Design and Development of an Inexpensive Inertial Measurement Unit in the Arduino Environment

Siva Sivamani Ganesh Kumar,
School of Electrical Engineering,
Vellore Institute of Technology,
Vellore, Tamilnadu, India
ganeshkumar.ss2020@vitstudent.ac.in;

Abhishek Gudipalli
School of Electrical Engineering
Vellore Institute of Technology
Vellore, Tamilnadu, India
abhishek.g@vit.ac.in;

Swee King Phang
School of Engineering
Taylor's University
Selangor, Malaysia
sweeking.phang@taylors.edu.my;

B Jaganatha Pandian
School of Electrical Engineering
Vellore Institute of Technology
Vellore, Tamil Nadu, India
jaganathapandian@vit.ac.in;

***Abstract-* Integration of Micro Electro Mechanical Systems (MEMS)-based Inertial Measurement Unit (IMU) for calculating roll, pitch, and yaw is presented in this paper. This paper presents the design of a low-cost IMU for calculating the attitude of an Unmanned Aerial Vehicle. In order to create a cheap inertial measurement unit that includes an accelerometer and gyroscope. Using the expanding microcontroller software environment, sensor integration with a 3-axis accelerometer and 3-axis gyroscope simulates 6 degrees of freedom orientation sensing. An inexpensive hardware implementation of many sensors is now possible thanks to the inclusion of computationally onboard microcontroller software like Arduino, which is used in a variety of aerospace applications.**

Keywords: Microcontroller, Arduino, sensors, IMU

I. Introduction

Due to their increased stability and endurance in a range of environments and activities, unmanned aerial vehicles (UAVs) have gained significance in both military and civilian applications [1]. Over 2900 unmanned aerial vehicles (UAVs) and over 900 will be in use by 2022, predicts the Association for Unmanned Vehicle Systems International (AUVSI) firms providing services around the world in 2020 [2]. A combination of gyros, accelerometers, and magnetometers is found in the Inertial Measurement Unit (IMU). The development of microelectromechanical devices has allowed for the production of lightweight and compact guidance systems [3], [4].

As it relates to aerospace Inertial measurement units (IMUs) assess orientation based on a variety of sensor inputs Degrees of freedom (DOFs) and are commonly comprised of accelerometers and gyroscopes for use in such applications. Due to their high reliability stringent accuracy and drift tolerances, inertial navigation systems (INS) for spacecraft and aviation can cost thousands of dollars. Improved sensor fusion and filters have converted low-cost IMUs, which have seen a surge in popularity among amateurs and flying enthusiasts, into viable, reliable orientation sensors[5]. Sensor fusion, the use of several sensors to detect and rectify faults in one another's inputs, can help mitigate this type of error and cut down on its propagation. To demonstrate the importance and practical efficiency of sensor fusion and filtering, this experiment explores the connection between an accelerometer and a gyroscope. A cost-effective Micro-Electro-Mechanical Systems (MEMS) accelerometer and gyroscope in conjunction with an open-source single-board Arduino microcontroller presents an affordable laboratory activity suitable for students and instructors. Both students and teachers can derive advantages from investigating the potential of these devices when combined with control filtering and sensor fusion techniques, as it allows for significant improvement in orientation accuracy at a reasonable cost using a 6-DOF IMU based on Arduino.

II Proposed Methodology

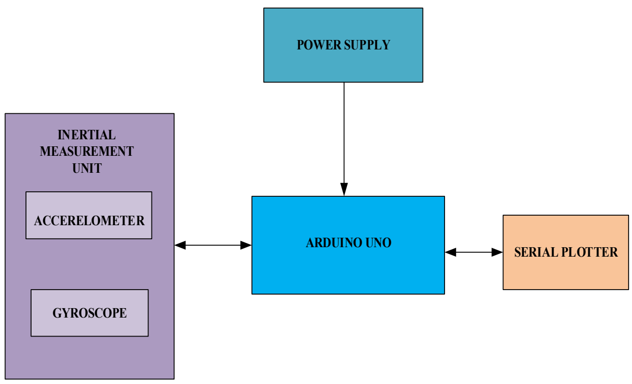

Fig 1. Block Diagram of IMU With Microcontroller

Fig 1 shows MEMS sensors integrated for measuring the acceleration and the angular orientation. The board takes control of the detected variations in IMU sensors. The sensors embedded in IMU are connected through Inter Integrated Circuits (I2C) protocol Arduino's Wire library facilitates interaction with I2C devices. The devices are controlled through an 8-bit address. Serial Data (SDA) and Serial Clock (SCL) pins of slave and master are connected to send and receive data.

The method for reading the accelerometer, gyroscope, and magnetometer sensors and storing the read data in the software buffer. This data is filtered and used for the computation of pitch, roll, and yaw values.

III METHODOLOGY

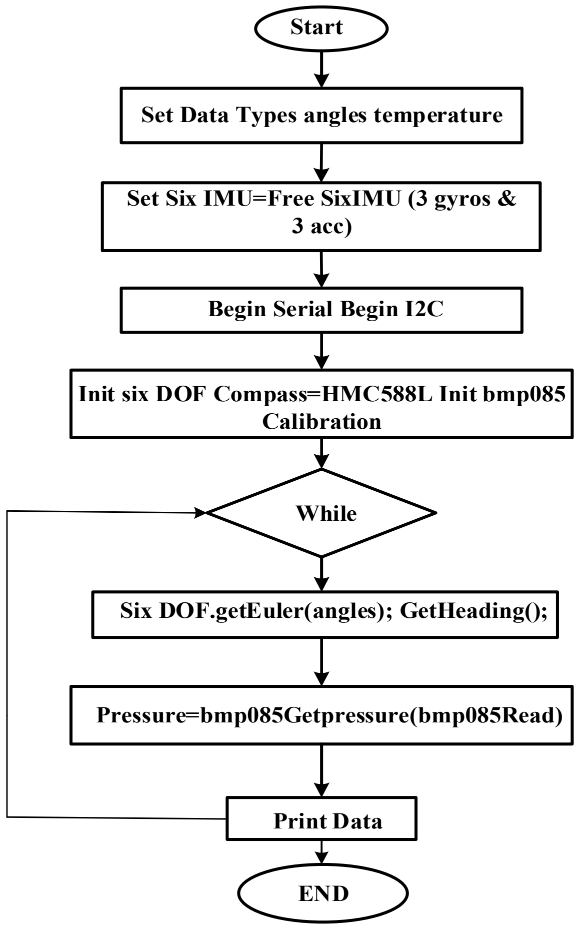

Fig 2 Flow Chart Of IMU

Initializing the IMU libraries and the I2C bus for data transmission is the first step in setting up an IMU with an Arduino, as shown in Fig 2. Select a data type next for the heading, temperature, pressure, and the three angles. Put in place six DOF's Free Six IMU objects Simply record the fault and return the compass to zero if it ever stops working properly. The calculations in Arduino code are included in a loop that is constantly executed after initialization. With "6 DOF" IMU sensors can measure the angular velocity and angle of rotation of all three axes relative to the beginning point. These numbers are fed into Arduino as inputs. Typical components of an IMU include acceleration, gyroscope, pressure, and magnetic sensors. Sensor values are optimized by calibrating the values read from these parts.

The UART and I2C should now begin communicating at a baud rate of 9600. Then, call init() on the compass, six-degrees-of-freedom accelerometer, and six-degrees-of-freedom gyroscope [6].

IV INERTIAL MEASUREMENT UNIT

With the help of accelerometers and gyroscopes, an inertial measurement unit (IMU) can determine and report an aircraft's speed, orientation, and the effects of gravity. IMUs are commonly used to pilot satellites, space shuttles, and airplanes, especially unmanned aerial vehicles (UAVs) [5].To function, an IMU employs one or more accelerometers, which measure the rate of acceleration in the present moment, and uses one or more gyroscopes to detect shifts in rotational characteristics including pitch, roll, and yaw. The concept, operation, and practical uses of IMU are all described in great detail and accessible in the published works [7], [8].

Electrical devices known as inertial sensors can detect and report forces based on mass inertia. These are usually acceleration forces that rotate and translate. Translational forces are measured by an accelerometer, whereas rotational forces are measured by a gyroscope and a rotation rate sensor. IMUs are systems based on these sensors, which are three-axis gyroscopes and accelerometers combined. Usually, they are employed to monitor an object's translation and spin during motion. Inertial sensor technology establishes a basic contrast between systems that are limited to gyroscopes and accelerometers and systems that are furthermore equipped with a magnetic field sensor (magnetometer). For this study, only accelerometers and gyroscopes are pertinent, and both are described. Inertial measurement units (IMUs) are self-contained devices that measure linear and angular motion using three accelerometers and three gyroscopes. An IMU can be gimbaled or strapped down, and in either configuration, it will provide readings for the sensor's or the body's angular velocity and acceleration integrations. The inertial measurement unit (IMU) used in this study has six degrees of freedom (DOF). This inertial measurement unit gives you data on six axes of movement (acceleration, rotation, and position) thanks to the inclusion of three accelerometers and three gyroscopes [9].

A.MPU6050 IMU sensor

To detect both rotational and linear movement of an item, the MPU6050 gadget has a three-axis accelerometer and a three-axis gyroscope. Moreover, it has an onboard digital motion processor that can calculate the quaternion, or equivalently, the object's attitude, using a six-axis Motion Fusion technique. Through the I2C interface, the sensor data is retrieved from a First In First Out (FIFO) buffer[10].MPU-6050 is a piece of equipment that processes movement. The MPU-6050 integrates a MEMS 3-axis gyroscope, a 3-axis accelerometer, and a Digital Motion Processor into a single silicon chip, thereby avoiding the cross-axis alignment problems inherent in using discrete components[6].

Its Features are:

I2C Digital output of 6 -axis Motion Fusion data in rotation matrix, quaternion, Euler Angle, or raw data format

Tri-Axis accelerometer with a programmable full-scale range of ±2g, ±4g, ±8g and ±16g

It has a Digital-output temperature sensor. It is used for measuring the acceleration of a device.

It can be used to perform the calculations from the alignment of the axis.

It can be used with an inertial measurement unit for calculating the angles in rad/ sec.

It is a low-cost sensor.

Fig 3 MPU6050

The Fig 3 shows the MPU6050 which consists of 8 pins for measuring acceleration and angular velocity.

IMU-based orientation estimation.

The gyroscopes and accelerometers displayed are the sensors used to determine orientation.

Both sensors have benefits, but both are prone to error. Because they use gravity as an input vector to determine an object's orientation, the orientation of the local coordinate system is calculated with the global coordinate system, and accelerometer data-based orientation estimation is most sensitive to the gravity vector element. However, since gravitational force is constant in the earth's direction, position estimation via gravity-influenced axes cannot be determined using an accelerometer. Gyroscopes detect rotational speeds along many axes with a high degree of accuracy. By integrating the angular velocity measurement over time, one may derive the angle around the measured axis; however, this process introduces small offset inaccuracies that eventually accumulate and cause a long-term drift. An IMU incorporates both sensors to enable more exact orientation estimation.

The data from both sensors may then be combined using filter techniques to account for sensor errors. These filters use gyroscope data for short-term changes since it is highly accurate and unaffected by outside influences. Accelerometer data is useful in the long run since it does not wander. The ability to correctly establish the direction of a measurement unit is dependent on the sensor's qualities as well as the methods for fusing and filtering the data.

B.Arduino Uno

Because the payload of a UAV is frequently restricted, the processing unit of the proposed module is a small-sized Arduino UNO microcontroller board. The Arduino Uno microcontroller is based on the Atmega 328P. There are 14 digital I/O pins, a 16MHz quartz crystal, a USB port, a power jack, an ICSP header, a reset button, and a USB connection. Nothing more than a USB cord to your computer, or an AC-to-DC adapter or battery, is required to get started with the microcontroller[9] .

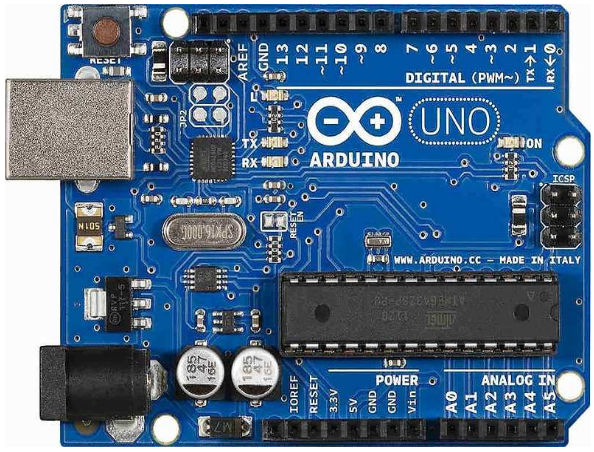

Fig 4 Arduino Uno Board

Fig 4 shows the Arduino UNO board consisting of a power supply and microcontroller with a reset switch.

C.I2C Protocol

It is the goal of the Inter-integrated Circuit (I2C) Protocol to facilitate communication between many "slave" digital integrated circuits and a single or multiple "master" chip(s). Whereas the Serial Peripheral Interface (SPI) is only capable of short-distance communications within a single device, I2C is used for data exchange connections between sensors. The I2C protocol is used for communication between the IMU sensor and the Arduino [11]. Two live wires and ground make up the I2C bus's physical construction. SDA and SCL are the active wires, and they work in both directions. For those unfamiliar, SDA stands for Serial Data, and SCL for Serial Clock. Whether it's a microcontroller unit, an LCD driver, some memory, or an application-specific integrated circuit, each device on the bus has its address[12].

A memory or I/O chip, but not an LCD driver, can work as both a transmitter and a receiver. The I2C bus supports multiple masters. Multiple ICs can be connected in this way, and any one of them can initiate a data transfer. The IC that first requests data from the bus is known as the Bus Master, per the I2C protocol specification[13]. As a result, at that point in time, every other IC is considered to be a Bus Slave. Since microcontrollers like the Arduino Uno fall into the category of bus masters, it is appropriate to use that term here. The MPU sensor also functions as a Bus Slave.

D.Accelerometer

The accelerometer can provide readings of up to +-16 g and has a high resolution of around 13 bits. The digital data is output in a 16-bit twos complement format. The SPI or I2C protocol can be used to communicate with it. The I2C protocol is used to facilitate communication in this work. The accelerometer measures acceleration in a static direction, making it ideal for use in tilt-sensing applications. In this case, gravity itself serves as the acceleration standard. It can also be used to quantify the dynamic acceleration brought on by things like movement. The accelerometer's scale factor is the ratio of acceleration change (input) to output signal change. Standard units are LSB per gram or mg per LSB [14].

For this work, +-2g as the output range is selected with full resolution (256LSB/g) where output resolution increases with +-2g range to maintain 4mg /LSB scale factor. This range is selected to read sensitive measurements like small vibrations. The smaller the range, the more detailed output is obtained. The output rate is set to 50Hz (as the main loop runs at 50Hz).

The gravity, which is known to be 9:81 msq, is the simplest approach to calibrate the accelerometers. When the accelerometers' full-scale range is small, this is rather accurate; but, when the full-scale range is more than 1g, it may introduce additional inaccuracy into the calculations. As previously stated, the MPU6050 has a minimum weight of 2g. Three axes must be calibrated for these sensors, which implies six constants must be found.

Assuming that, while the sensor is stationary, the gravitational acceleration equals the magnitude of the vector produced by the three axes. Thus, a collection of sensor data from at least six different locations is needed.

E. Gyroscope

It's a low-power, three-axis angular rate sensor. A whole scale of ±250/±500/±2000 dps is supported. It measures rates based on user-selectable bandwidth. In this paper, the gyroscope output data range is selected as 100Hz since it is the minimum frequency at which the sensor outputs the measurement. This does not affect overall IMU as the gyroscope operates at a higher frequency (0.01s) than the main loop which runs at 50Hz (0.02s). The sensor is set for continuous data update and little Endean data selection. A full scale of +-2000 dps (degrees per second) is used for the measurement of angular velocity. The gain of 0.07 DPS/digit is the scale factor at the full-scale range[8], [15] .

A system that spins at a known angular velocity must be identified before the gyroscopes can be calibrated, but the process is identical to that used for the accelerometers. A turntable has been utilized to measure angular velocity precisely, with a standard of 33 or 45 rpm. However, to achieve better outcomes, the rotation speed needs to be monitored properly. Due to a lack of time, this has not been completed.

As a result, just three more variables that match to the calibration function's slope need to be estimated.

F.Magnetometer

It is a 3-axis magnetometer manufactured by Honeywell. The applications of magnetometers are numerous. The two most prevalent applications are detecting ferrous (magnetic) metals. A magnetic field is produced whenever electric current runs through a conductor, and vice versa. This is the underlying theory that makes electromagnets work. This is also the basis upon which magnetometers operate [16]. By measuring and calculating the changes in current caused by the direction of Earth's magnetic fields, one can obtain a compass heading or other important information.

The magnetometer may be calibrated using the same method as gyroscopes and accelerometers, but since the earth's magnetic field is always there, there is no need to setup the board under any particular conditions. The user has to rotate the board in all directions while the magnetometer is sampling.

Features of the magnetometer are as follows, Internal Self-Test and 2.16 to 3.6 V low voltage and 100 uA low power consumption.

V RESULTS AND DISCUSSIONS

Several sensors have been chosen, and preliminary tests have been conducted. Continuous measurements are taken of yaw, pitch, and roll.

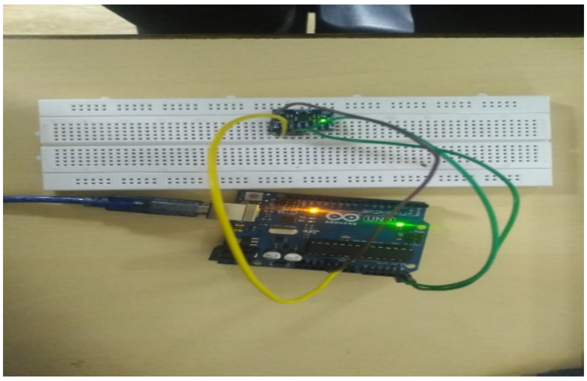

Fig 5 Hardware Setup

Fig 5 shows the hardware setup of the MPU6050 with the Arduino UNO which connects the SCL and SDA with the sensor.

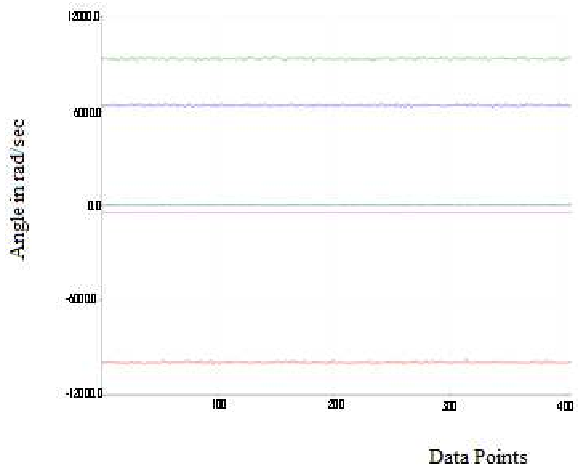

Fig 6 Measurement of Roll, Pitch, And Yaw

Fig 6 shows the yaw, pitch, and roll values are measured with the calibration of sensors and done. The graphs depicting the measured values are shown below. The graphs are plotted using the Serial Plotter tool in Arduino IDE. The measurements were made on a flat surface with minimal vibrations and low exposure to magnetic fields. The variation made by the sensor can be measured in the graph.

VI CONCLUSIONS

The measurements are done effectively using IMU in a short period with acceptable accuracy. They are accurate and the values are sensed in real-time. As the data is updated and the entire parameters are available at any instance of time. The lightweight and adaptable Arduino microcontroller board was opted for as the central processing unit. It combines readings from some low-cost sensors, like an MPU 6050, to determine the relevant variables. It is also important to create software that can display the data collected.

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