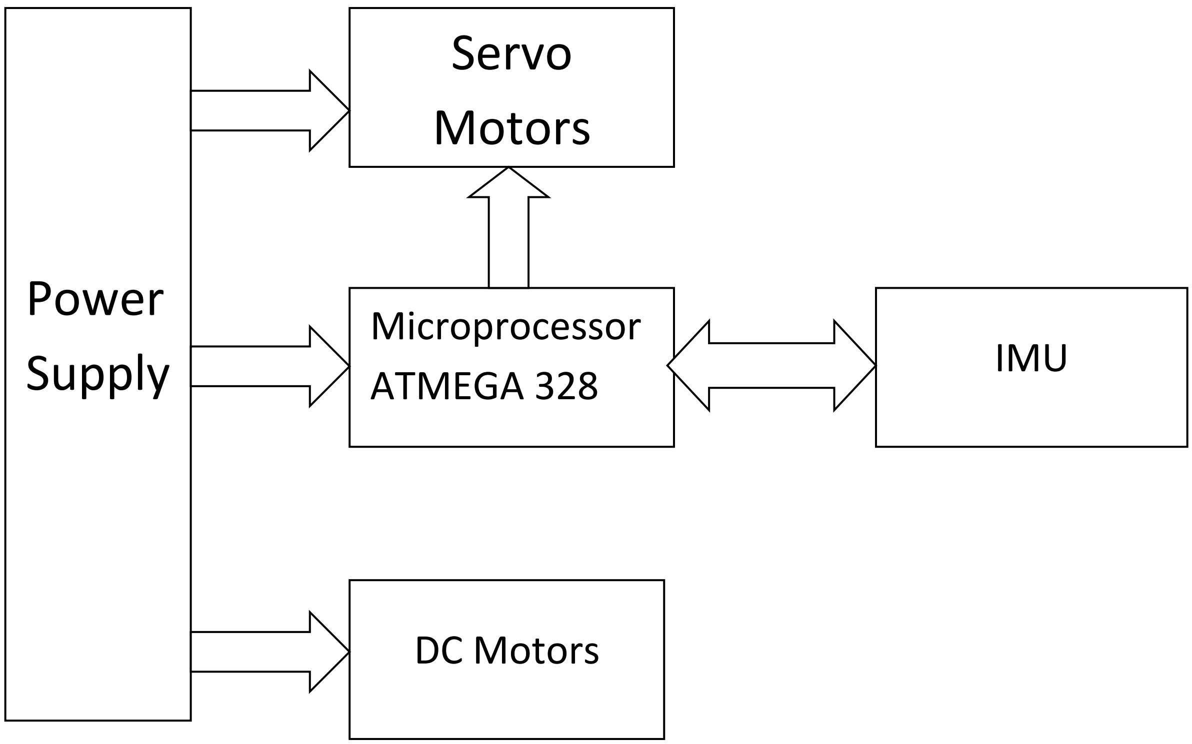


Fig. 2.1 Block Diagram of Inertial Measuring System

<u>Chapter 3</u>

Analysis and Planning

3.1 Project Planning

The project is planned in various stages which includes CAD design and practical approach to develop a mechanically stable design.

Week	Work Planned	Work Done	Percentage (%)
25/07/17 to 9/08/17	Selection of Group and finalization of Domain.	Group Selected and Domain name is Embedded System.	2%
03/08/17 to 07/08/17	Selection of topics based on the Domain.	Inertial Measuring System	4%
10/08/17 to 14/08/17	Research on the selected topics	Research has been done on the projects that can be done and used in industries and also at home.	5%
17/08/17 to 21/08/17	Presentation on the selected topics and finalization of topic.	Topic selected is Inertial Measuring System	7%
24/08/17 to 28/08/17	Doing literature survey by finding IEEE papers on digital vehicle data recorder	Found at least 3 IEEE papers.	10%
07/09/17 to 11/09/17	Gave presentation-1	Presenting the entire idea of how to go about the whole project.	14%

14/09/17 to 18/09/17	Learning the Basics of Processing Software	Presenting the entire idea of how to go about the whole project.	16%
21/09/17 to 25/09/17	Searching libraries and designing program	Searched libraries for MPU 6050 and designed program for IMU	18%
28/09/17 to 02/10/17	Learning about interfacing of Arduino with Processing Software	Studied how to interface GY-87 Module with Arduino	23%
11/10/17	Presentation-2	Presenting the entire idea of how to go about the whole project.	25%
12/10/17 to 16/10/17	Preparation of Blue Book.	Half the topics are done.	27%
19/10/17 to 23/10/17	Preparation of Blue Book.	Blue Book Report has been made and the Hard copy of the same has been created.	30%
23/11/17 to 27/11/17	Analysis	Analyzing what to implement and how to implement	50%
21/12/17 to 25/12/17	Implementation	Implementing the links	55%
11/01/18 to 15/01/18	Implementation	Implementing the links	65%

18/01/18 to 22/01/18	Implementation	Implementing the chassis and integrating with the electronics	70%
25/01/18 to 05/02/18	Implementation	Integrating and Re-coding of Arduino	75%
08/02/18 to 12/02/18	Analyzing	Analyzing the model	80%
15/02/18 to 19/02/18	Analyzing	Error correction of the links	85%
22/02/18 to 26/02/18	Analyzing	Encapsulating the wiring and providing casing for the model	90%
29/02/18 to 31/03/18	Error Correction		92%
1/04/18 to 09/04/18	Error Correction		95%
10/04/18 to 17/04/18	Black Book	Preparation of Blackbook	100%
TOTAL			**100% out of 100%**

3.1.1 Design Approach

We began by choosing an appropriate design for the link mechanism. Some of the mechanisms that were prominent after discussions were as shown below,

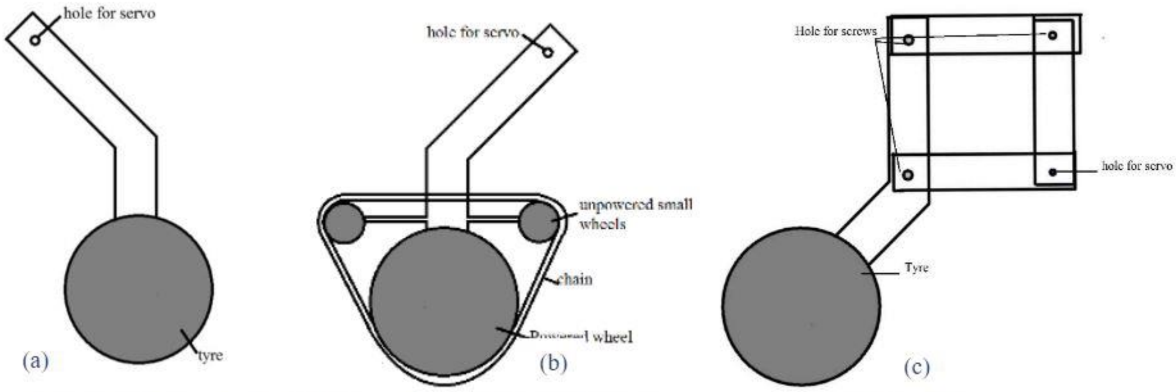


Figure 3-1 (a) The Laid Back Link (b) Three tyre Chain Supported (c) Modified Four Bar

Upon discussions, the various pros and cons of the designs were weighed upon and based on these discussions a design with the right amount of robustness and effectiveness was chosen. While the three tire chain supported was too complex a design and required higher torque servos. The laid back link design seemed ideal for the purpose but was rejected solely due to the fact the all the force on the link will directly act on the servo which could harm it. The modified link was finally chosen and further analysis and calculations were done.
After this step, the Electronic components were chosen and the microcontroller as interfaced with the IMU and servos. Primitive algorithms and codes were written and tested with suitable modifications.
The D.O.F. was calculated using the Gruebler's criterion.
$F = 3(N - 1) - 2P_1 - P_2 = 1$ Where, $N = 4$; $P_1 = 4$; $P_2 = 0$

3.1.2 Design Constraints

Some realistic design constraints that were kept in mind before the calculations were done were –

i. Economical – Since existing models are really expensive, a low-cost model is sought
ii. after. As it is intended to be an extra-terrestrial robot, lower cost will mean lower overall budget and more scope for funding on research.

iii. Manufacturability – Considering the economic factors, effective yet cheap

iv. manufacturing materials/methods have to be looked into. This will give us more flexibility to manufacture intricate and precise components.

v. Sustainability – When building a prototype a lot of factors have to be kept in

vi. mind considering how this design can be directly translated at a commercial/industrial level. These constraints include performance, and scaling up and reliability of the design. Rigorous testing and analysis must be done to make sure the prototype works for scaled up models.

3.1.3 Trade-Offs

Important trade-offs were done during the whole component selection and fabrication process. Some of the important ones are listed below.

i. Since Economical constraints were there, a lot of times while purchasing parts, cost

ii. was given more preference over quality and this compromised with the structural

iii. integrity of the frame.

iv. The microcontroller Arduino Uno is used in our model. As compared to the Arduino

v. Mega, this has lower computing power with a fewer output headers. This would limit

vi. us to smaller codes as we have lesser space for local variables but the Uno was chosen primarily because of its cost, dimensions, light weight and durability as compared to the Mega.

vii. Initially a 6 wheeled robot was conceptualized but due to the complexity involved,

viii. it was discarded as the project objective was to make it “simple-yet-effective”

3.1.4 Codes and Standards Used

Standard Screws; 2.6mm x 10mm
Standard Screws; 2.6mm x 6mm
Standard Nuts; 4mm x 3mm
Standard Jumper Wires 6" M/M - 20 AWG jumper wires

3.1.5 Computing Aspects

Embedded C language for ATmega328 microcontroller will be used. The processor is fixed on an Arduino Uno board.

3.1.6 Calculations

i. Dimensioning of links and chassis

All the dimensions involved initial assumptions which were set keeping in mind portable prototype and also on the availability of available pre-sized components. Listed below as the initial assumptions around which all the calculations are done

Assumptions:- Link breadth = 1.5 cm. (to accommodate holes for joints, each hole being 4 mm in diameter)

Link thickness = 3mm

Required Servo Deflection = ± 60°

ii. Hole to Hole Distance

Let, the links hit each other at an angle θ

x = 1.5/cos θ.................................... (Fig. 3.2)

For θ = 60°,

x = 3cm.

Giving a tolerance of 10°

x = 4.5 cm.

for θ = 70°

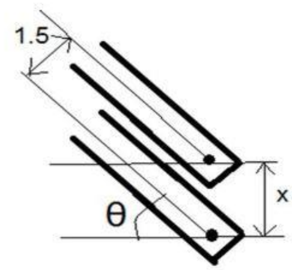


Figure 3.2 Hole to Hole Distance

iii. Short links

With a deflection of 60°, a displacement of ± 5cm was assumed

l = hole center to hole center distance

Therefore, 5 = l x sin (60)………….(Fig. 3.3)

L = 5.77 ≈ 5.8 cm, after adding 5mm gap each side

l = 6.8 cm.

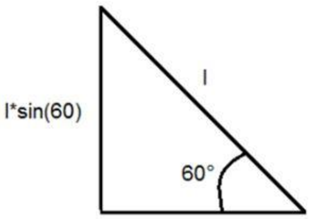


Figure 3.3 Short Link Calculation

iv. Long link

There is also a displacement in the x axis

l x cos (60) = 2.9cm (Fig. 3.4)

Motor diameter = 5cm. (Refer 3.6.3.3)

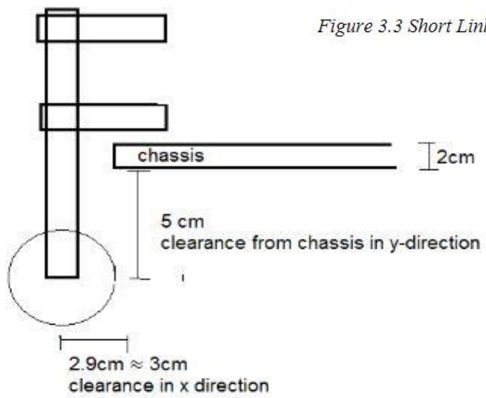


Figure 3.4 Long Link

A clearance in both x and y direction is needed (Fig. 3.5)
To give the necessary clearance, a J shaped link was chosen as the curve provided the least number of stress accumulation points. (Refer 3.7.2)
Accommodating the above mentioned changes the link was designed with the following dimensions.
Length in y = 12cm.
Length in x = 3 cm.
The motor tangent is after 3 cm in x direction to accommodate for motor movement in x direction.

v. Chassis

The chassis was made long enough to accommodate 2 servos and the central link's maximum lengths comfortably. The breadth was chosen such that a breadboard fits in it perfectly. Chassis dimensions –
Length = 40 cm, Breadth = 20 cm

Component	Dimension
Link Breadth	1.5 cm
Link Thickness	3mm
Displacement	5cm
Hole to Hole Distance	4.5cm
Short Link Length	6.8cm
J link Length	Vertical:12cm; Horizontal: 3 cm
Thickness of the chassis	2cm
Length of the chassis	40 cm
Breadth of the Chassis	20 cm
Central Link	Front 13cm:Back:6.5cm Angle between front and back: 140°

Table 3.1 Components Specification

3.1.7 Software Model

All the links were modelled and assembled using Solid Works. These design modifications were later incorporated before the fabrication of the robot. The final model of assembled links (Fig. 3.5) and robot (Fig. 3.6) are given below. It is important to note that initially, the central link was just a single link to support the robot while climbing but it was later realized that a shorter extra link was required to support the robot when it is on the sharp obstacle.

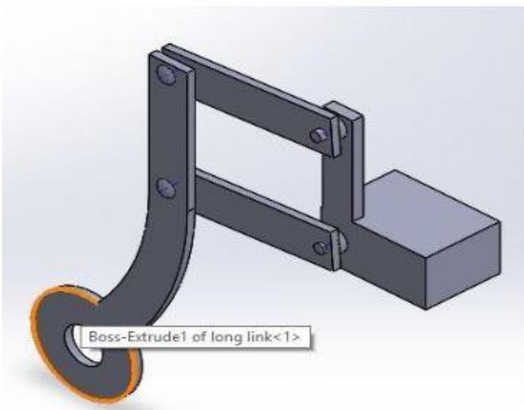


Fig 3.5 Assembled Links

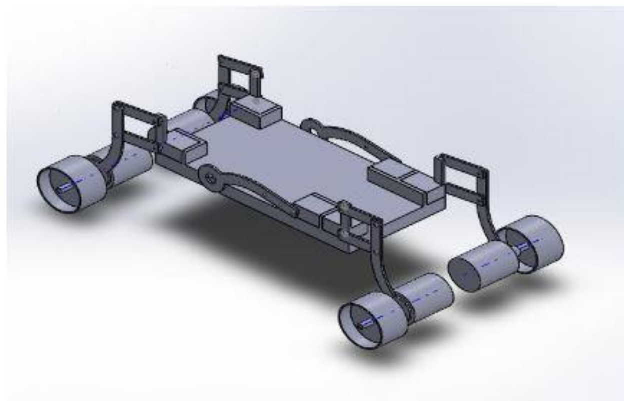


Fig 3.6 Robot Model

3.8 Schematic for electronic components

The following figure (Fig. 3.18) depicts the schematic for electronic components i.e. the IMU, servo motors, Arduino Uno and batteries.

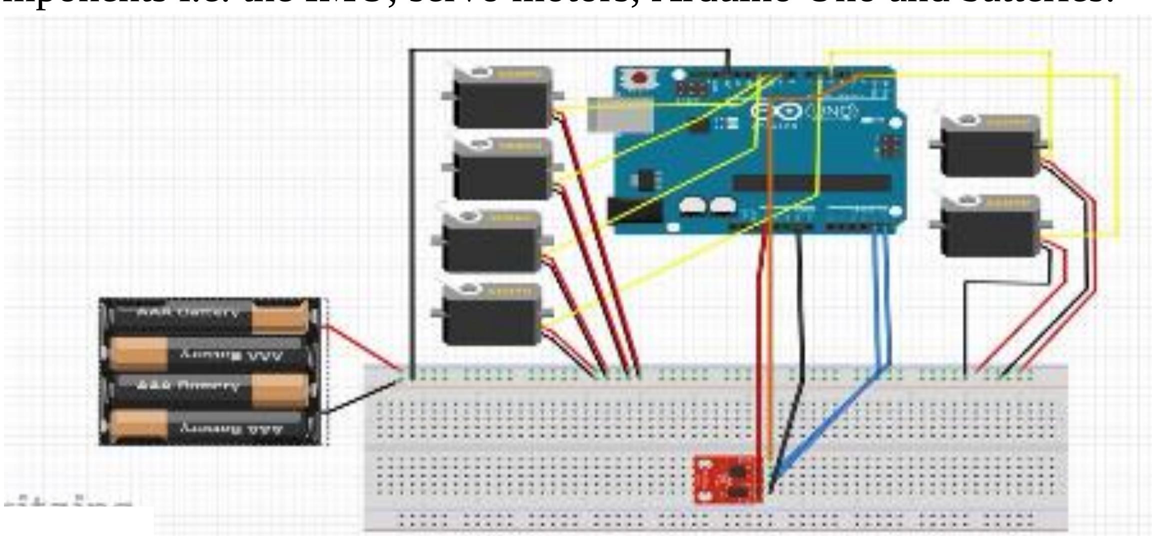


Fig 3.7 Schematic of Electronic Components

Chapter 4

Design, Implementation and Installation

4.1 Hardware Used

4.1.1 IMU -Inertial Measurement Unit

An inertial measurement unit (IMU) is an electronic device that measures and reports a body's velocity, orientation, and gravitational forces, using a combination of accelerometers gyroscopes and magnetometers. 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 calibrate against orientation drift. Angular and linear accelerometers are present in an IMU to detect changes in position and gyroscopic elements are present for maintaining an absolute angular reference .The sensors are micro electromechanical systems (MEMS) and hence are very accurate. The main purpose of an IMU in our project is to get the absolute angular orientation of the chassis. This data would be fed to the microcontroller which will take action in case there is a disturbance in the orientation.

4.1.2 MPU-6050

MotionInterface™ is becoming a "must-have" function being adopted by smartphone and tablet manufacturers due to the enormous value it adds to the end user experience. In smartphones, it finds use in applications such as gesture commands for applications and phone control, enhanced gaming, augmented reality, panoramic photo capture and viewing, and pedestrian and vehicle navigation. With its ability to precisely and accurately track user motions, Motion Tracking technology can convert handsets and tablets into powerful 3D intelligent devices that can be used in applications ranging from health and fitness monitoring to location-based services. Key requirements for Motion Interface enabled devices are small package size, low power consumption, high accuracy and repeatability, high shock tolerance, and application specific performance programmability – all at a low consumer price point.

The MPU-60X0 is the world's first integrated 6-axis Motion Tracking device that combines a 3-axis gyroscope, 3-axis accelerometer, and a Digital Motion Processor™ (DMP) all in a small 4x4x0.9mm package. With its dedicated I2C sensor bus, it directly accepts inputs from an external 3-axis compass to provide a complete 9-axis MotionFusion™ output. The MPU-60X0 Motion Tracking device, with its 6-axis integration, on-board MotionFusion™, and run-time calibration firmware, enables manufacturers to eliminate the costly and complex selection, qualification, and system level integration of discrete devices, guaranteeing optimal motion performance for consumers. The MPU-60X0 is also designed to interface with multiple non-inertial digital sensors, such as pressure sensors, on its auxiliary I2C port. The MPU-60X0 is footprint compatible with the MPU-30X0 family.

The MPU-60X0 features three 16-bit analog-to-digital converters (ADCs) for digitizing the gyroscope outputs and three 16-bit ADCs for digitizing the accelerometer outputs. For precision tracking of both fast and slow motions, the parts feature a user-programmable gyroscope full-scale range of ±250, ±500, ±1000, and ±2000°/sec (dps) and a user-programmable accelerometer full-scale range of ±2*g*, ±4*g*, ±8*g*, and ±16*g*.
An on-chip 1024 Byte FIFO buffer helps lower system power consumption by allowing the system processor to read the sensor data in bursts and then enter a low-power mode as the MPU collects more data. With all the necessary on-chip processing and sensor components required to support many motion-based use cases, the MPU-60X0 uniquely enables low-power Motion Interface applications in portable applications with reduced processing requirements for the system processor. By providing an integrated Motion Fusion output, the DMP in the MPU-60X0 offloads the intensive Motion Processing computation requirements from the system processor, minimizing the need for frequent polling of the motion sensor output.

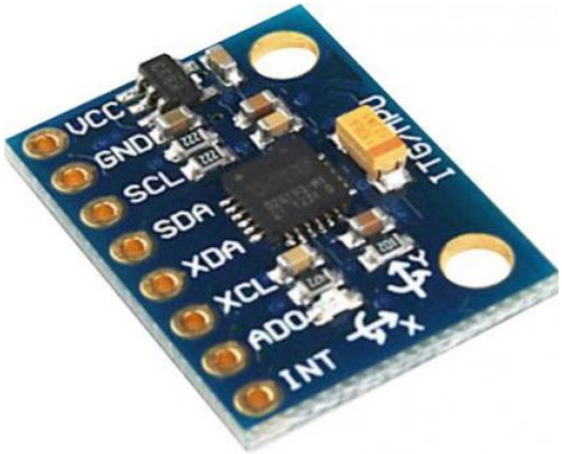


Fig 4.1 MPU 6050

Communication with all registers of the device is performed using either I2C at 400kHz or SPI at 1MHz (MPU-6000 only). For applications requiring faster communications, the sensor and interrupt registers may be read using SPI at 20MHz (MPU-6000 only). Additional features include an embedded temperature sensor and an on-chip oscillator with ±1% variation over the operating temperature range.

By leveraging its patented and volume-proven Nasiri-Fabrication platform, which integrates MEMS wafers with companion CMOS electronics through wafer-level

bonding, InvenSense has driven the MPU-60X0 package size down to a revolutionary footprint of 4x4x0.9mm (QFN), while providing the highest performance, lowest noise, and the lowest cost semiconductor packaging required for handheld consumer electronic devices. The part features a robust 10,000*g* shock tolerance, and has programmable low-pass filters for the gyroscopes, accelerometers, and the on-chip temperature sensor.
For power supply flexibility, the MPU-60X0 operates from VDD power supply voltage range of 2.375V-3.46V. Additionally, the MPU-6050 provides a VLOGIC reference pin (in addition to its analog supply pin: VDD), which sets the logic levels of its I2C interface. The VLOGIC voltage may be 1.8V±5% or VDD. We chose the MPU-6050 for our purpose as it was accurate to about 0.01 degree and was cheap. Some useful product specifications from its data sheet are as follows –

a) Digital-Output X, Y and Z-Axis angular rate sensors (gyroscopes) with a user-programmable full scale range of ±250, ±500, ±1000, and ±2000°/sec.
b) Integrated 16-bit ADCs enable simultaneous sampling of gyros
c) Improved low-frequency noise performance
d) Digitally-programmable low-pass filter
e) Gyroscope operating current: 3.6mA
f) An embedded temperature sensor and an on-chip oscillator with ±1% variation over the operating temperature range.

4.1.3 Servo

A servo motor is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity and acceleration. It consists of a suitable motor coupled to a sensor for position feedback. It also requires a relatively sophisticated controller, often a dedicated module designed specifically for use with servomotors. Servomotors are not a specific class of motor although the term servomotor is often used to refer to a motor suitable for use in a closed-loop control system. Servomotors are used in applications such as robotics, CNC machinery or automated manufacturing.

Fig 4.2 Tower Pro MG990R

Specifications

i. Modulation: Digital
ii. Torque: 4.8V: 130.54 oz-in (9.40 kg-cm)
iii. 6.0V: 152.76 oz-in (11.00 kg-cm)
iv. Speed: 4.8V: 0.19 sec/60°
v. 6.0V: 0.15 sec/60°
vi. Weight: 1.94 oz (55.0 g)
vii. Dimensions: Length:1.60 in (40.7 mm)
viii. Width:0.78 in (19.7 mm)
ix. Height:1.69 in (42.9 mm)
x. Gear Type: Metal
xi. Rotation/Support: Dual Bearings
xii. Rotational Range: 180 degree
xiii. Pulse Cycle: 1 ms

4.1.4 DC Motor

A **DC motor** is any of a class of rotary electrical machines that converts direct current electrical energy into mechanical energy. The most common types rely on the forces produced by magnetic fields. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic, to periodically change the direction of current flow in part of the motor.

Fig 4.3 DC motor with Gearbox

DC motors were the first type widely used, since they could be powered from existing direct-current lighting power distribution systems. A DC motor's speed can be controlled over a wide range, using either a variable supply voltage or by changing the strength of current in its field windings. Our application, i.e. planetary exploration requires low land speeds (0.14 km/h for mars curiosity rover). For a wheel with 68mm diameter, RPM required to attain a similar speed is 10RPM. Motor selected: Geared DC motor (10 RPM) (Fig. 4.3)

Specifications:-

i. DC supply: 4 to 12V
ii. RPM: 10 using Gearbox
iii. Torque : 12kgcm
iv. Total length: 46mm
v. Motor diameter: 36mm
vi. Motor length: 25mm
vii. Brush type: Precious metal
viii. Gear head diameter: 37mm
ix. Gear head length: 21mm
x. Output shaft: Centred
xi. Shaft diameter: 6mm
xii. Shaft length: 22mm
xiii. Motor weight: 125 gm

4.1.5 Wheels

A Rubber padded, 68mm diameter was chosen. The values are standard available market values and hence we did not go for custom made wheels. The wheel has a 4cm width and had grooves on it for improved traction. (Fig 4.4)

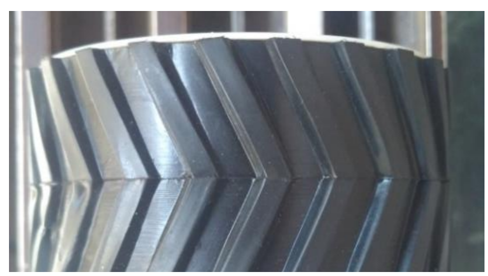


Fig 4.4 Rubber Padded Wheels

4.1.6 Arduino uno

The Arduino UNO is a widely used open-source microcontroller board based on the ATmega328P microcontroller and developed by Arduino.cc. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board features 14 Digital pins and 6 Analog pins. It is programmable with the Arduino IDE (Integrated Development Environment) via a type B USB cable.[4] It can be powered by a USB cable or by an external 9 volt battery, though it accepts voltages between 7 and 20 volts. It is also similar to the Arduino Nano and Leonardo. The hardware reference design is distributed under a Creative Commons Attribution Share-Alike 2.5 license and is available on the Arduino website. Layout and production files for some versions of the hardware are also available. "Uno" means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases. The Uno board is the first in a series of USB Arduino boards, and the reference model for the Arduino platform. The ATmega328 on the Arduino Uno comes preprogrammed with a bootloader that allows to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol. The Uno also differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter. The Arduino UNO is generally considered the most user-friendly and popular board, with boards being sold worldwide for less than 5$.

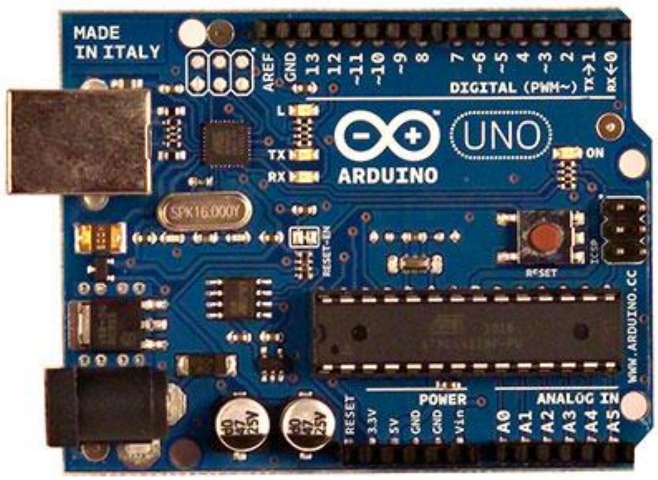


Fig 4.5 Arduino UNO

Specifications:

1. Microcontroller: ATmega328
2. Operating Voltage: 5V
3. Input Voltage (recommended): 7-12V
4. Input Voltage (limits): 6-20V
5. Digital I/O Pins: 14 (of which 6 provide PWM output)
6. Analog Input Pins: 6
7. DC Current per I/O Pin: 40 mA
8. DC Current for 3.3V Pin: 50 mA
9. Flash Memory: 32 KB of which 0.5 KB used by bootloader
10. SRAM: 2 KB (ATmega328)
11. Clock Speed: 16 MHz

4.2 Software Used

4.2.2 Processing

Processing is an open-source computer programming language and integrated development environment (IDE) built for the electronic arts, new media art, and visual design communities with the purpose of teaching non-programmers the fundamentals of computer programming in a visual context. The Processing language builds on the Java language but uses a simplified syntax and a graphics user interface. The need for processing software was felt in order understand the proper angulation and functionality of the MPU6050. The Graphical UI of the processing enabled us to have a proper understanding regarding the orientation of the chip.

4.2.3 Arduino IDE

The Arduino integrated development environment (IDE) is a cross-platform application (for Windows, macOS, Linux) that is written in the programming language Java. It originated from the IDE for the languages Processing and Wiring. It includes a code editor with features such as text cutting and pasting, searching and replacing text, automatic indenting, brace matching, and syntax highlighting, and provides simple one-click mechanisms to compile and upload programs to an Arduino board. It also contains a message area, a text console, a toolbar with buttons for common functions and a hierarchy of operation menus. A program written with the Arduino IDE is called a sketch.[57] Sketches are saved on the development computer as text files with the file extension .ino.

The entire code for the development of this project was written in the Arduino IDE and utilizing the available libraries of Arduino. The Arduino IDE was chosen as it is one of the easiest available tools and additionally the familiarity towards this environment inched us towards the use of this software.

4.3 Flow chart

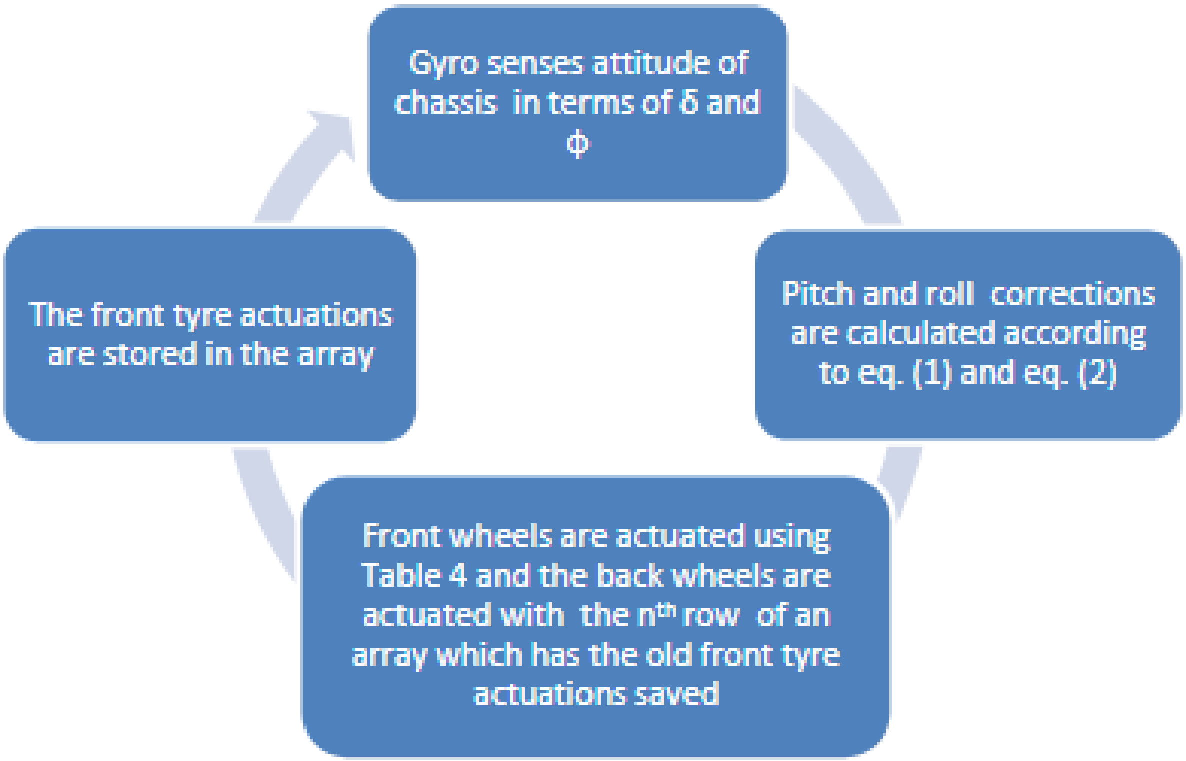


Fig. 4.6 Flow Chart of Inertial Measuring System

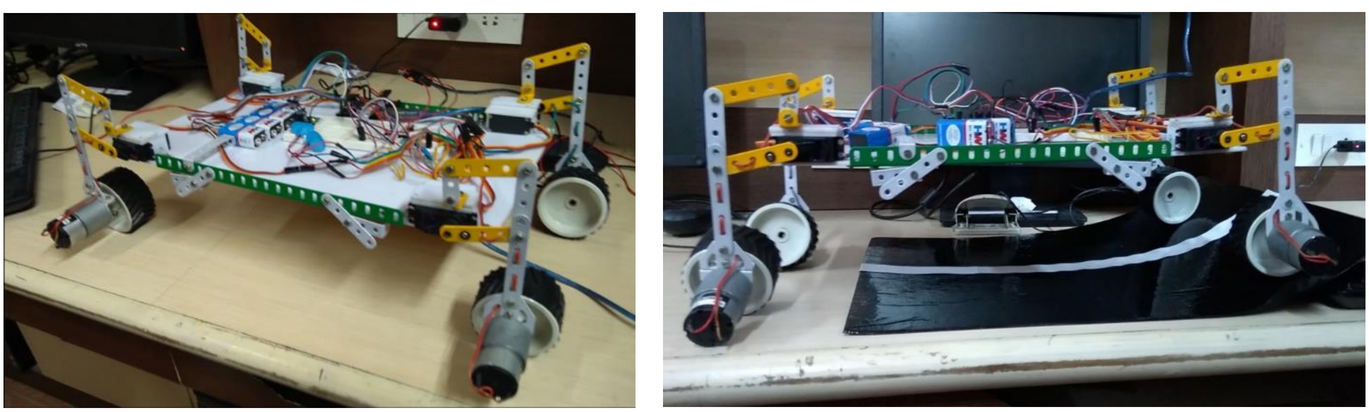


Fig. 4.7 Working Model Image

Chapter 5

Result and Discussion

5.1 Result

The primary goal of achieving a robotic suspension system which maintains a nearly horizontal chassis through a variety of terrains was largely satisfied. The bump –to -chassis length ratio = 5/55. This ratio is higher than a lot of conventional suspension systems. It is lower than systems like the rocker bogie suspension system but it is important to note that none of the systems with a higher ratio could maintain the chassis angle to such a high degree of accuracy. A scaled up model of about 3m in length can overcome a bump of about 30cm without even noticing it. Same applies for ditch depth too.

5.2 Discussions

1. The objective of the robot as a stair climbing robot was also successfully carried out, however the stair dimensions need to be proportional to the size of the robot. The negative feedback loop in the code resulted in extremely high accuracies of about 0.1 degrees, which is way more than what was aimed for.
2. Also, the code written resulted in auto–stabilization and recovery from any angle, something which wasn't intended to be one of the objectives to begin with.
3. Two major problems with the design were identified –-Since the distance of the wheel from the link was too high and unbalanced, there was a torque generated due to the robot's weight. This resulted in the buckling of the wheels and bending of links deeming it unsafe for use.-Lesser contact surface between links and weaker joints (due to improper manufacturing) resulted in a lot of unwanted deviation of the tires. This hampered the movement and speed of the robot and caused unnecessary stress.
4. These problems were rectified by the following design tweaks–-A cam shaped sleeve was used to be put over the cylinder of the J link, opposite to where the tire was fit, with the pointed part facing downwards. This part provides a counter torque and prevents the link from buckling.

Chapter 6

Conclusion and Future scope

6.1 Conclusion

1. The robotic suspension system is designed for a slow moving robot as most space exploration robots are slow moving in nature. The same suspension system may not work as efficiently for a fast moving robot. Thus it is important to note that robots with these suspension systems should ideally not be used for high speed operations.
2. The prototype that we have created did not have a motor driving circuit or a steering mechanism as they were both beyond the objective of the project.
3. The primary goal of achieving a robotic suspension system which maintains a nearly horizontal chassis through a variety of terrains was largely satisfied.

6.2 Future Scope for a Full Scale Model

1. The speed (in rpm) of each wheel is equal to 10.After testing, it was realized that the suspension system would be effective for relatively higher speeds as well.
2. The servo motors used are more than sufficient for our prototype and are very responsive. However, for a scaled up version of the prototype, stepper motors will be needed as the servo motors won't be able to handle much heavier loads.
3. Code for a larger prototype can include speed and acceleration control of stepper motor to avoid jerk. Advanced control systems and higher order stabilization will make the actuation vibration and jerk free.
4. An Arduino Uno was barely capable of storing local variables, which means higher processing power will be required for the controller to perform other tasks.
5. The code used by us in interfacing the microcontroller, IMU and the servo motors is not limited to the prototype that we have created, the code should work for a scaled up model as well
6. While the material used is durable and can sustain loads of up to 6 kg, it is recommended that a stronger yet lighter materials, like composites, be used in the manufacturing of the links for a scaled up model or for greater pay load capacity.

REFERENCE

[1] De Nardi, R., & Holland, O. (2006). Swarmav: A swarm of miniature aerial vehicles. In Proceedings of the 21st Bristol International UAV Systems Conference, April 2006

[2] Bills, C., Yosinski, J.: MAV stabilization using machine learning and onboard sensors. Technical Report CS6780, Cornell University (2010)

[3] Saska, M., Vonásek, V., Přeučil, L.: Roads sweeping by unmanned multi-vehicle formations. In: IEEE Int. Conf. on Robotics and Automation (2011)

[4] Zhang J. Tao T. Mei X. Jiang G. and Zhang D. "Non-linear robust control of a voltage-controlledmagnetic levitation system with a feedback linearizationapproach" Proc. Institution of Mechanical Engineers Part I: Jour. of Systems and Control Eng. Vol.225 2011

[5] Muscroft R.J.M. Sims-Williams D.B. and Cardwell D.A. "The Development of a Passive Magnetic Levitation System for Wind Tunnel Models" SAE Transactions: journal of passenger cars: mechanical systems 115 (6) pp. 415-419 2006

[6] Gysen B. Paulides J. Janssen J. Lomonova E. "Active Electromagnetic Suspension System for Improved Vehicle Dynamics" IEEE Transactions on Vehicular Technology Vol. 59 Issue 3 pp. 1-6 2008

[7] Babak, E, Hamidreza, B, Mir, BK, Golnaraghi, F (2011) A hybrid electromagnetic shock absorber for active vehicle suspension systems. Vehicle System Dynamics 49: 311–332

[8] Kawamoto, Y, Suda, Y, Inoue, H, Kondo, T (2007) Modeling of electromagnetic damper for automobile suspension. Journal of System Design and Dynamics 1: 524–535.

[9] Montazeri-Gh, M, Soleymani, M, Hashemi, S (2013) Impact of traffic conditions on the active suspension energy regeneration in hybrid electric vehicles. IEEE Transactions on Industrial Electronics 60: 4546–4553.

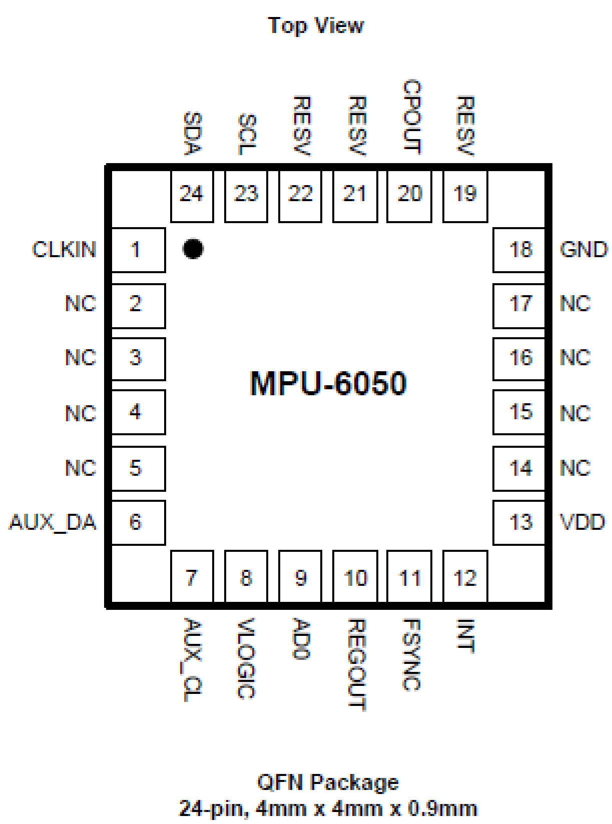
Appendix A:

Datasheets of MPU6050

Specifications and pin out of MPU 6050:

Parameter	Rating
Supply Voltage, VDD	-0.5V to +6V
VLOGIC Input Voltage Level (MPU-6050)	-0.5V to VDD + 0.5V
REGOUT	-0.5V to 2V
Input Voltage Level (CLKIN, AUX_DA, AD0, FSYNC, INT, SCL, SDA)	-0.5V to VDD + 0.5V
CPOUT (2.5V ≤ VDD ≤ 3.6V)	-0.5V to 30V
Acceleration (Any Axis, unpowered)	10,000g for 0.2ms
Operating Temperature Range	-40°C to +105°C
Storage Temperature Range	-40°C to +125°C
Electrostatic Discharge (ESD) Protection	2kV (HBM); 250V (MM)
Latch-up	JEDEC Class II (2),125°C ±100mA

Table (1a) Specifications of MPU 6050



Appendix B:

Code for Inertial Measuring System

Program

```
#include <Servo.h>
Servo myservoY;  //Variable decleration
Servo myservoX;
Servo myservoU;
Servo myservoV;
#include "MPU6050_6Axis_MotionApps20.h"
#if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
#include "Wire.h"
#endif
// class default I2C address is 0x68
// specific I2C addresses may be passed as a parameter here
//AD0 low = 0x68
// AD0 high = 0x69
MPU6050 mpu;
//MPU6050 mpu(0x69); // <-- use for AD0 high

#define OUTPUT_READABLE_YAWPITCHROLL
#define LED_PIN 13
bool blinkState = false;
// MPU control/status vars
bool dmpReady = false;  // set true if DMP init was successful
uint8_t mpuIntStatus;   // holds actual interrupt status byte from MPU
uint8_t devStatus;      // return status after each device operation (0 = success, !0 = error)
uint16_t packetSize;    // expected DMP packet size (default is 42 bytes)
```

```
uint16_t fifoCount;     // count of all bytes currently in FIFO
uint8_t fifoBuffer[64]; // FIFO storage buffer
// orientation/motion vars
Quaternion q;           // [w, x, y, z]         quaternio n container
VectorInt16 aa;         // [x, y, z]            accel sensor measurements
VectorInt16 aaReal;     // [x, y, z]            gravity-free accel sensor measurements
VectorInt16 aaWorld;    // [x, y, z]            world-frame accel sensor measurements
VectorFloat gravity;    // [x, y, z]            gravity vector
float euler[3];         // [psi, theta, phi]    Euler angle container
float ypr[3];           // [yaw, pitch, roll]   yaw/pitch/roll container and gravity vector
//float saveXU[55];
//float saveYV[55];
int i = 0;
int j = 0; //variable to determine delay
int neutralX = 80, neutralY = 93, neutralU = 60, neutralV = 87;
int currentX, currentY, currentU, currentV;
uint8_t teapotPacket[14] = { '$', 0x02, 0, 0, 0, 0, 0, 0, 0, 0, 0x00, 0x00, '\r', '\n' };
volatile bool mpuInterrupt = false;     // indicates whether MPU interrupt pin has gone high
void dmpDataReady() {
  mpuInterrupt = true;
}
int k=0;
void setup() {
  currentX = neutralX;
  currentY = neutralY;
```

```
  currentU = neutralU;
  currentV = neutralV;
for(k=0;k<=51;k++)
  {
    //saveYV[k]=neutralV;    // neutral set here for V
    //saveXU[k]=neutralU;    // neutral set here for U
  }
 // join I2C bus
#if I2CDEV_IMPLEMENTATION == I2CDEV_ARDUINO_WIRE
  Wire.begin();
  TWBR = 24; // 400kHz I2C clock (200kHz if CPU is 8MHz)
#elif I2CDEV_IMPLEMENTATION == I2CDEV_BUILTIN_FASTWIRE
  Fastwire::setup(400, true);
#endif
  //Attach servo
  myservoX.attach(9); // Attach X servo to pin 9
  myservoY.attach(10);// Attach Y servo to pin 10
  myservoU.attach(5); // Attach U servo to pin 5
  myservoV.attach(6); // Attach V servo to pin 6
  // initialize serial communication
  Serial.begin(115200);
  while (!Serial); // wait for Leonardo enumeration, others continue immediately
  // initialize device
  Serial.println(F("Initializing I2C devices..."));
  mpu.initialize();
```

```
  // verify connection
  Serial.println(F("Testing device connections..."));
  Serial.println(mpu.testConnection() ? F("MPU6050 connection successful") : F("MPU6050
connection failed"));
  // load and configure the DMP
Serial.println(F("Initializing DMP..."));
  devStatus = mpu.dmpInitialize();
  // supply gyro offsets here, scaled for min sensitivity
  mpu.setXGyroOffset(-1887);
  mpu.setYGyroOffset(-889);
  mpu.setZGyroOffset(13);
  mpu.setZAccelOffset(1452);
  // make sure it worked (returns 0 if so)
  if (devStatus == 0) {
    // turn on the DMP, now that it's ready
    Serial.println(F("Enabling DMP..."));
    mpu.setDMPEnabled(true);
    // enable Arduino interrupt detection
    Serial.println(F("Enabling interrupt detection (Arduino external interrupt 0)..."));
    attachInterrupt(0, dmpDataReady, RISING);
    mpuIntStatus = mpu.getIntStatus();
    // set our DMP Ready flag so the main loop() function knows it's okay to use it
    Serial.println(F("DMP ready! Waiting for first interrupt..."));
    dmpReady = true;
    // get expected DMP packet size for later comparison
```

```
    packetSize = mpu.dmpGetFIFOPacketSize();
    }
else
{
    // ERROR!
    // 1 = initial memory load failed
    // 2 = DMP configuration updates failed
    Serial.print(F("DMP Initialization failed (code "));
    Serial.print(devStatus);
    Serial.println(F(")"));

   }
  // configure LED for output
  pinMode(LED_PIN, OUTPUT);
  }
void loop() {
  // if programming failed, don't try to do anything
  if (!dmpReady) return;
  // wait for MPU interrupt or extra packet(s) available
  while (!mpuInterrupt && fifoCount < packetSize) {
  }
  // reset interrupt flag and get INT_STATUS byte
  mpuInterrupt = false;
  mpuIntStatus = mpu.getIntStatus();
  // get current FIFO count
```

```
  fifoCount = mpu.getFIFOCount();

  // check for overflow

  if ((mpuIntStatus & 0x10) || fifoCount == 1024) {

    // reset so we can continue cleanly

    mpu.resetFIFO();

    Serial.println(F("FIFO overflow!"));

    // otherwise, check for DMP data ready interrupt

  } else if (mpuIntStatus & 0x02) {

    // wait for correct available data length, should be a VERY short wait

while (fifoCount < packetSize) fifoCount = mpu.getFIFOCount();

    // read a packet from FIFO

    mpu.getFIFOBytes(fifoBuffer, packetSize);

    // track FIFO count here in case there is > 1 packet available and lets us immediately read
more without waiting for an interrupt

    fifoCount -= packetSize;

#ifdef OUTPUT_READABLE_YAWPITCHROLL

    // display Euler angles in degrees

    mpu.dmpGetQuaternion(&q, fifoBuffer);

    mpu.dmpGetGravity(&gravity, &q);

    mpu.dmpGetYawPitchRoll(ypr, &q, &gravity);

    Serial.print(i);

    Serial.print("\t");

    Serial.print(j); //variable to determine delay

    Serial.print("\t ypr\t");

    Serial.print(ypr[0] * 180 / M_PI);
```

```
    Serial.print("\t");

    Serial.print(ypr[1] * 180 / M_PI);

    Serial.print("\t");

    Serial.println(ypr[2] * 180 / M_PI);


    float pitch,roll,possY,possX;

    //FOR IT TO CALIBRATE

    if(i<500)

    {

myservoY.write(neutralY);

myservoX.write(neutralX);

myservoU.write(neutralU);

myservoV.write(neutralV);

    }

    //AFTER CALIBRATTION

    if((i%10)==0 && i>500)

    {

       pitch = (ypr[2] * 180 / M_PI);

       roll = (ypr[1] * -180 / M_PI);

       //SETTING CONTSTRAINTS

       pitch = constrain(pitch,-5.0,5.0);

       roll = constrain(roll,-11.0,11.0);

      if(pitch <=0.1 && pitch>= - 0.1 && roll <=0.5 && roll>= - 0.5)

      {

          pitch=0;
```

```
        roll=0; //to prevent it from being oversensitive
    }
    else
    {
        pitch = floatMap(pitch,-5.0,5.0,-50.0,50.0);    //pitch mapping
        roll = floatMap(roll,-11.0,11.0,-50.0,50.0);    //roll mapping
    }
        if(roll<0)
        {
          pitch = int(pitch);
          currentX = int(currentX);
          currentY = int(currentY);
          currentX = currentX + pitch;
          currentY = currentY - pitch +roll;                    //bump on right
        }
        else
{
          currentX = currentX + pitch+roll;                     //bump on left
          currentY = currentY - pitch;

}

        if(roll>0)
```

```
    {
      pitch = int(pitch);
      currentU = int(currentU);
      currentV = int(currentV);
      currentU = currentU + pitch - roll;
      currentV = currentV - pitch + roll ;            //bump on right
    }
    else
{
      currentU = currentU + pitch+roll;            //bump on left
      currentV = currentV - pitch;

}

   /*  if(roll<0)
    {
     pitch = int(pitch);
      currentX = int(currentX);
      currentY = int(currentY);
      currentU = int(currentU);
      currentV = int(currentV);
      if(pitch>0)
      {
      currentX = currentX + pitch;            //bump on left
      }
```

```
            if(pitch<0)
           {
            currentX = currentX + pitch - roll;
           }
          }
         */
/* if(i%10==0)
        {
        saveYV[51]=0;
        saveXU[51]=0;
        for(int l=0; l<=50; l++)   //one less than planned (n)
        {
            saveYV[l] = saveYV[l+1];  //FIFO
            saveXU[l] = saveXU[l+1];    //FIFO
        }
        j++;    //use this number to determine delay
        } */
   }
     currentX =constrain(currentX,neutralX-10,neutralX+50);
    currentY =constrain(currentY,neutralY-50,neutralY+5);
    currentU =constrain(currentU,neutralU-20,neutralU+30);
    currentV =constrain(currentV,neutralV-10,neutralV+50);
    myservoY.write(currentY);
    myservoX.write(currentX);
    myservoU.write(currentU);
```

```
      myservoV.write(currentV);
      //myservoV.write(saveYV[0]);  //V takes old Y   //0 is oldest value
      //myservoU.write(saveXU[0]);  //U takes old X

        i++;
#endif
      // blink LED to indicate activity
      blinkState = !blinkState;
      digitalWrite(LED_PIN, blinkState);
  }
}
float floatMap(float x, float inMin, float inMax, float outMin, float outMax)
{
 return (x-inMin)*(outMax-outMin)/(inMax-inMin)+outMin;
}
```

Appendix C:

Contact Details

Contact Information:

Sr No.	Name	Class	Roll No.	Email id	Mobile No.	Address
1.	Mrs. Archana Belge	Associate Professor		archanabelge3@gmail.com	8097220540	Thakur College of Engineering & Technology, Kandivali(East)
4.	Pratik Walawalkar (Team Leader)	BE-ETRX	60	pratikcr9@yahoo.in	9969059102	Borivali (West).
2.	Vishnu Nair	BE-ETRX	27	vishnunair273@gmail.com	9022224313	Vasai (West)
3.	Shivam Singh	BE-ETRX	49	shivamrpsingh@gmail.com	7021595096	Borivali (West)

Publications:

IEEE Paper on Inertial Measuring System

Inertial Measuring System

Vishnu Nair
Electronics Engineering
Thakur College of Engineering and Technology
vishnunair293@gmail.com

Pratik Walawalkar
Electronics Engineering
Thakur College of Engineering and Technology
pratikw7.28@gmail.com

Shivam Singh
Electronics Engineering
Thakur College of Engineering and Technology
thakurshivamrpsingh@gmail.com

Abstract: **Inertial measuring Unit (IMU) is an integrated chip that has an on-board accelerometer and gyroscope. The application using this chip is infinite and vivid, this paper dives into the automation paradigm of the IMU and we intend to develop a system that enables an automobile to drive through a bumpy road with ease and smoothness. The values provided by the IMU gives a steady reference with respect to the ground for the microprocessor to process the information and adjust the position of wheels.**

Keywords: IMU, Accelerometer, Gyroscope, DoF, Yaw, Pitch, Roll, Axis.

I. Introduction

This project will serve as a prototype which can be further implemented in large scale with help of this unit we are able to track position an object to which this unit is attached in real-time

This project can be related to hand gesture project, but this project has a capability to track as well as log position parameters as well

Power management has been one of the most discussed topic in the past decade because of the decrease in the energy reserves. Power shutdown is a major problem now-a-days and it occurs because a lot of power is wasted in industries.

1.1 Importance of the project and its background:

- Real time tracking
- Accurate results
- Data recording
- Energy Saving

II. Methodology

Real time motion tracking technology is the upcoming high end technology. Wireless transmission of the coordinates after processing various parameters like linear acceleration, angular momentum, magnetic flux after its integration into a processor, which provides the position of the object to which the IMU is attached.

We have designed this project with minimum external modules and peripherals making it cost effective

A. Types of IMU

IMU available in market now are in various types and shape. So, user can select what type, size and shape. The IMU can be selected from its degrees of freedom (DOF) that being developed by manufacturer. User can select from three DOF, five DOF and six DOF. For three DOF, the sensors configurations are two accelerometers and a gyroscope that measures yaw. For five DOF, the sensors configurations are three accelerometers and two gyroscopes that measure pitch and roll. For six DOF, all axes for accelerometer and gyroscope for measurement are available.

A. About MPU-6050 Six-Axis (Gyro + Accelerometer)

The MPU-6050 devices combine a 3-axis gyroscope and a 3-axis accelerometer on the same silicon die, together with an on board Digital Motion Processor™ (DMP™), which processes complex 6-axis Motion Fusion algorithms. The device can access external magnetometers or other sensors through an auxiliary master I²C bus, allowing the devices to gather a full set of sensor data without intervention from the system processor. The devices are offered in a 4 mm x 4 mm x 0.9 mm QFN package.

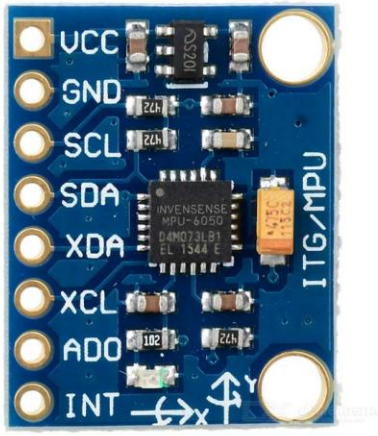


Fig. 1 MPU 6050

B. MPU 6050 features:

- I2C Interface.
- Supply voltage: 3 to 5 V.
- I/O voltage: 2.3 to 3.4 V.
- Triple axis gyro (angular rate sensor) with selectable scale (from ±250 to ±2000 dps)
- Triple axis accelerometer with selectable scale (from ±2g to ±16g)
- Temperature sensor with digital output.
- Digital Motion Processing™
- Size: 20 mm x 15 mm.

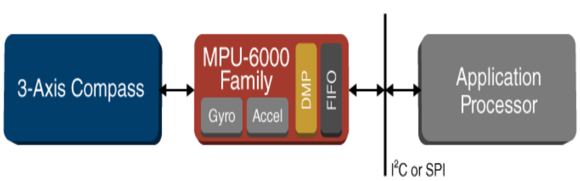


Fig 1-2. Block Diagram of MPU 6050

For precision tracking of both fast and slow motions, the parts feature a user-programmable gyro full-scale range of ±250, ±500, ±1000, and ±2000 °/sec (dps), and a user-programmable accelerometer full-scale range of ±2g, ±4g, ±8g, and ±16g. Additional features include an embedded temperature sensor and an on-chip oscillator with ±1% variation over the operating temperature range.

Formula:

$$\text{Required\_value}=\frac{\text{raw\_value}}{\text{proper\_sensitivity}} \quad (1)$$

C. Scope of the project.

This project has a very wide scope in visual reality where ever minute motion is tracked and analysed to produce an amazing life-like experience. The air bags in vehicles needs to be deployed on a specific degree of Impact, it should not malfunction and deploy on minor jerk or on applying brakes. If it happens so then the safety system might itself result into a mishap. Hence in order to sense the impact IMU can be used which can be calibrated to trigger on a specific intensity of impact. As the technology is advancing the is much more research activity in domain of Real time motion tracking.

D. Current scenario

Currently in order to track any object in 3- dimension we need complex wiring and grid of sensors for its real time tracking or we can track it using GPS but there are some limitations to it, like the position is not accurate and may vary due to environmental conditions and other physical parameters.

E. The proposed system

The system which we have proposed is very compact is size and hence it can be attached to any moving object like vehicles or on humans. The proposed change makes our system wearable as well as the components used in it makes the complete device cost effective and rugged. The inertial measurement unit works by detecting linear acceleration using one or more accelerometers and rotational rate using one or more gyroscopes. A magnetometer is utilized, which is commonly used as a heading reference. Typical configurations contain one accelerometer, gyro, and magnetometer per axis for each of the three vehicle axes: pitch, roll and yaw. Due to the presence of on board accelerometer, gyroscope and magnetometer on a single chip and with a central processor too the values are obtained in a systematic manner and these sensors provide our project with the ability to have nine degrees of freedom for motion tracking.

F. 3D orientation of MPU 6050

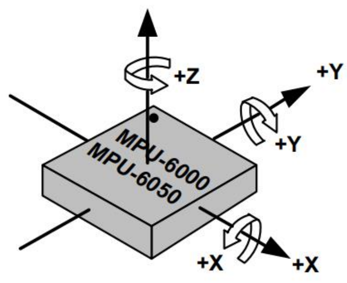


Fig 1-3. Orientation of Axes of Sensitivity and polarity of rotation

G. Block diagram

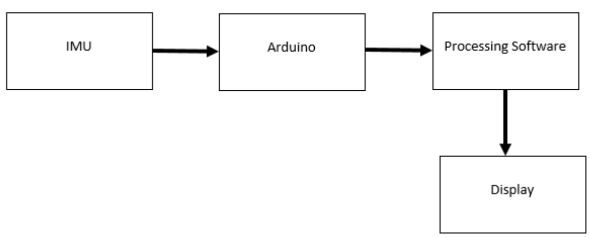


Fig 1-4. Block Diagram

1 2.9 Design Phase: Circuit Diagram

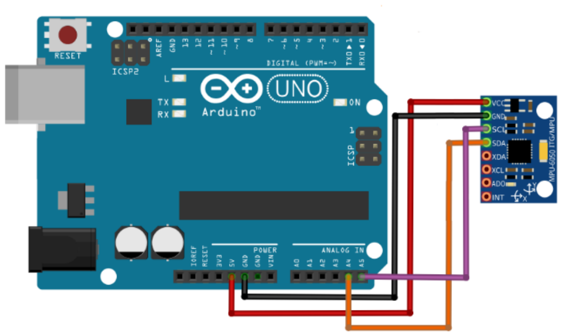


Fig 1-1. Interfacing IMU with Arduino

2.10 Interfacing the Arduino MPU 6050

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.

The program we will be running here, also takes advantage of the Arduino's interrupt pin. Connect your Arduino's digital pin 2 (interrupt pin 0) to the pin labelled as INT on the MPU 6050. Next, we need to set up the I2C lines. To do this, connect the pin labelled SDA on the MPU 6050 to the Arduino's analog pin 4 (SDA) and the pin labelled as SCL on the MPU 6050 to the Arduino's analog pin 5 (SCL). That's it, you have finished wiring up the Arduino MPU 6050!

III. LITERATURE SURVEY

A. How does accelerometer works:

Basic working of Accelerometer Operation:

According to newtons second law of motion that the acceleration (m/s^2) of body is directly proportional to the net force acting on that body, and inversely to its mass

Acceleration=Force(Newton)(m/s^2) *Mass (gram)

A micro Gimbal like mechanism which is used to detect the force in a particular direction. It basically measures acceleration through the force applied to one of the accelerometers axes.

An accelerometer is an electromechanical device, including holes, cavities, springs, and channel, that is fabricated using microfabrication technology. Accelerometers are fabricated using a multi – layer wafer process,

i. Piezoelectric Effect

A accelerometer works on piezoelectric effect. Let us imagine a cuboidal box with a small ball inside it, like shown in the diagram below. The walls of this box are made with piezoelectric crystals, if the box tilt on any of its side, the makes the box inclined and the gravity forces it to collide with the wall on that particular side, this results into production of piezoelectric current. Six walls in pair of three corresponds to 3 axis in 3D space. X, Y and Z Axes. Depending on the current produced from piezoelectric walls, we can determine the direction of inclination and its magnitude.

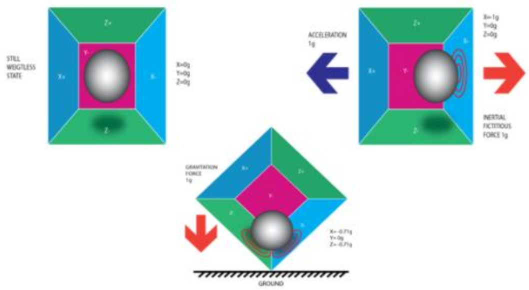


Fig 1-2. Piezoelectric Accelerometer

ii. Capacitive Effect

In case of accelerometer that works on capacitive sensing, outputs a voltage dependent on the distance between two planar capacitive surfaces. Both these plates are charged with an electrical current. As the gap between the plates changes the electrical capacity of the system, which can be measured as voltage output. This method of sensing results in high accuracy and stability. As capacitors are less affected by noise and other electromagnetic interference, the same goes with this type of accelerometer hence they are less prone to noise and variation with temperature and the typically dissipate less power, and can have large bandwidths, due to internal frequency circuits.

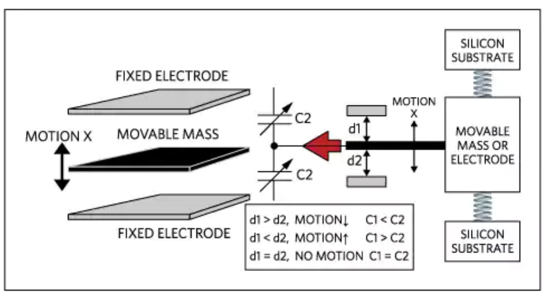


Fig 1-3 Acceleration associated with a single moving mass

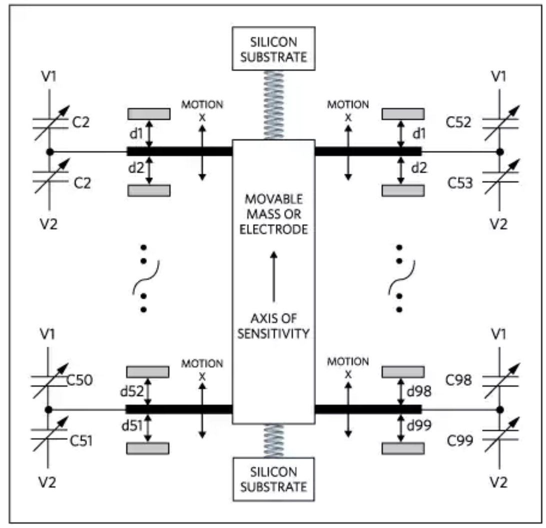


Fig 1-4. Acceleration associated with multiple masses

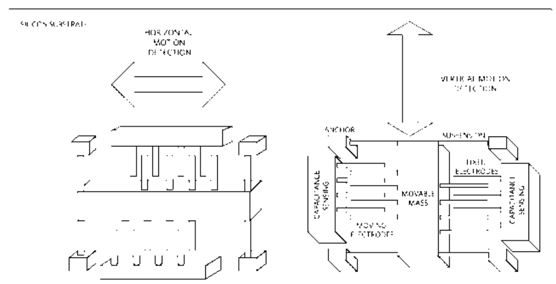


Fig 1-5. Mechanical model of 2-axis accelerometer

Basic working of Gyroscope

Gyroscopes work on the principle of Coriolis acceleration. Imagine that there is a fork-like structure that is in a constant back and forth motion. It is held in place using piezoelectric crystals. Whenever you try to tilt this arrangement, the crystals experience a force in the direction of inclination. This is caused as a result of the inertia of the moving fork. The crystals thus produce a current in consensus with the piezoelectric effect, and this current is amplified. The values are then refined by the host microcontroller.

Tuning Fork Gyroscope:

This type of Gyroscope contains a pair of masses that are driven to oscillate with equal amplitude but in opposite directions. While rotating the Coriolis force creates an orthogonal vibration which can be sensed by many types of mechanism. The figure below (Figure:9) uses comb type structure to drive the tuning force into resonance

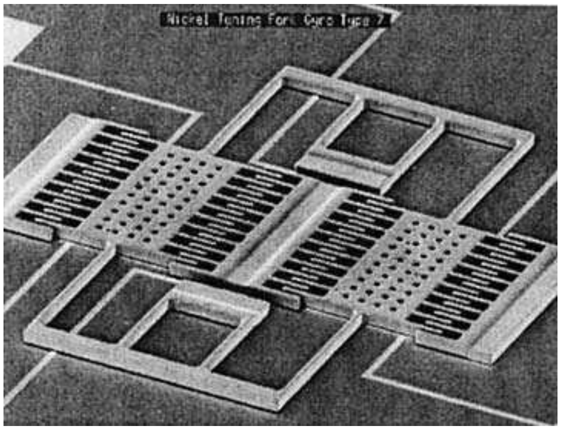


Fig 1-6. Comb type Tuning Fork Gyroscope Structure

The rotation caused the mass to vibrate which in turn vibrate out of the plane, this type of motion is sensed by the structure

IV. Result and Discussion

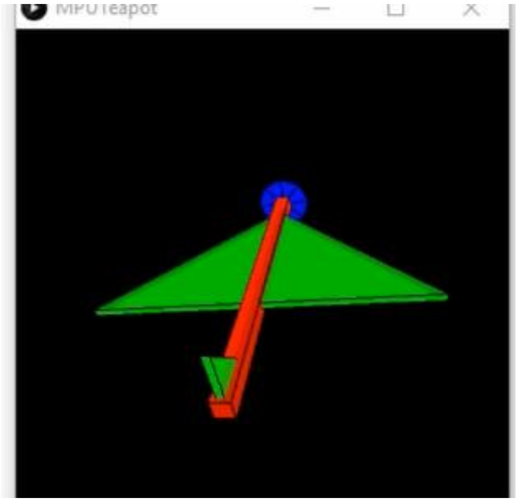


Fig 1-7. Result of 3D simulation

1. Raw data of accelerometer

Table 1. X-axis Readings

Ax	Range	Sensitivity	X-Axis
-15608	2g	16384	0.95g
-945	4g	8192	0.11g
256	8g	4096	0.06g
2655	16g	2048	0.8g

Table 2. Y-axis Readings

Ay	Range	Sensitivity	Y-axis
5065	2g	16384	0.31
-4856	4g	8192	0.59g
-255	8g	4096	0.06g
-589	16g	2048	0.28g

Table 3. Z-axis Readings

Az	Range	Sensitivity	Z-axis
450	2g	16384	0.027g
8159	4g	8192	0.99g
-3698	8g	4096	0.9g
898	16g	2048	0.43g

2. Raw data of gyroscope:

Table 4. X-axis Readings

Gx	Range	Sensitivity	X-Axis
-349	250	131	-2.66
65497	500	65.5	499.977
894	1000	32.8	27.25
2655	2000	16.4	161

Table 5. Y-axis Readings

Gy	Range	Sensitivity	Y-axis
-204	250	131	-1.355
31	500	65.5	0.756
6512	1000	32.8	198.53
-589	2000	16.4	-35.91

Table 6. Z-axis Readings

Gz	Range	Sensitivity	Z-axis
-247	250	131	-1.88
41	500	65.5	0.311
23645	1000	32.8	720.88
898	2000	16.4	54.75

V. Conclusion

By the realization of the above proposed system we can not only track real-time position of an object in 3-Dimension but also use the data for many other applications after processing it using various algorithms.

Acknowledgement

We thank our mentor's guide Prof. Archana Belge and Mr. Ganesh Gore for their valuable inputs and suggestions which were very instrumental in making this project a reality.

REFERENCE

[1] Webpage for interfacing IMU with Arduino: http://hotresistor.blogspot.in/2015/09/interfacing-arduino-with-gy-87.html. Accessed: October, 2017

[2] Video for interfacing IMU with Arduino: https://www.youtube.com/watch?v=x2vVsO5Hr2I. Accessed: October, 2017

[3] Webpage for interfacing MPU 6050 with Arduino: https://diyhacking.com/arduino-mpu-6050-imu-sensor-tutorial/. Accessed: February, 2017

[4] https://github.com/guywithaview/Arduino-Test/blob/master/GY87/GY87.ino. Accessed: October, 2017

[5] http://www.circuitstoday.com/interfacing-gyroscope-arduino Accessed: February, 2017

[6] Webpage for study of MPU 6050 Accelerometer and Gyroscope: https://www.invensense.com/products/motion-tracking/6-axis/mpu-6050/. Accessed: January, 2018

[7] De Nardi, R., & Holland, O. (2006). Swarmav: A swarm of miniature aerial vehicles. In Proceedings of the 21st Bristol International UAV Systems Conference, April 2006

[8] Bills, C., Yosinski, J.: MAV stabilization using machine learning and onboard sensors. Technical Report CS6780, Cornell University (2010)

[9] Saska, M., Vonásek, V., Přeučil, L.: Roads sweeping by unmanned multi-vehicle formations. In: IEEE Int. Conf. on Robotics and Automation (2011)

[10] Zhang J. Tao T. Mei X. Jiang G. and Zhang D. "Non-linear robust control of a voltage-controlledmagnetic levitation system with a feedback linearizationapproach" Proc. Institution of Mechanical Engineers Part I: Jour. of Systems and Control Eng. Vol.225 2011

[11] Muscroft R.J.M. Sims-Williams D.B. and Cardwell D.A. "The Development of a Passive Magnetic Levitation System for Wind Tunnel Models" SAE Transactions: journal of passenger cars: mechanical systems 115 (6) pp. 415-419 2006

[12] Gysen B. Paulides J. Janssen J. Lomonova E. "Active Electromagnetic Suspension System for Improved Vehicle Dynamics" IEEE Transactions on Vehicular Technology Vol. 59 Issue 3 pp. 1-6 2008

[13] Babak, E, Hamidreza, B, Mir, BK, Golnaraghi, F (2011) A hybrid electromagnetic shock absorber for active vehicle suspension systems. Vehicle System Dynamics 49: 311–332

[14] Kawamoto, Y, Suda, Y, Inoue, H, Kondo, T (2007) Modeling of electromagnetic damper for automobile suspension. Journal of System Design and Dynamics 1: 524–535.

[15] Montazeri-Gh, M, Soleymani, M, Hashemi, S (2013) Impact of traffic conditions on the active suspension energy regeneration in hybrid electric vehicles. IEEE Transactions on Industrial Electronics 60: 4546–4553.

Publications:

Certificates of Multicon – W 2018

THAKUR TRUSTS

Zagdu Singh Charitable Trust's (Regd.)

THAKUR COLLEGE OF ENGINEERING & TECHNOLOGY

(Approved by AICTE, Govt. of Maharashtra & Affiliated to University of Mumbai)

Thakur Village, Kandivali (E), Mumbai - 400101.

tcet Estd. 2001

ISO 9001 : 2015 Certified

NBA and NAAC Accredited

MULTICON-W 2018

9th National & International Conferences & Workshops

NCU 2018 Invention & Innovation

Certificate of Appreciation

CAEE 2018

This is to certify that ~~Dr.~~/Mr./~~Ms.~~ **VISHNU NAIR** has presented/published a **SHORT** length paper with the title **INERTIAL MEASURING SYSTEM** in the **Conference on Advances in Electronics Engineering (CAEE 2018)** organized during February, 23rd & 24th, 2018 at Thakur College of Engineering and Technology.

(Dr. Sandhya Save)	(Dr. Lochan Jolly)	(Dr. B. K. Mishra)
Convenor	Technical Chair	Principal & Programme Chair

Philanthropic Partners: Platinum — Theem College of Engineering, Boisar; Diamond — Anjuman-I-Islam's Kalsekar Technical Campus, New Panvel

Technocrat Partners

Other Partners: KILLER Style; FREE PRESS Print Media; CARNIVAL Cinema

Collaborators: IOSR Journals; i-manager Publications; IJSER; SAEINDIA

THAKUR TRUSTS

Zagdu Singh Charitable Trust's (Regd.)

THAKUR COLLEGE OF ENGINEERING & TECHNOLOGY

(Approved by AICTE, Govt. of Maharashtra & Affiliated to University of Mumbai)

Thakur Village, Kandivali (E), Mumbai - 400101.

Estd. 2001
ISO 9001 : 2015 Certified
NBA and NAAC Accredited

MULTICON-W 2018
9th National & International Conferences & Workshops

Certificate of Appreciation

CAEE 2018

This is to certify that ~~Dr.~~/Mr./~~Ms.~~ **SHIVAM SINGH** has presented/published a **SHORT** length paper with the title **INERTIAL MEASURING SYSTEM** in the **Conference on Advances in Electronics Engineering (CAEE 2018)** organized during February, 23rd & 24th, 2018 at Thakur College of Engineering and Technology.

(Dr. Sandhya Save) Convenor	(Dr. Lochan Jolly) Technical Chair	(Dr. B. K. Mishra) Principal & Programme Chair

Philanthropic Partners: Platinum – Theem College of Engineering, Boisar; Diamond – Anjuman-I-Islam's Kalsekar Technical Campus, New Panvel

Technocrat Partners

Other Partners: KILLER (Style), FREE PRESS (Print Media), CARNIVAL (Cinema)

Collaborators: IOSR Journals, i-manager Publications, IJSER, SAEINDIA

THAKUR TRUSTS

Zagdu Singh Charitable Trust's (Regd.)

THAKUR COLLEGE OF ENGINEERING & TECHNOLOGY

(Approved by AICTE, Govt. of Maharashtra & Affiliated to University of Mumbai)

Thakur Village, Kandivali (E), Mumbai - 400101.

tcet Estd. 2001

ISO 9001 : 2015 Certified

NBA and NAAC Accredited

MULTICON-W 2018 — 9th National & International Conferences & Workshops

Certificate of Appreciation

CAEE 2018

This is to certify that ~~Dr.~~/Mr./~~Ms.~~ **PRATIK WALAWALKAR** has presented/published a **SHORT** length paper with the title **INERTIAL MEASURING SYSTEM** in the **Conference on Advances in Electronics Engineering (CAEE 2018)** organized during February, 23rd & 24th, 2018 at Thakur College of Engineering and Technology.

(Dr. Sandhya Save)
Convenor

(Dr. Lochan Jolly)
Technical Chair

(Dr. B. K. Mishra)
Principal & Programme Chair

Philanthropic Partners — Platinum: Theem College of Engineering, Boisar; Diamond: Anjuman-I-Islam's Kalsekar Technical Campus, New Panvel

Technocrat Partners

Other Partners — KILLER (Style), FREE PRESS (Print Media), CARNIVAL (Cinema)

Collaborators — IOSR Journals, i-manager Publications, IJSER, SAEINDIA