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NUST COLLEGE OF
ELECTRICAL AND MECHANICAL ENGINEERING

INERTIAL NAVIGATION SYSTEM

A PROJECT REPORT

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Submitted by

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DECLARATION

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First of all, Alhamdulillah, that our FYP is finally made, and all Thanks to Allah for giving us the strength and morale to keep pushing forward and helping us every step of the way.

Secondly, we would like to offer hearty thanks to our supervisors, Dr. Ali Hassan, and Ms. Anum Abdul Salam, who helped us a lot, tremendously, on every single issue, whose help ad guidance became a source of strong determination for us. Thank You, sir & ma'am you played a great role in our lives, one that we can never forget.

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ABSTRACT

Inertial Navigation Systems (INS) are navigation systems that can calculate location either relative to a reference system/point or in absolute coordinates. An INS system is made up of at least three gyros and three accelerometers. This navigation solution includes at the very least the position (normally latitude, longitude). The primary idea behind an INS system is to monitor changes in relative motion (through acceleration measurement) to project a changing position in some inertial reference frame over time. INS systems are self-contained and do not rely on external assistance or visibility They can be used in tunnels or underwater, including in stealth operations, since there's no exposed tower that could be detected by radar. They're ideal for the host vehicle's integrated navigation, guiding, and control. This required relying on data readings from within the object rather than satellites or external sources, which was accomplished by incorporating sensors such as the magnetometer and MPU into the device. Sensor fusion was used to achieve the desired effect. The controller's serial monitor was used to monitor the sensor's reading. The project was created for 2d space (cars), but it can also be used in 3d space (missiles). The product is simple to operate. This product may be used by a potential customer to acquire autonomous capability for their subject.

Table of Contents

Table of Figures

Chapter 1: Introduction

1.1 Introduction

Inertial navigation is independent navigation technique in which measurements taken from accelerometers and gyroscopes are used to find the position and direction of a body relative to a known starting point and orientation. Inertial measurement units usually comprise three gyroscopes and three accelerometers, measuring angular velocity and linear acceleration from gyro and accelerometer respectively. By handling signals from these devices, it is possible to find the position and orientation of a body.

Inertial navigation is utilised in a variety of applications, including aircraft, missiles, spaceships, submarines, airplanes, and ships navigation. It is also utilised in some cell devices for tracing and location purposes. Small and light inertial navigation systems are now possible because to recent advancements in micro electromechanical system construction. These advancements have increased the number of conceivable applications, including human motion capture. [1].

A computer plus a platform or module housing accelerometers, gyroscopes, or other motion-sensing sensors makes up an inertial navigation system. The INS gets its position and velocity from another source initially, such as a human operator or a GPS satellite receiver. It is given the starting orientation, and then it calculates its own updated location and velocity using input from the IMU. The advantage of an INS is that once it has been initialised, it does not require any external reference points to identify its position and orientation.

A change in its position, such as moving north or south, a shift in its speed and direction of movement, and a shift in its orientation can all be detected by an INS. It accomplishes this by calculating the system's linear acceleration and angular velocity. It is also immune to blocking and deceit because it does not require an external reference after setup.

Many moving devices use inertial navigation systems. However, the scenarios in which they are useful are limited because to their high cost and complexity.

The angular velocity of the sensor frame in relation to its inertial reference frame is determined by gyroscopes. Using the system's original orientation in the inertial reference frame as the beginning condition and integrating the angular velocity, the system's current orientation is always known. This is like a blindfolded car passenger feeling the car turn left and right or tilt up and down as it climbs or descends hills. The passenger can tell which way the automobile is going based on this information alone, but not how quickly or slow it is driving or whether it is sliding sideways.

Accelerometers measure linear acceleration in a mobile vehicle's sensor or body frame, but only in directions that can be measured in respect to the moving system, because the accelerometers are anchored to the system and rotate with it, but they have no awareness of their own orientation. This is like a blindfolded passenger in a car feeling pressed back into their seat as the vehicle accelerates forward or pulled forward as it slows down; and feeling pressed down into their seat as the vehicle accelerates up a hill or rising up out of their seat as the car passes over the crest of a hill and begins to descend. They can tell whether the vehicle is accelerating forward, backward, left, right, up toward the car's ceiling, or down toward the car's floor relative to itself based on this information alone; that is, whether it is accelerating forward, backward, left, right, up toward the car's ceiling, or down toward the car's floor, measured relative to the car, but not relative to the Earth, because they didn't know which way the car was facing when the felt the acceleration.

It is possible to determine the linear acceleration of the system in the inertial reference frame by tracking both the current angular velocity of the system and the current linear acceleration of the system measured relative to the moving system. The system's inertial velocities are calculated by integrating the inertial accelerations with the original velocity as the initial condition, and the inertial position is calculated by integrating the inertial velocities again with the original position as the beginning condition. In our example, if the blindfolded passenger knew where the car was pointed and how fast it was going before being blindfolded, and if they can keep track of both how the car has turned and how it has accelerated and decelerated since then, they can precisely know the car's current position, orientation, and velocity at any given time. [2].

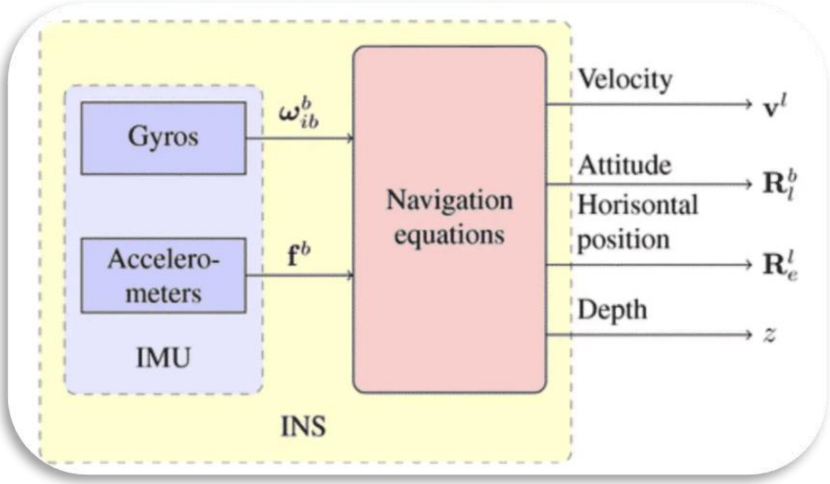


Figure 1 INS Illustrated

1.2 Motivation

The major purpose of autonomous device designers is to construct instruments for fulfilling activities such as exploring undiscovered territory or performing tasks in harmful radiation zones. Unmanned flying objects include military drones, mobile robots, spaceships, exoskeletons, and intelligent clothing that detects body signals. These are just a few of the many useful technologies now in development.

One of the biggest challenges that occur during the production of autonomous mobile objects is the difficulty of exact navigation. To navigate an object, it is important to know its exact location and orientation in relation to its known surroundings. Developing a sensor system that is capable of both environment perception and monitoring inner object parameters is a major challenge in unmanned mobile objects. Because control algorithms rely on readily available sensor data, adaptability and dependability are important considerations.

There has been a lot of research recently in inertial object orientation measurement. IMUs (inertial measuring units) are electrical devices that detect the current orientation of an item. [3]. Typically, they monitor changes in the rotation and acceleration of an item. They must meet a set of standards as measurement devices, such as the smallest possible size and weight, as well as customizable filtered output data. The sensor should be able to function in severe temperatures and pressures. The most important requirement is to deliver high-quality data as quickly as feasible. There is also a need for mobile devices to use as little electricity as possible.

To meet these standards, current inertial measurement units make use of the most recent technological advancements. At least two different types of sub sensors are commonly used in such sensors. An accelerometer is a device that measures linear acceleration. The second component is a gyroscope, which measures angular acceleration. In addition, numerous types of sensors are installed inside the IMU. Reference magnetometers, which are used to detect north direction, are one of the most used supplementary sensors. Temperature sensors are utilised in temperature compensation algorithms, and altimeters are employed in UAVs.

Linear accelerometers determine the direction of movement by measuring the linear acceleration of an item. There are normally three measuring axes X, Y, and Z used to quantify movement, independent of the type of autonomous equipment (fig. 1). A linear accelerometer is present for each axis. Modern sensors allow a single chip to measure data along all three axes. Accelerometers are utilised in a variety of applications, including collision detection, object orientation measurement, and user interface. Linear acceleration can be measured in a variety of ways. As a result, sensors employing capacity, piezoelectric, piezo resistant, magneto responsive, Hall effect, and microelectromechanical systems have been developed.

Gyroscopes are sensors that measure acceleration as well as rotation. [5]. However, the acceleration is angular rather than linear. There are three measurement axes as well. Yaw, pitch, and roll are the conventional names for them. Figure 1 depicts the axes coordinate system. The law of conservation of momentum governs gyroscopes. In order to function, they must maintain a fast rotation speed on the one hand and low bearing friction on the other. Mechanical, optical, and MEMS gyroscopes are the three basic types. Because mechanical and optical sensors are substantially larger than MEMS, the latter is typically used in practical applications.

MEMS technology is now used in the majority of produced inertial measurement units. Despite their ease of use, the main advantage of such gadgets is their compact size. Silicon, glass, and polymer materials are used to make electro micromechanical chips. Microelectronic technologies such as photolithography are used to create processor masks. The circuits of MEMS sensors are split into two sections. The mechanical component is in charge of monitoring angular and linear velocity. Signals from the mechanical part are converted by the electrical part using an analog-digital converter. Electrostatic phenomena predominate over mass insertion due to the comparatively large surface to volume ratio. [4].

Micromechanical systems are frequently utilised in the navigation of mobile platforms and vehicles, as well as in the autopilots of aerial ships, boats, and ground vehicles. Another application is to help stabilise opto-electrical gimbals. IMUs are also utilised in PCs for HDD security during a fall, and for seatbelts locking during a detected collision. It's also utilised in photo cameras to reduce the impact of vibration. Modern toys for children also utilise inertial measurement units.

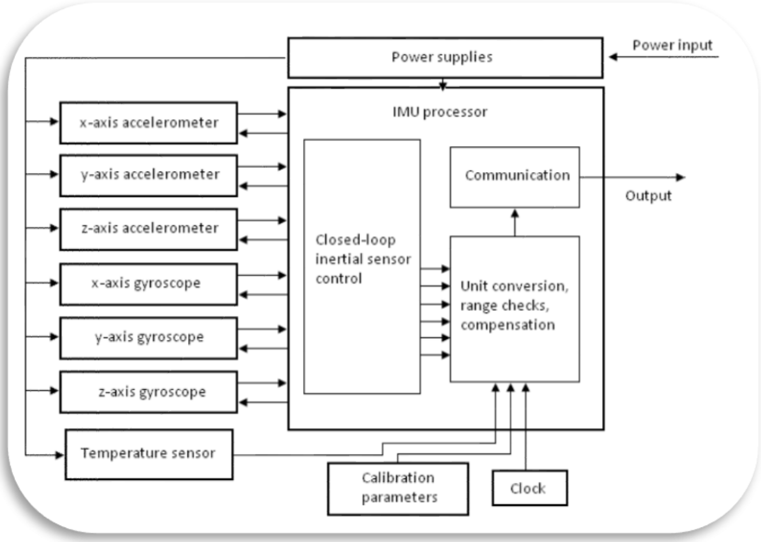


Figure 2 Inertial Measurement Unit Operation Schema

1.3 Scope

We wish to design a system that is navigating from within the vehicle and is only dependent on the current and previous location information of the vehicle, and partially dependent on GPS. The IMU fitted inside the car will give us the acceleration from which we will calculate the position of body through dead reckoning. The car will be able to move from one way point to the other autonomously. The way points will be provided from the app or the distance can be given to the car and the car will travel the distance through inertial navigation.

The scope of the project can be defined in terms of the following objectives:

- To design an application that is capable of constantly updating current location after taking the information of new location and rotation of the object and feed it to a controller.
- To design a system that will provide position and angle updates at a quicker rate than the GPS
- To design a system that locates the object without the need of any external source

1.4 Structure

Following is the structure of the report ahead:

- Chapter 2, it mainly deals with the explanation of basics of navigation and gives us a comparison between GPS and INS
- Chapter 3, it tells us about the products already present in the field and a literature review.
- Chapter 4, it deals with the design and development of the INS device, the details of the modules used in the projects.
- Chapter 5, it deals with tests undertaken to establish the working effectiveness of the device
- Chapter 6, it consists of concluding the report and exploring future possibilities and directions in which the project can be taken

Chapter 2: What is Navigation & INS

2.1 Navigation

Navigation is a method of determining the position and direction of any object or platform. Navigation has been a part of traveling for humans for a long time, whether it be celestial observation, simple pathfinding using directions, or using a GPS. If we have to go from one point to the other, we have to use the navigation in some sort of way and the easier the method of navigation is the easier it is to navigate between two points.

2.2 Types of Navigation

To select the best way to navigate we have to rule out errors caused by each type of navigation. In most cases, the biggest error that is introduced in any type of navigation is human error. So, to select the best way of navigation we have to eliminate the methods in which human error is minimum. So that means we have to rely upon sensors and machines to figure out the measurements and then use some complex algorithms to find the position and orientation to navigate.

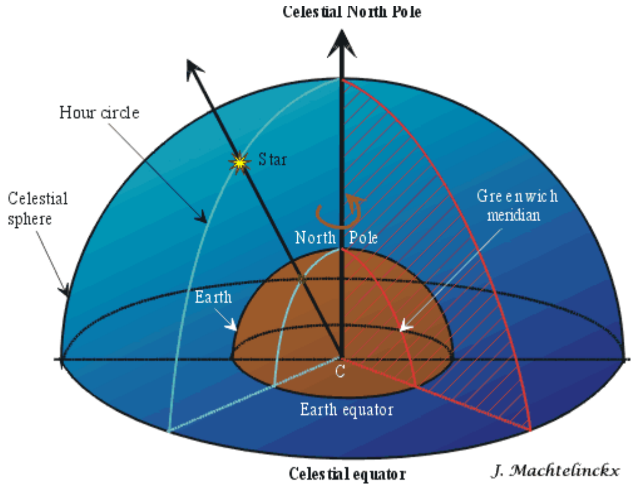


Figure 3 Celestial Navigation

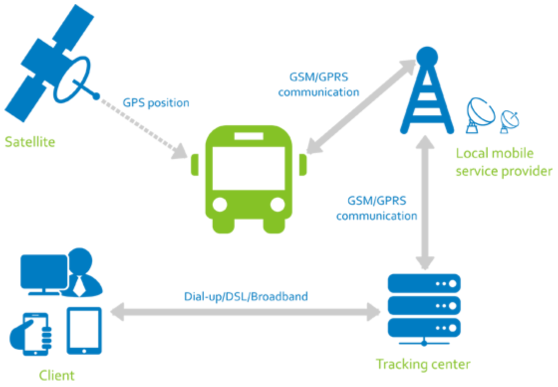


Figure 4 GPS Navigation

2.3 GPS Errors

One of the most common methods used today is GPS which in itself is a great method to use to navigate but it introduces a lot of errors, even though the human error in it is almost down to zero, it still has errors.

For example, The rate at which it updates the location is slow, it mostly relies on Wi-Fi or places with good signals from the satellites to give accurate position and direction. So, if we don’t have both of them (Wi-Fi and a good satellite signal) we won’t be able to navigate. And if we have either one then the accuracy of navigation will drop.

The layers in the atmosphere affect the time in which the GPS signal traveled from the satellite to us, this delay ends up diluting the distances readings of the GPS to a lot of feet. There are some satellites that have a correction mechanism that can detect this interference and correct the data using their measurements but the cost a lot and cannot be used for every satellite. The Sun also interferes with the GPS signal. This affects the correction mechanism placed in the satellites to solve the delaying effect so even if this mechanism was installed in all the satellites this would still be inefficient and probably cost more.

When the GPS starts or stops to gather points after the receiver is turned on or off it gathers some random points. These points have noise and are not correct because the receiver needs some time to start gathering correct points after it turned on or off and these points are not corrected and may end up adding the errors in the readings

Another error faced by the GPS is path estimation error, when the GPS calculates which path to take and which not to take it maps out several other paths with similar or a bit higher time of approach. These estimations are in error because in some heavy populated areas with a lot of buildings and architecture or with a lot of trees, predicting the path becomes hard because now it is not clear what the past is it is obstructed by tall buildings or by trees so this path estimation in these areas will be wrong.

The following are the principal sources of GPS positional error:

- Calculation of atmospheric interference and rounding mistakes
- Data errors in the ephemeris (orbital route).
- Effects using several paths

Figure 6 GPS Errors to Distance

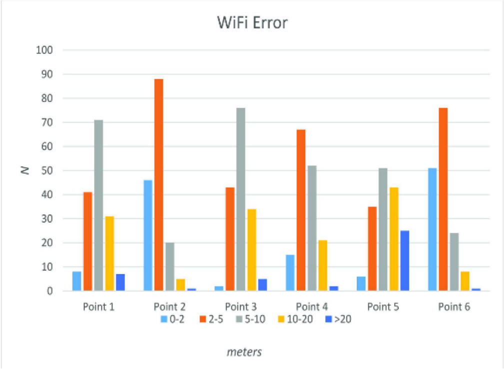


Figure 5 Wi-Fi Errors to Distance

2.4 Minimizing Errors

To Cater to this problem, we have other methods that use the environment to navigate and estimate the location, others use lidar technology to know where to turn and where to stop so that they don't have to wait to get good signals to start to navigate. There also, another method of navigating that solves the problems faced by the GPS.

2.5 Inertial Navigation System (INS)

To Cater to this problem, we have other methods that use the environment to navigate and estimate the location, others use lidar technology to know where to turn and where to stop so that they don't have to wait to get good signals to start to navigate. There also, another method of navigating that solves the problems faced by the GPS.

It is a method that uses inertial values of the object/platform and estimates the location and position of the object/platform. It has a high sample rate and gives location estimation at a faster speed. It does not need GPS or Wi-Fi to function properly and can be used in any area where there are little to no satellite signals. It is mostly used in a high-speed platform such as drones and missiles to navigate their way with almost zero error percentage. So, using this method can be a better option than using a GPS. Because it is dependent on the speed, orientation, and elevation of the object/platform it is connected to.

Inertial Navigation System is one of the most important methods used for positioning of vehicles. This navigation is based on basic physics laws of motion (Newtons laws). Linear and angular acceleration is measured by sensors such as accelerometers and gyroscopes. These measurements are the integrated and distance and angles are collected from these measurements. Both the accelerometer and gyroscope have a total of 6 degrees of freedom 3 for each, this helps in a more open and easy movement for the vehicles. Then filters and algorithms are used to correctly pinpoint the location of the vehicles and help in navigation the path for the vehicles. This has become a necessary thing for most of the vehicles on 2D (land) or in 3D (in space) areas. Most of the vehicles use INS or INS integrated with GPS.

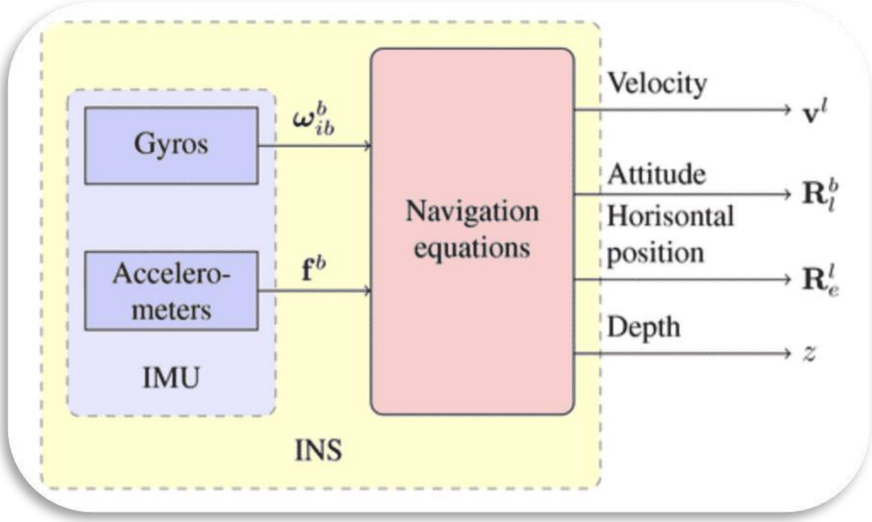


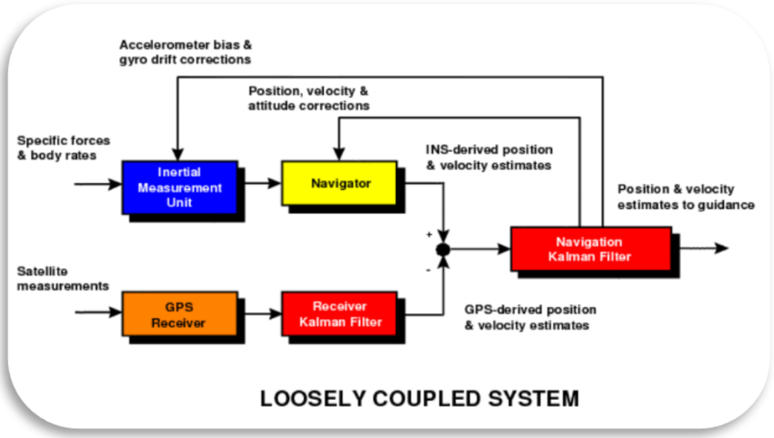
Figure 7 INS

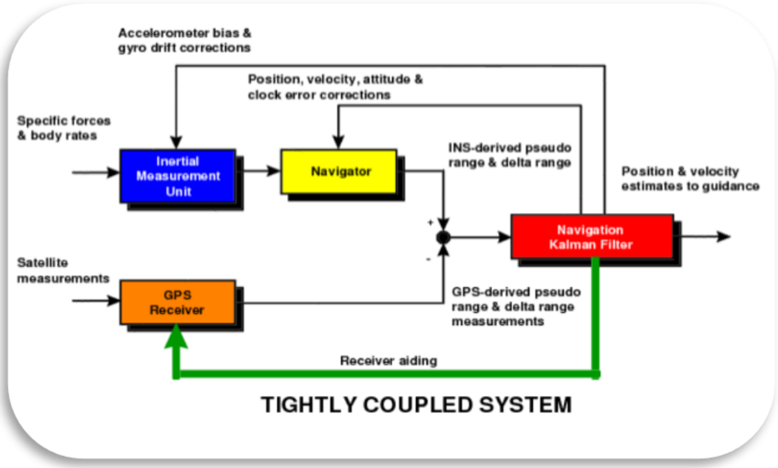
Inertial navigation is also a type of navigation in which environment elements are used but it more relied on the inertial values i.e., acceleration, rotation, and orientation of the body/platform. From a navigation point of view, it is a very safe and valid way of navigation as it has almost zero chances of error and is really for autonomous vehicles. INS technology is ideal for complicated operations on land, sea, air, and space since it is immune to jamming and spoofing. Powerful IMUs and precise data are packaged into a lightweight device in the newest improvements in inertial navigation systems. IMUs, on the other hand, continue to confront problems, such as increasing calculation errors with each subsequent positional computation. As a result, inertial navigation systems perform best when used in conjunction with other guidance systems. From time to time, such as with GPS, correct the calculated car position.

Although inertial navigation systems have been around since the 1940s, advancement, curiosity, and an ever-increasing desire for precision have all contributed to the development of a new generation of cutting-edge navigation. The ability of your aircraft to navigate successfully should not be jeopardized by GPS denial. To learn more about how ASEI employs GPS and INS to create navigational solutions for every project, contact us today

2.6 INS vs GPS

It is self-contained and does not reliant on external assistance or visibility. It can be used in tunnels, underwater, and anywhere else. It's built for integrated navigation, guidance, and control of the host vehicle from the start. The derivatives of the variables to be controlled are measured by their IMU (e.g., position, velocity, and attitude). It is inherently stealthy and resilient to jamming. It doesn't have any receivers or produces any detectable radiation, and it doesn't need an external antenna that could be detected by radar





The fact that INS can aid with flight without the need for GPS technology makes it a realistic navigational solution. To configure the vehicle's initial position, velocity, and orientation, global positioning systems or an operator are required. However, without the use of the global navigation satellite system, INS systems can give exact navigation.

Inertial navigation systems calculate location, velocity, and other aspects of movement using accelerometer sensors and gyroscopes. As the plane continues on its journey, the INS device will constantly compute and update all of the motion elements based on data from motion sensors.

The Global Positioning System (GPS) is a satellite-based navigation system with a ground control component. For all modes of transportation, these systems provide precise data on geographical location, time, velocity, and other information. However, to provide correct navigation, they require a constant connection to the satellite system. After initialization, inertial navigation systems are entirely autonomous, which means they do not require GPS and are immune to radar jamming because they are self-contained.

2.7 INS + GPS

GPS is a 24/7, all conditions and all the time working position system, it is available for use every time and is ready to go. INS is using motion of the object and some computation to find and estimate the position of the object. When both of these systems i.e., GPS+INS, are integrated together they can counter the limitation of each other and give a better and more sound estimation of position and navigation. There are a bunch of systems in the market today that use low cost and efficient GPS and INS modules and give a low costing GPS/INS system that can be applied to a variety of vehicles and navigate them perfectly and with minimum amount of errors. In fact, a lot of them are becoming very prominent and gaining a big reputation in the market.

Although GPS and INS have their own advantages and disadvantages, they both cater to flaws of each other to some extent. GPS can give a better map and path for the object/platform to travel but it lacks the high sample rate and quick update of the location. These two issues are solved by an INS which can give a better estimate of distance travel and a faster location update which is required, Plus an INS can work where a GPS cannot work and a GPS can work where an INS cannot work. This makes the GPS+INS navigation the best solution for navigation. In fact, this system is used a lot in a lot of military vehicles to solve the GPS spoofing problem and GPS jamming problems.

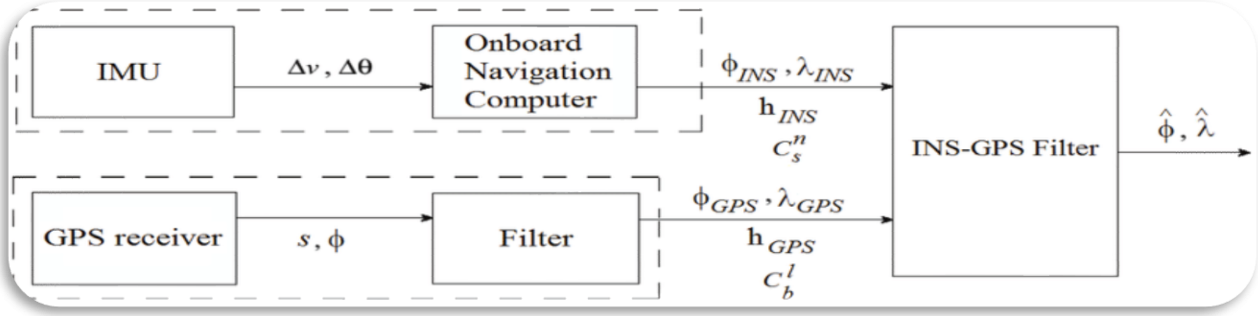


Figure 8 INS + GPS

The use of a modular Kalman filter approach to GPS/INS integration is given. There are two Kalman filters in use. [14]. One is a local filter, which processes GPS data and provides the most reliable position and velocity calculations in the vicinity. It's also an infrared filter that compares the GPS sensor's findings to the inertial correlation and regression. Due to the obvious inertial system's outstanding short-term accuracy, the position data from INS can be employed for cycle gap identification and resolution. The flexibility of combining GPS and INS, as well as the ease of implementation, are two main advantages of this technology. The decentralized filter achieves the same global optimal estimation accuracy as the centralized Kalman filter when compared to centralized filtering. When a suboptimal cascaded filter is utilized, the accuracy does not suffer, which has certain advantages in terms of processing efficiency.

Because of its complementing properties, the GPS/INS system has been used a lot for navigation in vehicles these days. [15]. By employing raw GPS measurements, the tightly linked integration strategy provides an advantage over only using INS or only using GPS, but it introduces nonlinearity into the Kalman filter's measurement equation. As a result, the most common method for navigation using range or pseudo-range measurements is to linearize the measurements of an extended Kalman filter (EKF). [13]. But the mistakes in EKF modeling will produce bias and divergence issues, especially if cheap inertial devices are used. To retain some nonlinearities. The simulations result show that the nonlinear terms included in the filtering process have a significant impact on integration performance, particularly when a low-quality INS is used in the integrated system. In addition, a two-stage cascaded estimating method is employed, which avoids the difficulties of calculating nonlinear equations and decreases the computational cost of the suggested methodology greatly, making the quadratic EKF strategy proposed in this study particularly effective in practice.

2.8 Filters:

Filters in any computation are used to filter out the raw and irregular changes in the data acquired. Filters help us average out the readings and give a more correct picture of our estimation or of the result. Using them can help increase the accuracy of the readings. Every type of computation has different filters when we want to go in depth with the accuracy of the results. These filters are of different types and help us determine different parts of computational accuracy.

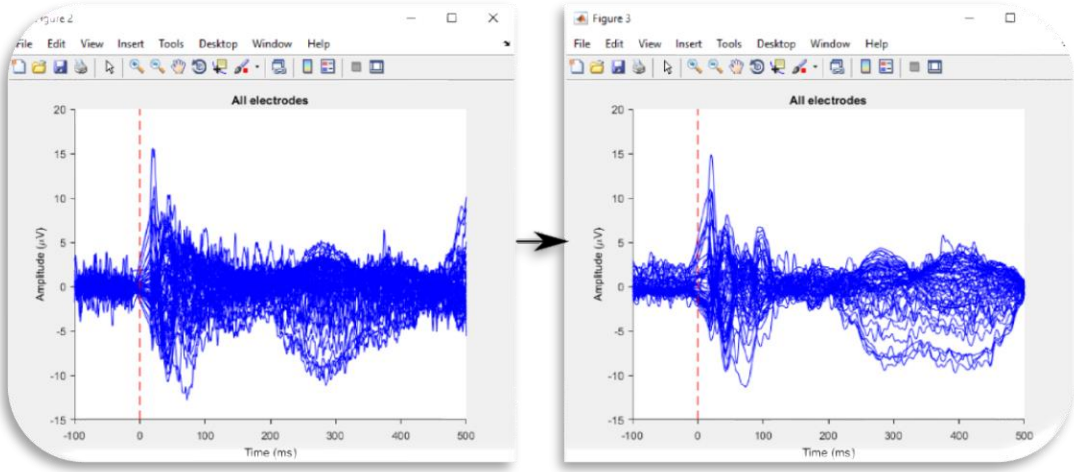


Figure 9 Reading Before & After the Use of filter

Chapter 3: Related Products

3.1 Related Products

The proposed product consists of an IMU and an microcontroller. The IMU is used to gather relevant data of a moving object. This data is passed to the microcontroller which uses a state-of-the-art algorithm based on a filter to apply sensor fusion and compile the data and determine the current location of the object.

Many other products are available which serve the same purpose. Some of them are as follows:

- Attitude Heading Reference System (AHRS)
- uINS RTK Compatible Sensor Module
- Ellipse 2 Micro MPU
- Ellipse A

3.1.1 Attitude Heading Reference System (AHRS)

The AHRS is a small Attitude Heading Reference System (AHRS) [16] with magnetometer, barometric pressure sensor, and L1 GPS (GNSS) receiver that is precision calibrated. Angular rates, linear acceleration, magnetic field, barometric altitude, and GPS WGS84 geo-position are all measured by the AHRS. The Euler and quaternion attitude states are estimated via sensor fusion of IMU and magnetic field output. All devices come with comprehensive sensor calibration for bias, scale factor, and cross-axis alignment.

Figure 10 AHRS

3.1.2 uINS RTK Compatible Sensor – Module

Attitude/orientation, velocity, and position are all provided by a miniature calibrated GPS-aided Inertial Navigation System (GPS-INS). Position Accuracy in Real Time Kinematics (RTK).

The uINS is a high-precision GPS-aided Inertial Navigation System (GPS-INS) that combines MEMs gyro, accelerometer, magnetometer, barometric pressure, and GPS (GNSS) sensors to give optimal attitude/orientation, velocity, and position prediction. Sensor calibration, which is standard on all units, reduces the negative impacts of manufacturing variance and improves sensor performance.

Figure 11 uINS Module

3.1.3 Ellipse 2 Micro IMU

The Ellipse 2 Micro IMU is a miniature inertial measurement unit (IMU). Three gyroscopes, three accelerometers, three magnetometers, and a temperature sensor are included. From -40 to 85°C, this IMU has been rigorously calibrated.

It has the following characteristics:

- Lightweight and compact
- Full Development Kit
- ROS Driver
- Cost-effective, suited for high-volume projects
- High-quality IMU calibrated in dynamics and temperature

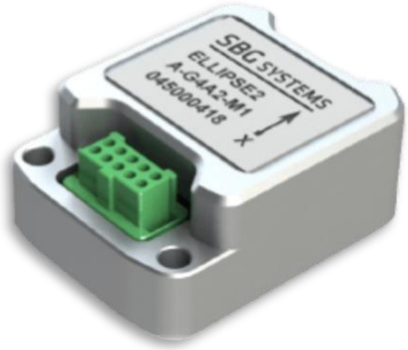


Figure 12 Ellipse 2 Micro MPU

3.1.4 Ellipse-A

A small inertial measuring device, the Ellipse 2 Micro IMU (IMU). A temperature sensor, three gyroscopes, three accelerometers, three magnetometers, and three gyroscopes are incorporated. This IMU has been thoroughly calibrated from -40 to 85°C.

The following are its characteristics:

- Cost-effective and appropriate for high-volume projects
- High-quality IMU calibrated in dynamics and temperature
- Full Development Kit
- ROS Driver

Figure 13 Ellipse-A

3.2 Literature Review:

Dead reckoning navigation is required due to the limitations of traditional position fixing systems, which require a direct line of sight between the platform to be navigated and the well-known fixed positions. To explain, GNSS navigation requires a direct line of sight between the GNSS receiver and at least four satellites in order to acquire the navigation states of the traversed platform. This is a rare occurrence in practice, especially when navigation takes place in urban or indoor environments. As a result, dead reckoning, particularly inertial navigation, is necessary in GNSS-denied environments to provide a navigation solution during periods when location fixing is not available. [6].

The linear and/or rotational speeds of motion, as well as the force exerted on a moving body, could be estimated using Newton's second law of motion. Inertial sensors appear as a result. The two most prevalent types of inertial sensors are accelerometers and gyroscopes. Gyroscopes and accelerometers both detect specific forces or accelerations, but accelerometers measure angular velocities.

The linear and rotational speeds of motion, as well as the force exerted on a moving body, could be estimated using Newton's second law of motion. Inertial sensors appear as a result. The two most prevalent types of inertial sensors are accelerometers and gyroscopes. Gyroscopes and accelerometers both detect specific forces or accelerations, but accelerometers measure angular velocities. When the inertial sensors assembly is arranged into specific geometric forms that ensure capturing the motion of any particular platform, it is referred to as an inertial measurement unit (IMU). IMUs, on the other hand, are frequently employed in conjunction with on-board data processing to convert raw measurements into useable particular forces or angular velocities.

To capture the three-dimensional motion of the platform to which it is attached, a typical IMU comprises of three accelerometers and three gyroscopes positioned along three mutually orthogonal axes. Inertial navigation, on the other hand, is carried out by analyzing the inertial data collected by IMUs. The inertial data is mathematically reduced into variations in location, velocity, and orientation for the moving platform. As a result, the navigation states might be accumulated over time to establish the platform's current position, velocity, and orientation.

As a result, an inertial navigation system is a system that determines the navigation states of any moving platform to which it is attached using IMU measurements.

An inertial navigation system is a navigation system that incorporates an IMU and a method of integrating inertial measurements into a comprehensive navigation solution. Inertial sensors are susceptible to errors, which can be systematic or sporadic. To eliminate systematic mistakes, mathematical models and calibrations might be used.

Systematic errors in inertial sensors include scale factor biases, scale factor nonlinearity, and cross-coupling of sensitive axes measurements. A persistent disparity between the recorded quantity and the sensor's real input is known as bias in an inertial sensor. On the other side, a scale factor is an error that represents the difference between the amount of data input to an inertial sensor and the amount of data reported by the sensor. An inertial sensor should, in most situations, generate an output value that is equal to the input value applied to the sensor. Resulting one has to be the expected input–output ratio. In the input–output connection of an inertial sensor, a scaling factor, on the other hand, would show as a deviation from one. Another sort of systematic error is scale-factor non-linearity. The input–output relationship of a sensor is usually assumed to be linear. However, the inertial sensor's input–output link may not be linear due to environmental conditions and particular sensor designs, which is a systematic error that must be handled.

When inertial sensors are poorly installed within a geometric assembly of an IMU, cross-coupling error occurs. Cross-coupling is caused by the non-orthogonality of the sensitive axis of inertial sensors. [7]. Resulting, residual inertial readings from an axis that is supposed to be orthogonal to the sensitive axis are measured by inertial sensors, which are either accelerometers or gyroscopes. It appears that inertial sensors are susceptible to random errors, which manifest as disruptions in the inertial measurement data obtained by sensors. Random mistakes can be attributed to electrical or mechanical sources, depending on the design and construction of the inertial sensors. Nevertheless, the inertial sensor's technology, design, and manufacturing practices dictate the magnitude and relevance of such random errors on the inertial navigation solution. As a result, an IMU's performance in terms of giving an accurate navigation solution is determined by the order of magnitude of systematic and random errors contained in its data. As a result, IMUs are assessed on their accuracy and performance.

The two types of INSs are stable platform INSs and strap down INSs. [8]. It's conceivable to make the case that this arrangement is chronological. The strap down INSs, on the other hand, have gradually replaced the stable platform INSs over the years. On the other hand, Stable platform INSs are still used in some navigation applications and are not completely phased out. Stable platform INSs are the most common name for mechanical INSs.

Commercialized inertial sensors, which are utilized to make strap down INSs, are based on a range of technologies However, the inertial navigation business is dominated by a few fundamental technologies. This section discusses the sensor core operation principles and predicted performance of the major state-of-the-art inertial navigation systems. This section covers the key technologies for angular rate sensors and accelerometers. An inertial sensor is made up of three key components that work together to generate a fully working sensor, regardless of the underlying technology. An inertial sensor has a motion transduction mechanism, a signal conditional mechanism, and a sensor read-out component. [9].

An IMU is made up of an angular rate sensor that estimates the platform's attitude by measuring the angular rates of any moving platform. The accuracy of angular rate sensors varies widely, which can be summarized holistically by bias of the angular rate sensors. Biases with different angular rate sensors range from less than 0.00010°/h to 1.0°/s class or worse. The working environment of most angular rate sensors is sensitive, which might have certain detrimental implications. [10].

The accelerometer is the second component of the IMU. Accelerometers are inertial sensors that detect the amount of an accelerating force, also known as the specific force, as described in Sect. 0. In comparison to angular rate sensors, the inertial sensor engineering is more developed in terms of accelerometers. Nonetheless, modern accelerometers comprise a wide range of sensors that operate on diverse principles and technologies. Mechanical sensors that utilize the classical pendulum concept, as well as current solid-state sensors, are examples of state-of-the-art accelerometers. [10]. As a result, accelerometers are available in a wide variety of accuracies.

Chapter 4: Implementation

4.1 The Moveable Platform

The purpose of the moveable platform was to move from one point to another. So that we can record the sensors reading & perform operations according to our needs. It can move in forward, backward, right, or left according to the path provided (remotely). The platform was remote-controlled by the Bluetooth sensor. To move the platform, we used the motors for which the Motor Driver Shield was used. And to provide the interface among them the Arduino Mega was used.

Tools Used

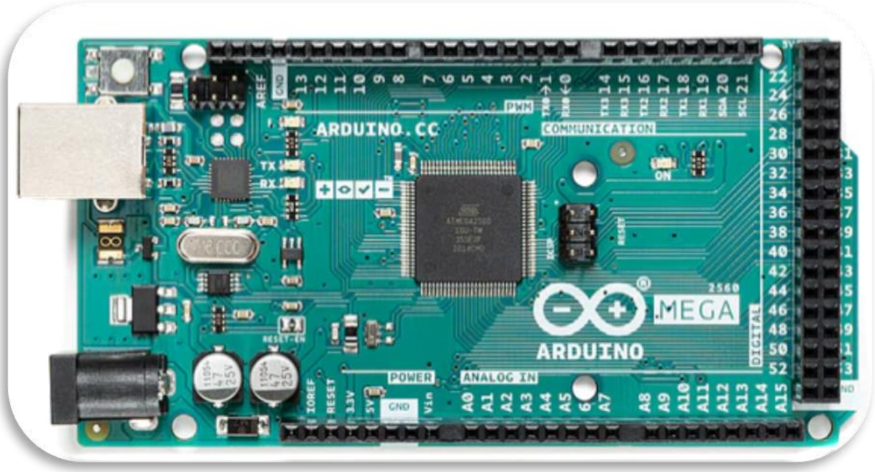
Following are the tools mainly used to build the project. These tools are divided into:

- Hardware
- Software

4.1.1 Hardware

Arduino Mega

The ATmega2560 is the basis for the Arduino Mega 2560 microcontroller board. It contains 54 digital input/output pins, 16 analogue inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It comes with everything you'll need to get started with the microcontroller; simply plug it into a computer with a USB cable or power it with an AC-to-DC adapter or battery. Most shields created for the Uno and previous boards Duemilanove or Diecimila are compatible with the Mega 2560 board.



Motor Diver

The L298N is a 15-lead Milliwatt and PowerSO20 packaging with an integrated monolithic circuit. It's a high-voltage, high-current dual full-bridge driver that can drive inductive loads like relays, solenoids, DC motors, and stepping motors. The device can be enabled or disabled using two enable inputs that are independent of the in-put signals. Each bridge's bottom transistors' emitters are coupled together, and an external sensing resistor can be connected to the matching external terminal. To allow the logic to operate at a lower voltage, an additional Supply input is provided.

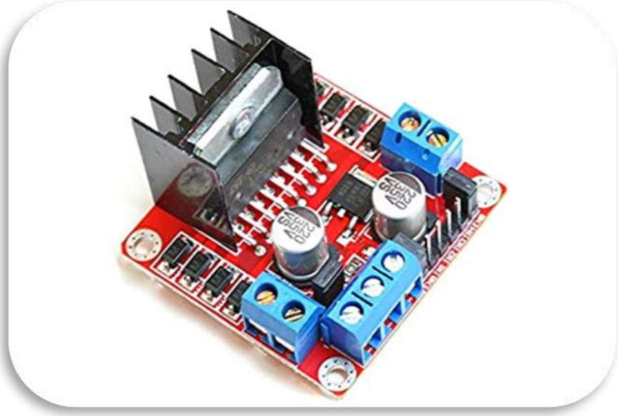


Figure 14 L298 Motor Driver Shield

Bluetooth module (HC05)

It's utilized in a variety of consumer products, including wireless headsets, game controllers, wireless mice, wireless keyboards, and more.

It has a range of up to 100 meters, depending on the transmitter and receiver, as well as the atmosphere, geography, and urban conditions.

IEEE 802.15.1 is a standardized protocol for creating wireless Personal Area Networks (PAN). It sends data over the air using frequency-hopping spread spectrum (FHSS) radio technology.

It communicates with devices using serial communication. It uses a serial port to connect with the microcontroller (USART).

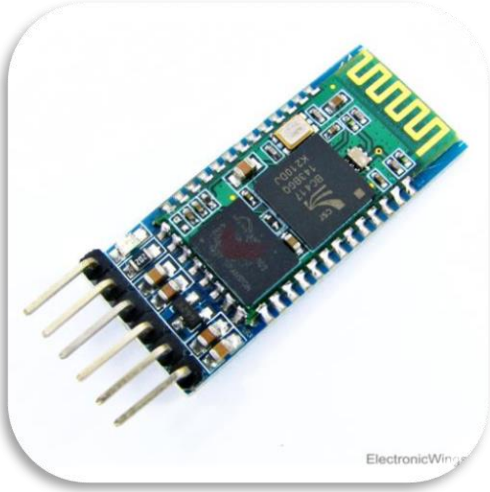


Figure 15 HC-05

GPS Module (Neo 6m)

A u-blox NEO-6M GPS chip is at the heart of the module. The chip is about the size of a postage stamp, yet it packs a lot of functionality into its little frame.

It can monitor up to 22 satellites on 50 channels and reaches the highest level of sensitivity in the industry, -161 dB tracking, while drawing only 45 milliamps from the power source.

The chip's Power Save Mode is one of its best features (PSM). By selectively switching parts of the receiver ON and OFF, it provides for a reduction in system power usage. This decreases the module's power consumption to just 11mA, making it appropriate for power-constrained applications such as GPS wristwatches.

Figure 16 Neo 6m GPS

MPU6050

This compact electronic module combines a high-precision 3-axis gyroscope and a 3-axis accelerometer to form an inertial measurement unit that calculates your robots' acceleration and angular rate. [11].

The DMP (Digital Motion Processor) built on the same silicon die is without a doubt the MPU-6050 module's greatest advantage, as it enables 9-axis Motion Fusion algorithms while resolving any alignment difficulties and mistakes produced by small components. It's also capable of detecting sensors and movement.

The MPU-6050 SparkFun 3-Axis Gyro & Accelerometer module has pins spaced 2.54 mm apart for convenient connection not just to your Arduino or Raspberry Pi board, but also to other add-ons. [11].

The auxiliary master I2C bus is used to connect your 3-axis gyro to a magnetometer or any of a variety of other sensors for supplementing your navigation data (altitude and moisture measurements, presence sensors, etc.) and boosting the proprioception of your robotics product or drone.

MPU-6050 3-Axis Gyro & Accelerometer Module Technical Specifications

2.3–3.4 V (supply voltage)

3.9 mA maximum consumption

Accelerometer:

Ranges of measurement: 2 g, 4 g, 8 g, 16 g

Tolerance for calibration: 3%

Gyroscope:

Ranges of measurement: 250/500/1000/2000 °/sar

Tolerance for calibration: 3%

Interface I2C

Temperature sensor built-in

CLK, FSYNC, and AD0 have selectable jumpers.

Temperature range: -40 °C to +85 °C

25.5 x 15.2 x 2.48 mm Dimensions

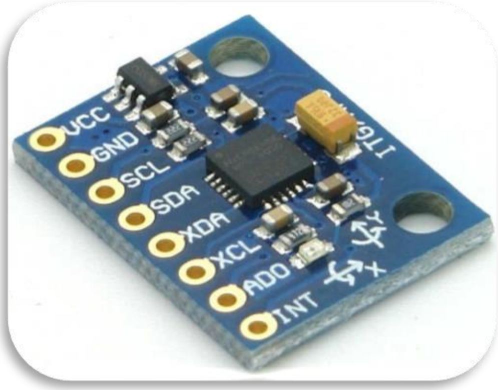


Figure 17 MPU6050

4.1.2 Software Tools

Arduino IDE

We used Arduino IDE to code our program which basically included code to run the car and to calibrate the readings taken from the MPU6050 and then calculate distance from them.

```
  modified 2 Sep 2016
  by Arturo Guadalupi
  modified 8 Sep 2016
  by Colby Newman

  This example code is in the public

  http://www.arduino.cc/en/Tutorial/B
*/

// the setup function runs once when
void setup() {
  // initialize digital pin LED_BUILT
  pinMode(LED_BUILTIN, OUTPUT);
}

// the loop function runs over and ov
void loop() {
  digitalWrite(LED_BUILTIN, HIGH);
```

AN OPEN PROJECT WRITTEN, DEBUGGED, AND SUPPORTED BY ARDUINO.CC AND THE ARDUINO COMMUNITY WORLDWIDE

LEARN MORE ABOUT THE CONTRIBUTORS OF ARDUINO.CC on arduino.cc/credits

Figure 18 Arduino IDE

Remote Controller App

The mobile apps were used to control the movement of the platform & to access the functionality or perform function calls.

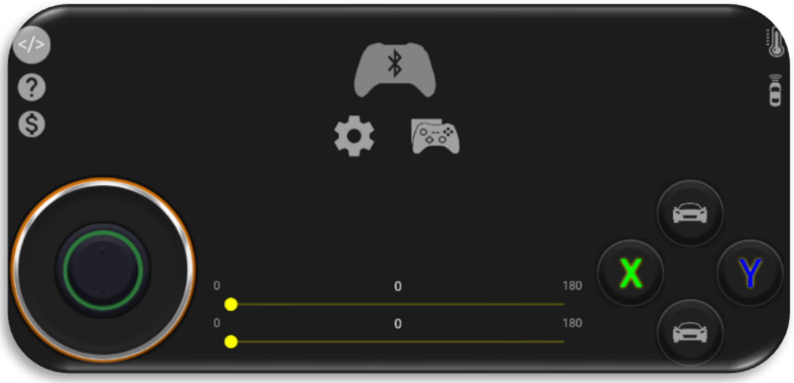


Figure 19 Controller App (1)

Figure 20 Controller App(2)

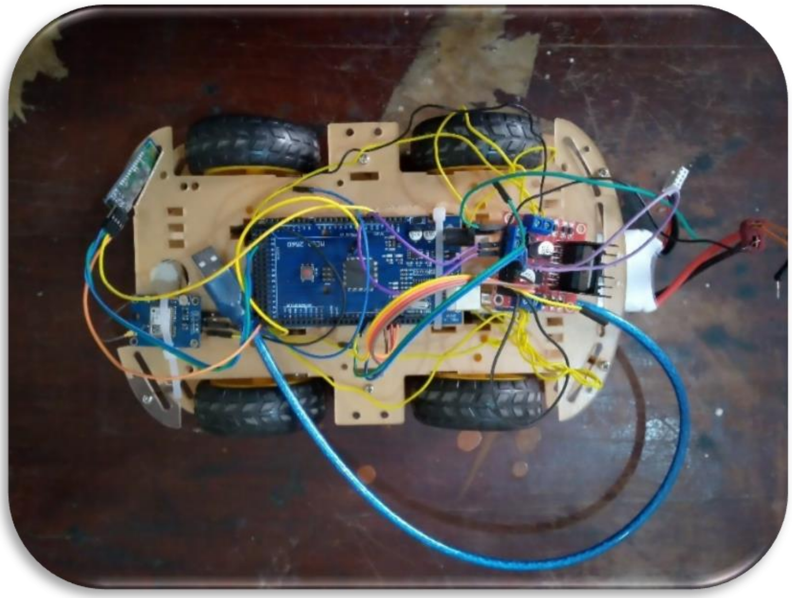


Figure 21 Moveable Platform

4.2 Sensors Integration with Platform

We combined the sensors with the mobile platform to obtain sensor data. It was both the most difficult and the most crucial step. Because the circuit must be completed, the connections must be made according to the design. On the platform/Arduino, the following sensors were implemented.

- Bluetooth Sensor (HC – 05)
- Magnetometer (HMC – 5883L)
- Neo-6m GPS
- MPU – 6050

4.2.1 Bluetooth Sensor

The only purpose to use the Bluetooth Sensor was to control the movement of the platform remotely and to send testing commands to the main controller (Arduino Mega).

The following testing commands were performed using Bluetooth Terminal App:

- Serial Communication
- Function calls
- To test transmitter & receiver

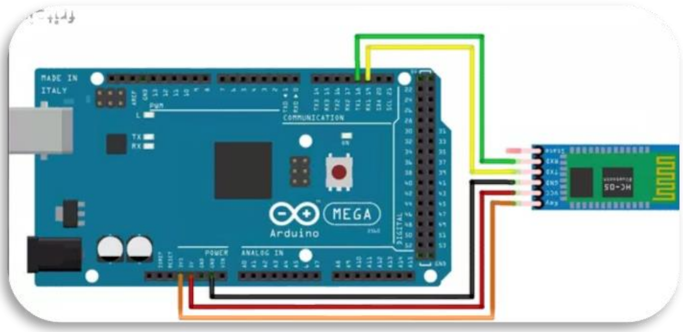
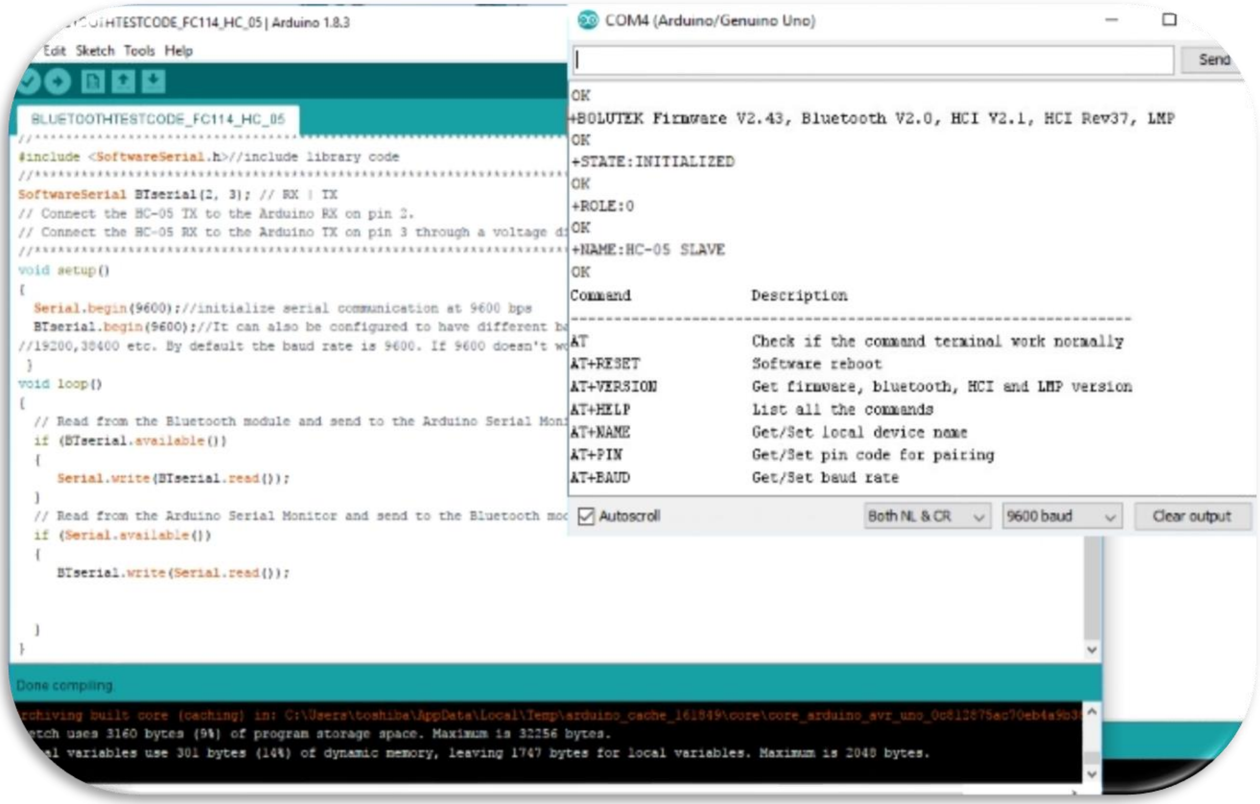


Figure 22 Bluetooth Connection with Arduino

Figure 23 Terminal App



```
//*********************************
#include <SoftwareSerial.h>//include library code
//*****************************************************************************
SoftwareSerial BTserial(2, 3); // RX | TX
// Connect the HC-05 TX to the Arduino RX on pin 2.
// Connect the HC-05 RX to the Arduino TX on pin 3 through a voltage di
//*****************************************************************************
void setup()
{
  Serial.begin(9600);//initialize serial communication at 9600 bps
  BTserial.begin(9600);//It can also be configured to have different ba
//19200,38400 etc. By default the baud rate is 9600. If 9600 doesn't wo
 }
void loop()
{
  // Read from the Bluetooth module and send to the Arduino Serial Moni
  if (BTserial.available())
  {
    Serial.write(BTserial.read());
  }
  // Read from the Arduino Serial Monitor and send to the Bluetooth moc
  if (Serial.available())
  {
    BTserial.write(Serial.read());


  }
}
```

```
OK
+BOLUTEK Firmware V2.43, Bluetooth V2.0, HCI V2.1, HCI Rev37, LMP
OK
+STATE:INITIALIZED
OK
+ROLE:0
OK
+NAME:HC-05 SLAVE
OK
Command                 Description
-------------------------------------------------------------
AT                      Check if the command terminal work normally
AT+RESET                Software reboot
AT+VERSION              Get firmware, bluetooth, HCI and LMP version
AT+HELP                 List all the commands
AT+NAME                 Get/Set local device name
AT+PIN                  Get/Set pin code for pairing
AT+BAUD                 Get/Set baud rate
```

```
rchiving built core (caching) in: C:\Users\toshiba\AppData\Local\Temp\arduino_cache_161849\core\core_arduino_avr_uno_0c812875ac70eb4a9b3
etch uses 3160 bytes (9%) of program storage space. Maximum is 32256 bytes.
al variables use 301 bytes (14%) of dynamic memory, leaving 1747 bytes for local variables. Maximum is 2048 bytes.
```

Figure 24 Bluetooth Serial Communication with Arduino

4.2.2 Magnetometer

The magnetometer was used as a compass to determine the direction of travel or the heading of a device. It also measures the Earth's magnetic field along the X, Y, and Z axes from milli-gauss to 8 gausses. The controller was communicated via the I2C protocol.

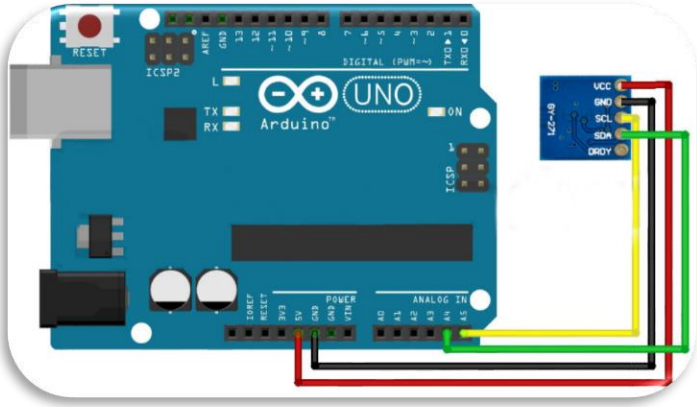


Figure 25 Magnetometer Connection with Arduino

4.2.3 Neo- 6m GPS

The platform's initial location was determined using GPS. And to offer coordinates that serve as the platform's waypoints (map). And, to gain an edge over GPS, we employed the constraint that GPS will only work if it is connected to at least four satellites.

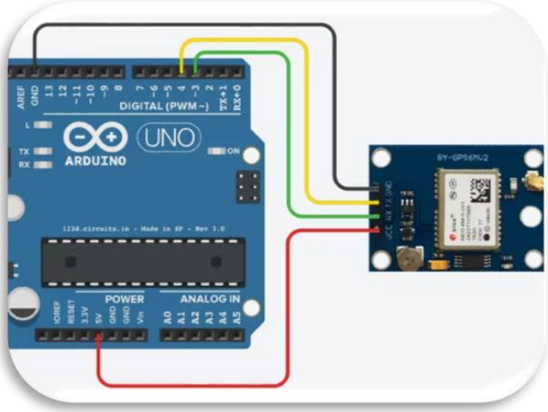


Figure 26 GPS Connection with Arduino

4.2.4 MPU – 6050

Throughout the project, this was the principal sensor. Its components include a user-programmable gyro and an accelerometer, and it was used to track both fast and slow motions with precision.

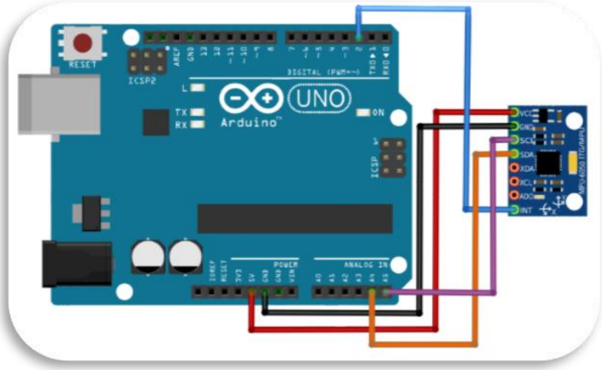


Figure 27 MPU - 6050 Connection with Arduino

4.3 The Algorithm

We had to execute a **Sensor Fusion** and **Dead Reconning** for the Algorithm because we were obtaining various data from different sensors and fusing them to get our desired result.

Sensor Fusion of combining sensor data and from others to provide results with less inaccuracy than if these elements were used independently. [17]. For example, combining multiple sources of data such as camcorders and Wi-Fi localization signals can result in a more exact indoor object location estimation. In this case, uncertainty reduction could refer to the result of a new perspective, such like depth perception, or it could allude to the terms "more accurate," "more complete," or "more dependable."

Dead Reckoning is the process to determine a ship's or aircraft's location without use of celestial navigation while using a ledger of something like the tracks sail or flown, the distance (which may be inferred from velocity), the known basic framework, and also the known or projected drift.

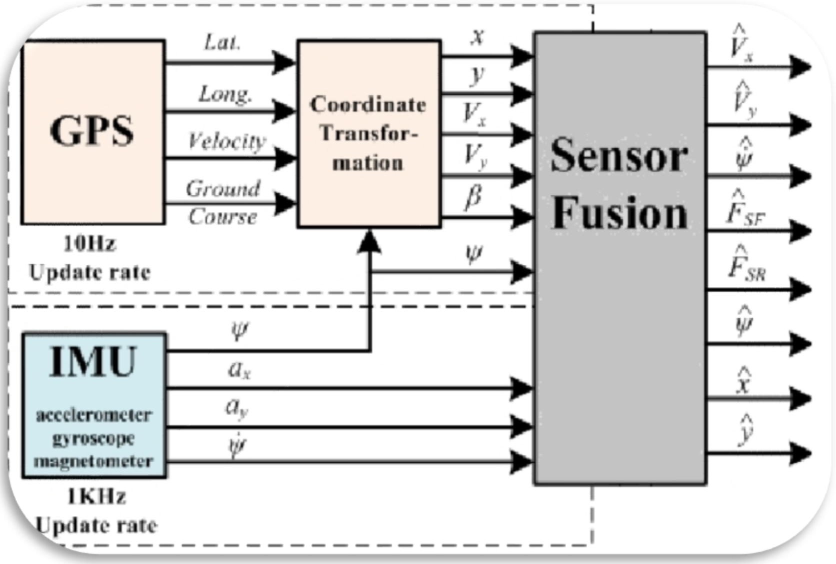


Figure 28 Sensor Fusion

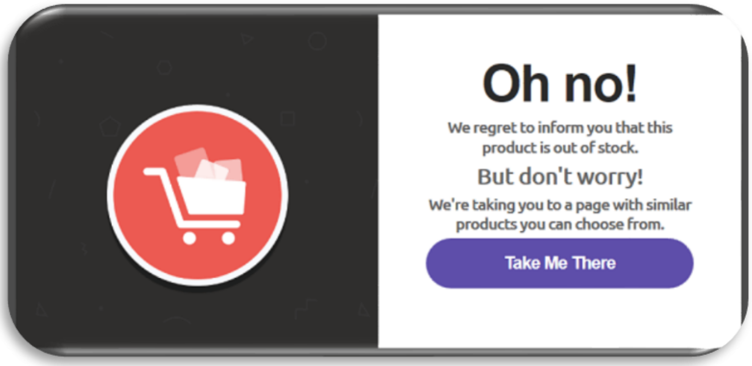
4.4 Problems

Without obstacles, the project or experience is incomplete. There is no solution without a problem, or one could say that an issue comes with a solution. In this project, we've run into a lot of issues. The following are the primary issues:

- Components unavailability
- Wiring
- Components malfunction
- Compass calibration
- MPU 6050 readings

4.4.1 Components Unavailability

This was the very first problem we encountered when we began the project. Both the local market and the internet store were out of stock on some of the components. When we contacted the local market sellers, they told us that the components will be available soon, causing a slight delay in the project.



Oh no!

We regret to inform you that this product is out of stock.

But don't worry!

We're taking you to a page with similar products you can choose from.

Figure 29 Out of Stock

4.4.2 Wiring

One of the most crucial aspects of any hardware project is to pay attention to the wiring. Because you can't complete the circuitry without adequate wiring. In addition, suitable series and parallel connections must be made. If you alter the terminals by accident, the entire circuit may be ruined. That's exactly what happened in our instance when we mistakenly switched the battery terminals, causing our Motor Driver Shield's two ICs to burn. As a result, the Motor Driver Shield has to be reordered.

Figure 30 Sensor Malfunction due to bad wiring

4.4.3 Components Malfunction

One of the problems was with the wiring, and another was with duplicate components.

We started by purchasing an Arduino UNO. When we first started working on it, we discovered that our system had failed to detect it. We thought it was a connecter issue, but when we changed the connecter, the problem reappeared. We searched the internet and discovered that the Arduino may have been replicated, and when we checked it, the results revealed something we hadn't expected: the Arduino had been duplicated. Rather than repairing Arduino and risking future difficulties, we got the Arduino Mega, which has more ports and does not come in pairs.

Second, the magnetometer had the same problem as the Arduino. We place an order for HMC5883L. We discovered it was QMC5883L after working with it. When we repurchase, we discover that the new magnetometer is also a QMC5883L with the label HMC5883L. That's when we decided to switch the library of HMC5883L to QMC5993L.

Figure 31 Watch Out

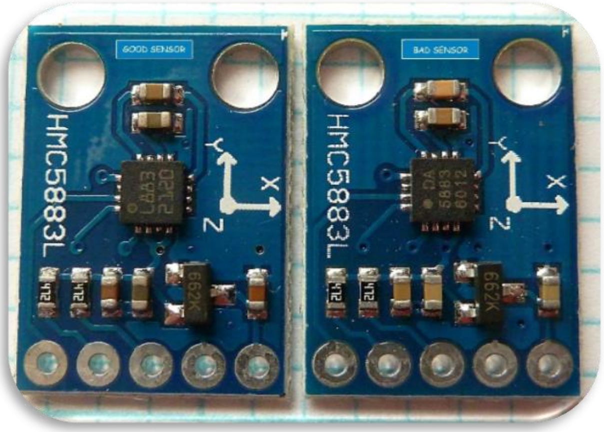
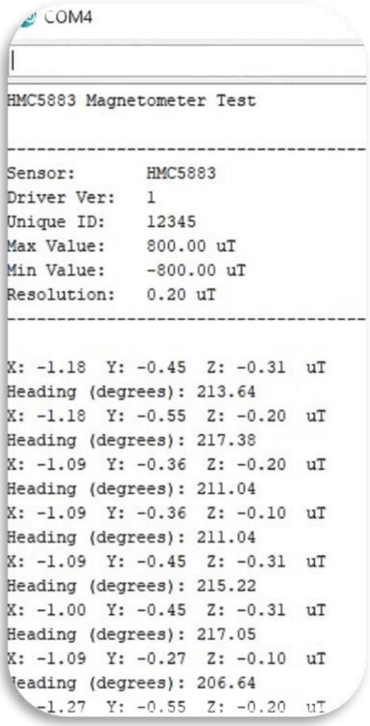


Figure 32 QMC5883L labeled as HMC5883L

4.4.4 Compass Calibration

The QMC5883L is really hard to calibrate, and we faced a lot of issues in only aligning it to the right direction. The main problem is the alignment of the compass to real axis and even a tiny bit of magnetic or iron interference can make the compass give false reading. A single piece of small metal can interfere with the reading. To solve this problem first we had to make a stand and an antenna for the compass, then place it so it is facing the right way. After doing that we had to carefully calibrate it, so no interference is near it.

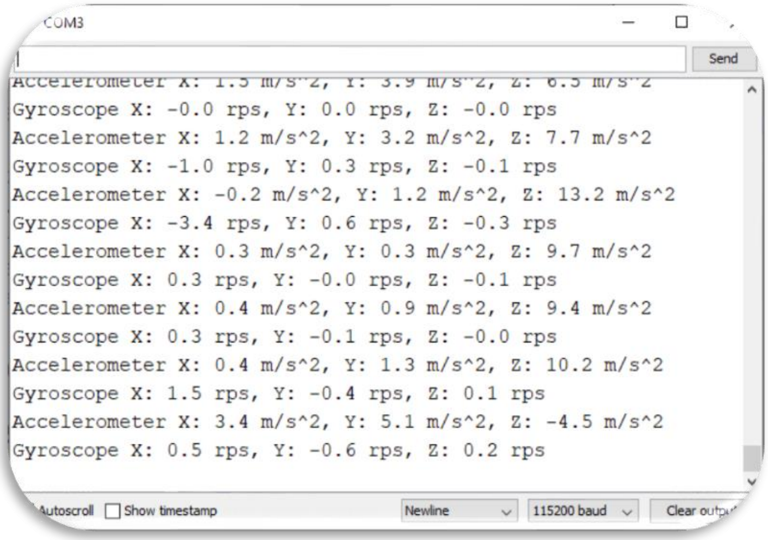


```
HMC5883 Magnetometer Test

------------------------------------
Sensor:       HMC5883
Driver Ver:   1
Unique ID:    12345
Max Value:    800.00 uT
Min Value:    -800.00 uT
Resolution:   0.20 uT
------------------------------------

X: -1.18  Y: -0.45  Z: -0.31  uT
Heading (degrees): 213.64
X: -1.18  Y: -0.55  Z: -0.20  uT
Heading (degrees): 217.38
X: -1.09  Y: -0.36  Z: -0.20  uT
Heading (degrees): 211.04
X: -1.09  Y: -0.36  Z: -0.10  uT
Heading (degrees): 211.04
X: -1.09  Y: -0.45  Z: -0.31  uT
Heading (degrees): 215.22
X: -1.00  Y: -0.45  Z: -0.31  uT
Heading (degrees): 217.05
X: -1.09  Y: -0.27  Z: -0.10  uT
eading (degrees): 206.64
 -1.27  Y: -0.55  Z: -0.20  uT
```

Figure 33 Wrong Values

4.4.5 MPU 6050 Readings

When we started to integrate the MPU in our system the reading of the MPU were not stable and no matter what we do the readings were not equal to any real-world values. We had to find an offset and a multiplicator offset to make the reading so that they can be used to measure distance.



```
Accelerometer X: 1.5 m/s^2, Y: 3.9 m/s^2, Z: 6.5 m/s^2
Gyroscope X: -0.0 rps, Y: 0.0 rps, Z: -0.0 rps
Accelerometer X: 1.2 m/s^2, Y: 3.2 m/s^2, Z: 7.7 m/s^2
Gyroscope X: -1.0 rps, Y: 0.3 rps, Z: -0.1 rps
Accelerometer X: -0.2 m/s^2, Y: 1.2 m/s^2, Z: 13.2 m/s^2
Gyroscope X: -3.4 rps, Y: 0.6 rps, Z: -0.3 rps
Accelerometer X: 0.3 m/s^2, Y: 0.3 m/s^2, Z: 9.7 m/s^2
Gyroscope X: 0.3 rps, Y: -0.0 rps, Z: -0.1 rps
Accelerometer X: 0.4 m/s^2, Y: 0.9 m/s^2, Z: 9.4 m/s^2
Gyroscope X: 0.3 rps, Y: -0.1 rps, Z: -0.0 rps
Accelerometer X: 0.4 m/s^2, Y: 1.3 m/s^2, Z: 10.2 m/s^2
Gyroscope X: 1.5 rps, Y: -0.4 rps, Z: 0.1 rps
Accelerometer X: 3.4 m/s^2, Y: 5.1 m/s^2, Z: -4.5 m/s^2
Gyroscope X: 0.5 rps, Y: -0.6 rps, Z: 0.2 rps
```

Figure 34 MPU6050 Readings

Chapter 5: Testing

The testing procedure was separated into four stages, as follows:

- Unit Testing
- Integration Testing
- Data Reading, Calibration & Testing
- System Testing

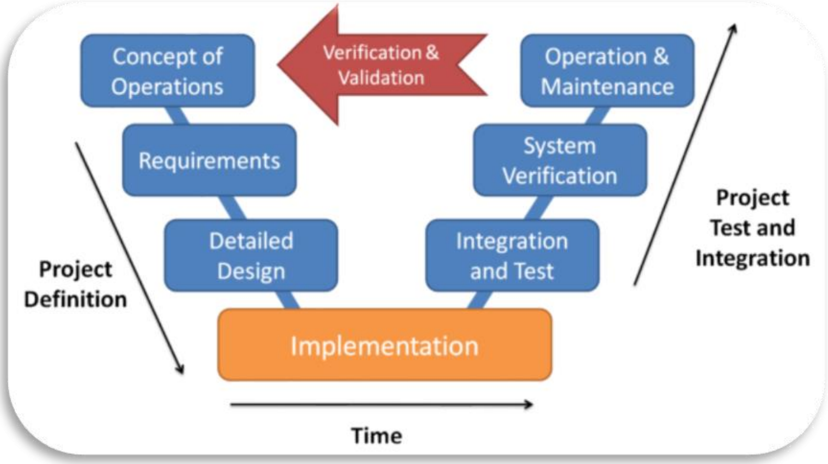


Figure 35 Testing

5.1 Unit Testing

During this time, the project is subjected to tests that look at specific units or components of the hardware to see if they're all working properly. The advantage of this testing process is that it allows us to identify which components are failing so that they can be replaced as soon as feasible. [18].

In this phase, we found that the Arduino and magnetometer we were using were faulty so replace them or changed them according to our needs.

5.2 Integration Testing

Individuals can use this testing to aggregate all of the modules in a project and test them all together. This level of testing is intended to discover problems in the interfaces between modules/components. This is especially advantageous because it determines how well the components work together. [18].

As the project's complexity grew, we updated the functionality and how components interacted during this phase. Initially, we experimented with altering codes on the console, burning them into Arduino, and so on. However, as time went on, we began to employ serial communication, which sped up the process of changing code and burning on Arduino.

5.3 Data Reading, Calibration & Testing

We read the data from the sensors in this phase and compared it to a trusted source or documentation to ensure we were reading the proper data. For example, in the case of GPS, we took a reading from the Neo-6m GPS sensor and compared it to the reading from the Mobile's GPS to ensure it was accurate.

Furthermore, the readings from hardware components aren't always reliable. To receive accurate results, you must calibrate the sensors according to your needs. The GPS sensors were calibrated to ensure that their readings were precise to within 8 meters. And the MPU was calibrated in such a way that it delivers no reading in its initial position unless the motion is detected at a specific angle.

5.4 System Testing

During this phase, the entire system is thoroughly tested. At this level, the purpose is to determine whether the system has met all of the requirements and to ensure that it fulfills Quality Standards. [18].

We put the project to the test in both indoor and outdoor settings. The findings were better in an outside environment since we were able to connect to the GPS there. However, the inside environment didn't behave as we expected because we couldn't connect to the GPS there.

In addition, the accuracy for reaching the destination was within 3-8 meters. This was accomplished through extensive testing.

Chapter 6: Conclusion & Future Prospects

6.1 Conclusion

In conclusion, the intricacy of an INS necessitates a significant investment in competent engineering to prevent certain critical hazards. Even if position and velocity measurements are unavailable for a while, this investment is well worth it because the output is dependable and precise.

The project created a mobile platform with an MPU and additional components. The mobile app was used to move the platform and access platform capabilities. The project was manufactured and designed from start to finish, from prototyping to testing. The project's initial goals have therefore been met, and they are listed below:

- A system that navigates by determining the location based on prior positions.
- A technology that provides faster location updates than GPS.
- A system that uses inertial values to orient an object's position.

6.2 Future Prospects

The present project is optimized for two-dimensional space. This can be used as a foundation for 3d space in the future. Because this project is in 2D space, it may be applied to any vehicle that can travel in 2D space. Automobiles, bicycles, buses, and bicycles, for example. It will be used for planes, flying jets, and missiles in 3D space.

Furthermore, the precision can be enhanced to 0-2 meters. This can be accomplished by replacing low-cost sensors with high-quality ones. Installing a Wi-Fi module can also extend the range of a remotely controlled platform.

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