IMU BASED INFERENCE SYSTEM

A PROJECT REPORT
for
MINOR PROJECT

Submitted by

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BONAFIDE CERTIFICATE

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INTERNAL EXAMINER- I

INTERNAL EXAMINER-II

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Introduction

Issues Involving Road Travel:

While roadways play a crucial role in transportation and connectivity, they also come with certain disadvantages. Here are some common disadvantages associated with roadways:

Traffic Congestion:

One of the significant challenges of roadways is traffic congestion. Especially in urban areas, high population density and increased vehicular traffic can lead to congestion, resulting in delays, increased travel times, and frustration for commuters.

Accidents and Safety Concerns:

Roadways are susceptible to accidents, which can result in injuries, fatalities, and property damage. Factors such as speeding, reckless driving, and inadequate road infrastructure can contribute to road accidents.

Infrastructure Maintenance Costs:

Building and maintaining road infrastructure require significant financial resources. Governments and local authorities must allocate funds for construction, repair, and maintenance, which can be a strain on budgets.

Limited Capacity and Congestion Costs:

Roadways have a finite capacity, and as urbanization and population growth continue, the demand for transportation often exceeds the road network's capacLimited Accessibility in Remote Areas:

In remote or rural areas, road infrastructure may be limited or nonexistent. This lack of accessibility can hinder economic development, healthcare access, and educational opportunities for residents in these areas.ity. Congestion costs, including time wasted in traffic and increased fuel consumption, can have economic implications.

Why There Needs to be a Change:

Potholes and poor road quality present significant challenges to the functionality, safety, and overall infrastructure of transportation networks. Potholes, often formed due to the combination of factors such as freeze-thaw cycles, heavy traffic, and insufficient road maintenance, create depressions in the road surface. These disruptions pose a range of issues for motorists, leading to increased vehicle maintenance costs as tires, suspensions, and alignments suffer wear and tear from navigating these road hazards. Beyond the financial burden on individual drivers, potholes also contribute to safety concerns, as they can lead to accidents and impact the overall efficiency of traffic flow.

According to the World Health Organization (WHO), road traffic injuries were a leading cause of death globally, with over 1.3 million people dying in road accidents annually. Road traffic injuries were also a major cause of disability globally. Road accident rates vary significantly by region. Low- and middle-income countries tend to have higher rates of road traffic injuries and fatalities compared to high-income countries. Factors such as infrastructure quality, enforcement of traffic laws, and vehicle safety standards contribute to these variances. Pedestrians, cyclists, and motorcyclists are often considered vulnerable road users and are at a higher risk of injury or death in road accidents. In many regions, a significant portion of road traffic fatalities involve these groups.

How the Quality of Roadways Impact People:

Road conditions have a significant impact on various aspects of our daily lives, influencing everything from personal safety and well-being to economic activities. Here are several ways in which road conditions affect our lives:

Safety and Accidents:

Poor road conditions, such as potholes, uneven surfaces, and inadequate signage, contribute to road accidents. Accidents can result in injuries, fatalities, and property damage, affecting the safety of drivers, passengers, pedestrians, and cyclists.
Vehicle Maintenance Costs:

Rough and deteriorated roads can lead to increased wear and tear on vehicles. Potholes, bumps, and uneven surfaces may cause damage to tires, suspensions, and alignments, resulting in higher maintenance costs for vehicle owners.

Travel Time and Efficiency:

Good road conditions contribute to smoother and more efficient traffic flow, reducing travel times for commuters and goods transport. On the other hand, poor road conditions, congestion, and bottlenecks can lead to delays, affecting daily schedules and productivity.

Economic Impact:

Well-maintained roads are essential for economic activities. Businesses rely on efficient transportation networks for the movement of goods and services. Poor road conditions can lead to increased operational costs, transportation delays, and disruptions in supply chains, impacting local and national economies.

Public Transportation and Accessibility:

The quality of road infrastructure affects public transportation services, including buses and other modes of transit. Poor road conditions can result in discomfort for passengers and increased maintenance costs for transit operators. Additionally, inadequate road infrastructure limits accessibility for individuals with disabilities, affecting their ability to use public transportation and navigate public spaces.

Quality of Life:

The overall quality of road infrastructure contributes to the aesthetic appeal and livability of communities. Well-maintained roads enhance the visual environment and create a positive atmosphere for residents. Conversely, deteriorated roads can negatively impact the appearance of neighborhoods and affect the quality of life.

Environmental Impact:

Road conditions can have environmental consequences. Inadequate drainage systems and poorly constructed roads may contribute to soil erosion, water runoff issues, and environmental degradation. Sustainable road management practices can help minimize the environmental impact of transportation infrastructure.

Health and Well-being:

The condition of roads can influence public health. Poorly maintained roads contribute to accidents and may deter individuals from engaging in physical activities such as walking or cycling. Accessible and well-maintained sidewalks and bike lanes promote a healthier lifestyle.

Tourism and Recreation:

Road conditions play a role in tourism and recreational activities. Well-maintained roads are crucial for attracting tourists, supporting local businesses, and facilitating travel to recreational destinations. In contrast, poor road conditions may deter visitors and limit opportunities for tourism-related economic growth.

Thus information about the quality of the roadway one intends to travel on, is critical to safety planning and punctuality.Yet there is no such means of easy availability. Therefore an IMU based inference system that gives real time data about the physical conditions of a roadway is clearly indicated so that important journeys can be planned with ease.

Abstract

This study is about an IMU based inferencing system that collects data through an Inertial measurement unit and a GPS and sends it to a cloud platform to store and process data to reach an intelligent inference. The IMU data (ie) the accelerometric and gyroscopic data are processed to generate tilt sensitive pitch, roll and yaw angles which are processed along with corresponding GPS data and used to survey a section of a roadway and score the roadway as accurately as possible based on the degree of ease during travel. The scores generated are in comparison to other roads. The condition of a roadway can be viewed in real-time so that routes can be planned accordingly.

Block Diagram:

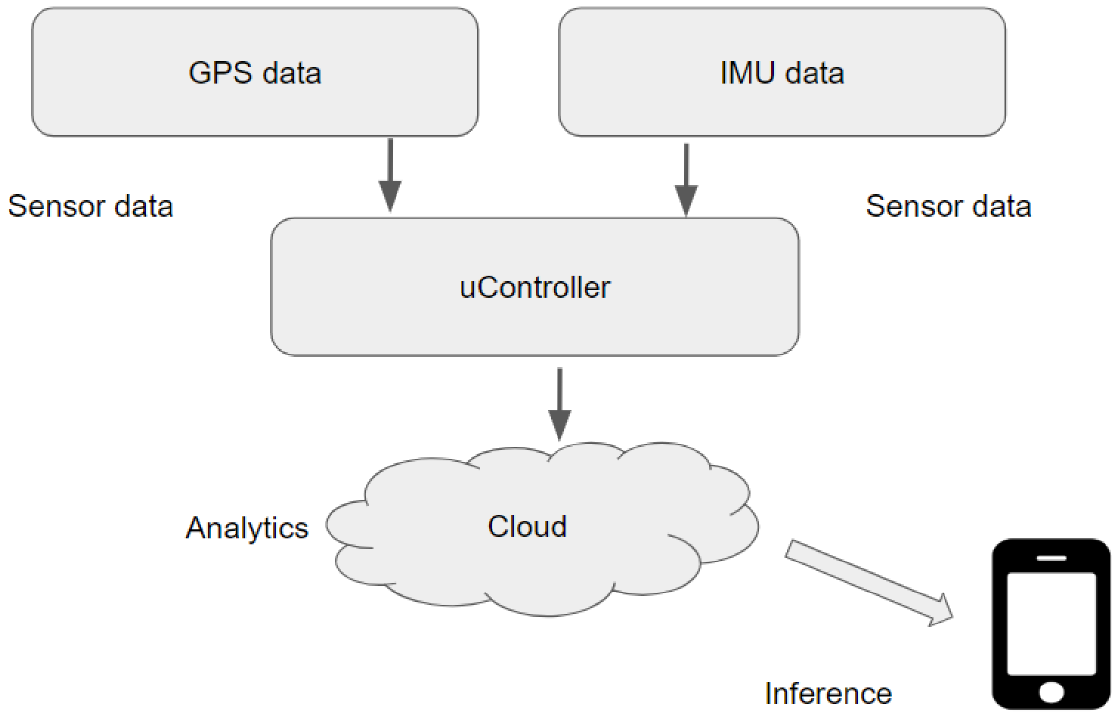


Figure 1: Block diagram

Working Mechanism

IMU Data:

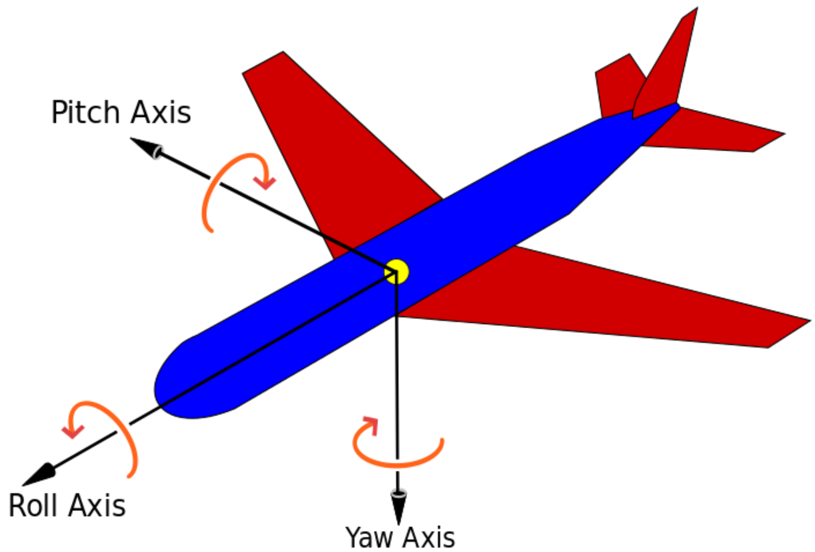


Figure 2: roll,pitch,yaw

Accelerometer Data:

Measurement of Acceleration. Accelerometers measure proper acceleration, which includes both the constant force of gravity and any dynamic acceleration the device is experiencing. The data is usually expressed in terms of acceleration along the three axes: x, y, and z.
Accelerometers are sensors that measure acceleration, typically in three axes (X, Y, and Z), and are commonly used to determine the orientation of an object or detect changes in velocity. Accelerometers provide data in the form of acceleration values, which can be used to calculate various parameters, including displacement, velocity, and orientation
The accelerometer provides acceleration values along the X, Y, and Z axes. These values are typically in units of m/s^2 or g ($1\ g \approx 9.81\ m/s^2$).
To calculate the pitch and roll angles (orientation of the object with respect to the horizontal plane), you can use trigonometric functions. The following formulas are commonly used:

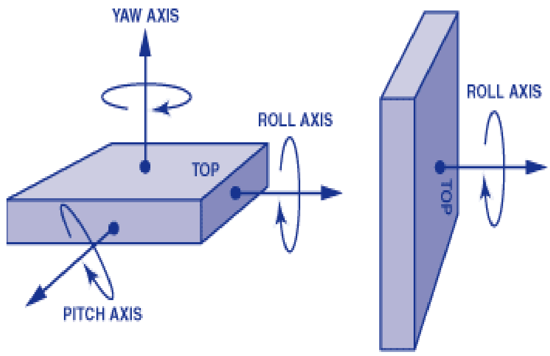


Figure 3: axis

$$\tan\phi_{xyz} = \left(\frac{G_{py}}{G_{pz}}\right)$$

$$\tan\theta_{xyz} = \left(\frac{-G_{px}}{\sqrt{G_{py}^2 + G_{pz}^2}}\right)$$

Where,

G refers to the acceleration due to gravity in X,Y and Z direction

θ refers to the pitch

$\$\phi$ Refers to the roll

Gyroscope Data:

Measurement of Angular Velocity: Gyroscopes measure the rate of rotation or angular velocity around the device's three axes: pitch, roll, and yaw. The data indicates how fast the device is rotating in each of these directions.

Problem with only using accelerometer data: It is vulnerable to vibrations
Problem with only using gyroscope data: It is prone to drift.

Understanding the Kalman Filter

The Kalman filter, a groundbreaking mathematical algorithm developed by Rudolf E. Kálmán in the 1960s, is a versatile tool in the realm of estimation and prediction. Though it has found applications in diverse fields such as control systems, robotics, and navigation, understanding the Kalman filter at its core requires delving into its fundamental concepts.

1. State Estimation:
At the heart of the Kalman filter is the concept of state estimation. In a dynamic system, the state represents the internal parameters or variables that define its current condition. The Kalman filter aims to estimate this state, taking into account both the system's dynamics and external measurements. This estimation process involves predicting the next state based on past estimates and then updating the estimate when new measurements become available.

2. Prediction and Correction:
The Kalman filter operates through a cyclical process of prediction and correction. In the prediction phase, the filter uses a mathematical model to forecast the future state of the system. This prediction is inherently imperfect due to the inherent uncertainty in dynamic systems. In the correction phase, the filter incorporates new measurements to refine the state estimate. The balance between the prediction and measurement updates is determined by the uncertainties associated with each, making the Kalman filter adaptive to changing conditions.

3. System Dynamics and State Transition:
The Kalman filter relies on a system dynamics model that describes how the state of the system evolves over time. This model incorporates information about the system's behavior, motion, or evolution. The state transition matrix represents how the system transitions from one state to another, forming the foundation for predicting the future state in the absence of new measurements.

4. Covariance Matrices:
Central to the Kalman filter's effectiveness are the covariance matrices associated with the state and measurements. The covariance matrix of the predicted state accounts for the uncertainty introduced during the prediction phase. Similarly, the covariance matrix of the measurements

represents the uncertainty associated with the sensors or measurement devices. These matrices guide the filter in appropriately weighting the contributions of the prediction and measurement in the final state estimate.

5. Innovation and Kalman Gain:
The Kalman filter introduces the concepts of innovation and Kalman gain. Innovation is the difference between the actual measurement and the predicted measurement based on the current state estimate. The Kalman gain is a key factor in determining how much weight to give to the innovation during the correction phase. It is a dynamic parameter that adapts based on the relative uncertainties of the predicted state and the measurements.

In essence, the Kalman filter provides a systematic and efficient way to navigate the inherent challenges of estimating the state of dynamic systems in the presence of uncertainty. Its elegance lies in its ability to continually refine estimates as new information becomes available, making it a cornerstone in the realm of estimation theory. While applications showcase its real-world utility, understanding the core principles of the Kalman filter unveils its significance as a mathematical framework for optimal state estimation.

Low Pass Filter

A digital low-pass filter (LPF) is a type of filter used in digital signal processing to allow signals with a frequency lower than a specified cutoff frequency to pass through while attenuating signals with frequencies higher than the cutoff. Low-pass filters find applications in various domains, including audio processing, communication systems, image processing, and sensor signal conditioning.

Cloud Inferencing:

The accelerometer and gyroscope data in pitch, roll and yaw form are sent over to the cloud via telemetry.

Implementation: For implementation, Microsoft Azure was used

1. An IOT hub was created to facilitate telemetry data exchange to the hardware.
2. A stream analytics job (SAJ) was created to handle the updation of the data.
3. A blob container was used to store the data (Pitch, Roll, Yaw, Location,Message Count

iJSON format.

Cloud inferencing is a pivotal aspect of modern machine learning (ML) and artificial intelligence (AI) workflows, offering a scalable and efficient solution for running inference tasks on cloud-based servers. In the realm of machine learning, inference is the stage where a trained model applies its learned knowledge to new, unseen data to make predictions or classifications. Cloud inferencing involves offloading these inference tasks to cloud computing environments, providing a range of advantages in terms of scalability, flexibility, and resource management.

Code:

```
#include<Wire.h>
#include<math.h>

  long accelX,accelY,accelZ;
  float gforceX,gforceY,gforceZ,accPitch,accRoll,accPitchO=0,accPitchN,accRollN,accRollO=0;

  long GyroX,GyroY,GyroZ;
float phiG=0;
float thetaG=0;
float theta=0;
float phi=0;
float rotX,rotY,rotZ;
float dt;
unsigned long millisOld;
//done

void setup() {

  Serial.begin(9600); //removed
 Wire.begin(4,5);
  setupMPU();

  // put your setup code here, to run once:

}

void loop() {
```

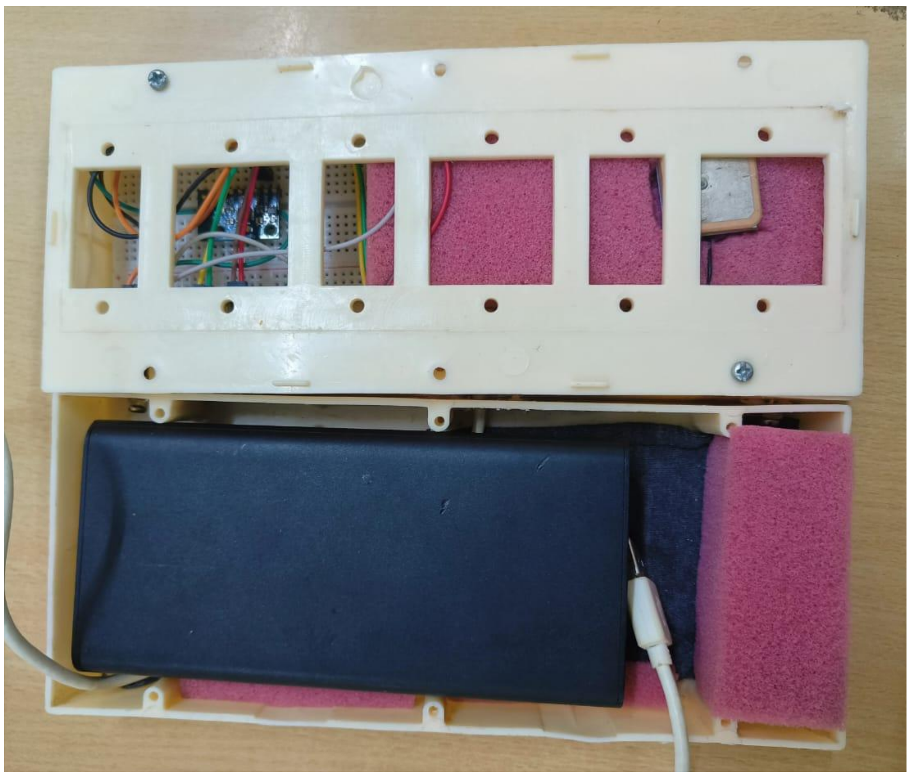
```
  RecordAccel();
  RecordGyro();
  //delay(100);
 // printdata();  //removed from
 // Serial.print("Gyro (deg)");

  Serial.print(theta);
  Serial.print(',');

  Serial.print(phi);
  Serial.print(',');

  //Serial.print(rotZ);
  //Serial.print(',');
 // Serial.print(" Accel (g)");

  Serial.print(accPitch);
  Serial.print(',');

  Serial.print(accPitchN);
  Serial.print(',');

  Serial.println(gforceZ);  //removed till
  //delay(100);

  // put your main code here, to run repeatedly:

}




void setupMPU()
{
  Wire.beginTransmission(0b1101000);
  Wire.write(0x6B);   // Accessing the register 6B - Power Management (Sec. 4.28)
  Wire.write(0b0000000);
  Wire.endTransmission();
  Wire.beginTransmission(0b1101000);
```

```
  Wire.write(0x1C);     //Aceeloro config register
  Wire.write(0b0000000);
  Wire.endTransmission();
  Wire.beginTransmission(0b1101000);
  Wire.write(0x1B);      //Gyro config register
  Wire.write(0b0000000);
  Wire.endTransmission();
}

void RecordAccel()
{
  Wire.beginTransmission(0b1101000);
  Wire.write(0x3B);             //first register/byte of output
  Wire.endTransmission();
  Wire.requestFrom(0b1101000,6);  //get 6 bytes from MPU
  while(Wire.available()<6);

    accelX=Wire.read()<<8|Wire.read();        //
    accelY=Wire.read()<<8|Wire.read();
    accelZ=Wire.read()<<8|Wire.read();
    ProcessAccel();

  }

  void ProcessAccel()
  {
  gforceX=(accelX/16384.0);      //sensitivity=16384

  gforceY=(accelY/16384.0)-0.03;

  gforceZ=(accelZ/16384.0)-0.13;
   if(gforceX>2)
    {
     gforceX=-1*(4-gforceX);
    }
    if(gforceY>2)
    {
     gforceY=-1*(4-gforceY);
    }
```

```
    if(gforceZ>2)
    {
      gforceZ=-1*(4-gforceZ);
    }
accPitch=atan2(gforceX,gforceZ)*(180/3.14159625)+2;
accRoll=atan2(gforceY,gforceZ)*(180/3.14159625);


  }
void RecordGyro()
{
  Wire.beginTransmission(0b1101000);
  Wire.write(0x43);         //first register/byte of output
  Wire.endTransmission();
  Wire.requestFrom(0b1101000,6);
  while(Wire.available()<6);

    GyroX=Wire.read()<<8|Wire.read();
    GyroY=Wire.read()<<8|Wire.read();
    GyroZ=Wire.read()<<8|Wire.read();
    ProcessGyro();

}

void ProcessGyro()
{
  rotX= (GyroX/131.0)+2.5;
  rotY= (GyroY/131.0)-2;
  rotZ= GyroZ/131.0;

  //rotX=(60-rotX)-2;
  if(rotX>250)
  {
    rotX=-1*(500-rotX);
  }
  if(rotY>250)
  {
    rotY=-1*(500-rotY);
  }
  dt=(millis()-millisOld)/1000.0;    //Euler integration of angular velocity, could use trapezoidal
```

```
  millisOld=millis();
  thetaG=(rotY*dt);
  phiG=phiG+(rotX*dt);
  //theta=(thetaG)*0.90+ accPitch*0.10;
  theta=(theta+rotY*dt)*0.90+ accPitch*0.10;
  phi=(phi+rotX*dt)*0.90+ accRoll*0.10;
}


void FilterA()
{
 theta=(theta+rotY*dt)*0.80+ accPitch*0.20;
}
```

Implementation Setup:



Hardware Used

MPU6050- 6 axis Accelerometer and Gyroscope:

The MPU6050, a product of InvenSense (now part of TDK Corporation), stands as a prominent component in the realm of motion sensing. This integrated circuit combines a three-axis gyroscope and a three-axis accelerometer on a single chip, presenting a compact and efficient solution for precise motion tracking and analysis.

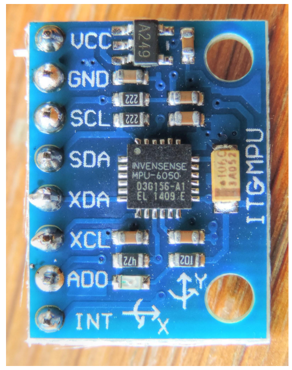


Figure 4: MPU6050

Key Components:

Three-Axis Gyroscope:
Central to the MPU6050 is its three-axis gyroscope, a crucial element for measuring angular velocity. This capability enables the sensor to accurately capture rotational movements around the X, Y, and Z axes.

Three-Axis Accelerometer:
Complementing the gyroscope, the three-axis accelerometer measures accelerations along the X, Y, and Z axes. This dual functionality provides comprehensive data on both rotational and linear motion, making the MPU6050 a versatile sensor.

Digital Motion Processor (DMP):
A noteworthy feature of the MPU6050 is its Digital Motion Processor. This component alleviates the burden on the main processor by handling complex motion processing tasks. This not only enhances the efficiency of motion tracking but also simplifies integration with various microcontrollers and processors.
Communication Interface: The MPU6050 employs the I2C (Inter-Integrated Circuit) communication protocol, facilitating seamless interaction with external devices. This standardized interface enhances the sensor's compatibility, allowing for integration into a diverse array of electronic systems.

Technical Features:

Low Power Consumption:

Designed with energy efficiency in mind, the MPU6050 is well-suited for battery-powered applications. Its low power consumption ensures prolonged operation in devices where energy conservation is critical.

Temperature Sensor:
The integrated temperature sensor provides information about the operating temperature. This data is essential for compensating temperature-dependent variations in sensor readings, contributing to the accuracy of motion tracking in diverse environmental conditions.

FIFO Buffer:
To accommodate varying data processing speeds, the MPU6050 incorporates a FIFO (First In, First Out) buffer. This feature allows the device to store data temporarily, preventing data loss during rapid changes in motion.

Challenges and Considerations:

Noise and Calibration:
Similar to any sensor, the MPU6050 is susceptible to noise. Proper calibration is crucial to mitigate the impact of noise on sensor readings and ensure the accuracy of motion tracking.

Limited Measurement Range:
The MPU6050 has constraints regarding the maximum angular rate and acceleration it can measure. In high-performance applications, additional sensors with higher measurement ranges may be necessary.

Significance:

The MPU6050's significance lies in its ability to provide precise motion data in a compact form factor. Its dual functionality, incorporating both gyroscope and accelerometer, addresses the requirements of applications demanding comprehensive motion analysis.

Miniaturization:
Over time, advancements in microelectromechanical systems (MEMS) technology may lead to the development of even smaller and more power-efficient motion sensors, expanding the range of applications for sensors like the MPU6050.

Integration Trends:
Ongoing trends in sensor fusion and integration with other sensor types may contribute to the evolution of the MPU6050. Combined with advancements in machine learning, these trends could lead to more sophisticated and context-aware motion tracking systems.
In conclusion, the MPU6050 remains a cornerstone in motion-sensing technology, offering a compact and efficient solution for capturing and analyzing motion data. Its technical features, challenges, and potential for evolution underscore its importance in the landscape of sensor technology, providing valuable insights into the complexities of motion tracking without delving into specific applications

Power Management in MPU6050:

The MPU6050, a versatile motion-tracking device, incorporates robust power management features that play a pivotal role in optimizing energy consumption and extending battery life in applications where power efficiency is paramount.

1. Low Power Consumption Design: One of the key aspects contributing to the MPU6050's efficiency is its low power consumption design. This feature is particularly crucial in battery-operated devices, such as wearable technology, where minimizing power usage is essential for prolonged operation.

2. Sleep Mode: The MPU6050 is equipped with a sleep mode, allowing it to enter a low-power state when not actively engaged in motion tracking tasks. During periods of inactivity, the sensor can be configured to reduce its power consumption significantly. This sleep mode is programmable, providing flexibility to developers in tailoring power management strategies to the specific requirements of their applications.

3. Wake-on-Motion: To further enhance power efficiency, the MPU6050 supports a wake-on-motion feature. This feature enables the sensor to remain in a low-power state until a significant motion event occurs. Upon detecting motion, the MPU6050 can swiftly transition to an active state, ready to capture and process motion data. This dynamic power management mechanism ensures that the sensor is active only when necessary, conserving power during idle periods.

4. FIFO Buffer and Burst Mode: The MPU6050 includes a FIFO (First In, First Out) buffer, which can be leveraged to store motion data temporarily. This buffer facilitates efficient power management by allowing the main processor to operate in burst mode, where it can read multiple

sensor values from the FIFO in a single transaction. This minimizes the time the main processor needs to be active, contributing to overall power savings.

5. Clock Source Options: The MPU6050 offers various clock source options, including an internal oscillator and the ability to synchronize with an external clock. Selecting an appropriate clock source is essential for balancing performance and power consumption based on the specific needs of the application. The flexibility in choosing the clock source allows developers to optimize the MPU6050's power profile based on the operational requirements.

6. Temperature Sensor and Compensation: The integrated temperature sensor in the MPU6050 not only contributes to accurate motion tracking but also plays a role in power management. Temperature variations can affect sensor readings, and the MPU6050 allows for temperature compensation, ensuring that power management algorithms adapt to environmental changes, maintaining accuracy while conserving energy.

Registers in MPU6050:

Registers in the MPU6050 are essential components that facilitate communication and control between the sensor and external devices such as microcontrollers or processors. These registers, organized in a memory structure, play a critical role in configuring the behavior of the MPU6050, retrieving motion data, and implementing various features. This page provides an overview of the register structure and introduces key categories of registers in the MPU6050.

Register Structure:
The MPU6050 features a set of registers accessible through the I2C (Inter-Integrated Circuit) communication protocol. Each register is a dedicated memory location that holds specific information or configuration settings. By reading from and writing to these registers, developers can interact with the MPU6050 to customize its functionality according to the requirements of the application.

Categories of Registers:

Configuration and Control Registers:

Power Management Register (Register 0x6B):
Controls the overall power state of the MPU6050, allowing users to enable or disable the sensor, configure the sleep mode, and select the clock source.

Gyroscope and Accelerometer Configuration Registers (Registers 0x1B to 0x1E):
Control various aspects of the gyroscope and accelerometer functionality, including the full-scale range, influencing sensitivity.

Configuration Register (Register 0x1A):
Provides additional configuration options, such as setting the Digital Low Pass Filter (DLPF) bandwidth and configuring the external sync functionality.

Motion Data Registers:
Accelerometer and Gyroscope Data Registers (Registers 0x3B to 0x48): These registers store the raw sensor data obtained from the accelerometers and gyroscopes. The data is presented in 16-bit two's complement format, and users can retrieve this information for further processing or analysis.

FIFO (First In, First Out) Buffer Registers:

FIFO Enable Register (Register 0x23):
Configures which sensor data types are written to the FIFO buffer.

FIFO Count Registers (Registers 0x72 to 0x73):
Provide information about the current number of bytes stored in the FIFO buffer.

FIFO Buffer Registers (Registers 0x74 to 0x77):
Store the actual data in the FIFO buffer. These registers allow for temporary storage of motion data, enabling more efficient data retrieval.

Advanced Control Registers:

Interrupt Configuration Register (Register 0x38):
Allows users to configure interrupts based on specific conditions, such as motion detection, data ready, or FIFO overflow. Proper utilization of interrupts can significantly enhance the efficiency of data retrieval and processing.

User Control Register (Register 0x6A):
Provides control over various auxiliary features, including the master clock configuration and the ability to reset sensor signals. It also facilitates the enabling or disabling of the I2C master mode.

Calibration Registers:

Gyroscope and Accelerometer Offset Registers (Registers 0x13 to 0x18):
Calibration is a crucial step in ensuring the accuracy of motion data. These registers store the offset values that can be adjusted to compensate for biases and environmental factors affecting sensor readings.

Temperature Offset Register (Register 0x6B, bit 0):
In addition to gyroscope and accelerometer calibration, the MPU6050 allows for compensating temperature-related variations. This single bit in the Power Management Register can be manipulated to enable or disable the temperature sensor offset.

Accelerometer Configuration:
This register is used to trigger the accelerometer self test and configure the accelerometer full scale range. This register also configures the Digital High Pass Filter (DHPF).

Register (Hex)	Register (Decimal)	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
1C	28	XA_ST	YA_ST	ZA_ST	AFS_SEL[1:0]		-		

Figure 5: Accelerometer config

Accelerometer self-test permits users to test the mechanical and electrical portions of the accelerometer. The self-test for each accelerometer axis can be activated by controlling the XA_ST, YA_ST, and ZA_ST bits of this register. Self-test for each axis may be performed independently or all at the same time. When self-test is activated, the on-board electronics will actuate the appropriate sensor. This actuation simulates an external force. The actuated sensor, in turn, will produce a corresponding output signal. The output signal is used to observe the self-test response. The self-test response is defined as follows: Self-test response = Sensor output with self-test enabled – Sensor output without self-test enabled When the value of the self-test response is within the min/max limits of the product specification, the part has passed the self test. When the selftest response exceeds the min/max values specified in the document, the part is deemed to have failed the self-test. AFS_SEL selects the full scale range of the accelerometer outputs according to the following table.

AFS_SEL	FULL SCALE RANGE
0	+2g

1	+4g
2	+8g
3	+16g

Table 1: Accelerometer sensitivity

Accelerometer Measurement: These registers store the most recent accelerometer measurements.

Register (Hex)	Register (Decimal)	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
3B	59	ACCEL_XOUT[15:8]							
3C	60	ACCEL_XOUT[7:0]							
3D	61	ACCEL_YOUT[15:8]							
3E	62	ACCEL_YOUT[7:0]							
3F	63	ACCEL_ZOUT[15:8]							
40	64	ACCEL_ZOUT[7:0]							

Figure 6: Accelerometer measurement

Accelerometer measurements are written to these registers at the Sample Rate as defined in Register 25. The accelerometer measurement registers, along with the temperature measurement registers, gyroscope measurement registers, and external sensor data registers, are composed of two sets of registers: an internal register set and a user-facing read register set. The data within the accelerometer sensors' internal register set is always updated at the Sample Rate. Meanwhile, the user-facing read register set duplicates the internal register set's data values whenever the serial interface is idle. This guarantees that a burst read of sensor registers will read measurements from the same sampling instant. Note that if burst reads are not used, the user is responsible for ensuring a set of single byte reads correspond to a single sampling instant by checking the Data Ready interrupt. Each 16-bit accelerometer measurement has a full scale defined in ACCEL_FS (Register 28). For each full scale setting, the accelerometers' sensitivity per LSB in ACCEL_xOUT is shown in the table below.

AFS_SEL	**Full Scale Range**	**LSB Sensitivity**
0	+2g	16384 LSB/g

1	+4g	8192 LSB/g
2	+8g	4096 LSB/g
3	+16g	2048 LSB/g

Table 2: Accelerometer full scale

ACCEL_XOUT 16-bit 2’s complement value Stores the most recent X axis accelerometer measurement.
ACCEL_YOUT 16-bit 2’s complement value. Stores the most recent Y axis accelerometer measurement.
ACCEL_ZOUT 16-bit 2’s complement value. Stores the most recent Z axis accelerometer measurement.

Gyroscope Configuration:

Register (Hex)	Register (Decimal)	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
1B	27	XG_ST	YG_ST	ZG_ST	FS_SEL[1:0]		-	-	-

Figure 7: Gyroscope config

This register is used to trigger gyroscope self-test and configure the gyroscopes’ full scale range. Description: Gyroscope self-test permits users to test the mechanical and electrical portions of the gyroscope. The self-test for each gyroscope axis can be activated by controlling the XG_ST, YG_ST, and ZG_ST bits of this register. Self-test for each axis may be performed independently or all at the same time. When self-test is activated, the on-board electronics will actuate the appropriate sensor. This actuation will move the sensor’s proof masses over a distance equivalent to a pre-defined Coriolis force. This proof mass displacement results in a change in the sensor output, which is reflected in the output signal. The output signal is used to observe the self-test response. The self-test response is defined as follows: Self-test response = Sensor output with self-test enabled – Sensor output without selftest enabled The self-test limits for each gyroscope axis is provided in the electrical characteristics tables of the MPU-6000/MPU-6050 Product Specification document. When the value of the self-test response is within the min/max limits of the product specification, the part has passed self test. When the self-test response exceeds the min/max values specified in the document, the part is deemed to have failed self-test. FS_SEL selects the full scale range of the gyroscope outputs according to the following table.

FS_SEL	FULL SCALE RANGE
0	± 250 °/s
1	± 500 °/s
2	± 1000 °/s
3	± 2000 °/s

Table 3: Gyroscope sensitivity

Gyroscope Measurements:
These registers store the most recent gyroscope measurements.

Register (Hex)	Register (Decimal)	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
43	67	GYRO_XOUT[15:8]							
44	68	GYRO_XOUT[7:0]							
45	69	GYRO_YOUT[15:8]							
46	70	GYRO_YOUT[7:0]							
47	71	GYRO_ZOUT[15:8]							
48	72	GYRO_ZOUT[7:0]							

Figure 8: Gyroscope measurement

Gyroscope measurements are written to these registers at the Sample Rate as defined in Register 25. These gyroscope measurement registers, along with the accelerometer measurement registers, temperature measurement registers, and external sensor data registers, are composed of two sets of registers: an internal register set and a user-facing read register set. The data within the gyroscope sensors' internal register set is always updated at the Sample Rate. Meanwhile, the user-facing read register set duplicates the internal register set's data values whenever the serial interface is idle. This guarantees that a burst read of sensor registers will read measurements from the same sampling instant. Note that if burst reads are not used, the user is responsible for ensuring a set of single byte reads correspond to a single sampling instant by checking the Data Ready interrupt. Each 16-bit gyroscope measurement has a full scale defined in FS_SEL (Register 27). For each full scale setting, the gyroscopes' sensitivity per LSB in GYRO_xOUT is shown in the table below

FS_SEL	Full Scale Range	LSB Sensitivity
0	± 250 °/s	131 LSB°/s
1	± 500 °/s	65.5 LSB°/s
2	± 1000 °/s	32.8 LSB°/s
3	± 2000 °/s	16.4 LSB°/s

Table 4: Gyroscope full scale

GYRO_XOUT 16-bit 2's complement value: Stores the most recent X axis gyroscope measurement.
GYRO_YOUT 16-bit 2's complement value. Stores the most recent Y axis gyroscope measurement.
GYRO_ZOUT 16-bit 2's complement value. Stores the most recent Z axis gyroscope measurement.

GPS Module NEO 6M:

The NEO-6 module series is a family of stand-alone GPS receivers featuring the high performance u-blox 6 positioning engine. These flexible and cost effective receivers offer numerous connectivity options in a miniature 16 x 12.2 x 2.4 mm package. Their compact architecture and power and memory options make NEO-6 modules ideal for battery operated mobile devices with very strict cost and space constraints.The 50-channel u-blox 6 positioning engine boasts a Time-To-First-Fix (TTFF) of under 1 second. The dedicated acquisition engine, with 2 million correlators, is capable of massive parallel time/frequency space searches,enabling it to find satellites instantly. Innovative design and technology suppresses jamming sources and mitigates multipath effects, giving NEO-6 GPS receivers excellent navigation performance even in the most challenging environments.

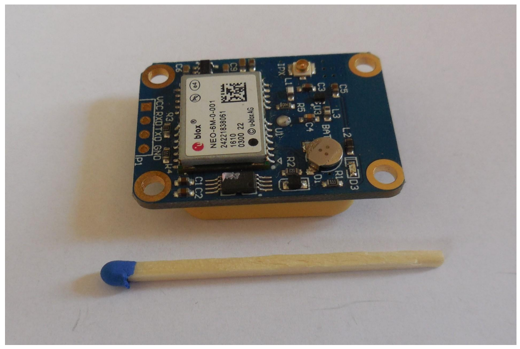


Figure 9: Neo 6M GPS

Specifications:

Timepulse and frequency reference:
NEO-6T comes with a timepulse output which can be configured from 0.25 Hz up to 10 MHz. The timepulse can either be used for time synchronization (i.e. 1 pulse per second) or as a reference frequency in the MHz range. Atimepulse in the MHz range provides excellent long-term frequency accuracy and stability.

Time mark:
NEO-6M can be used for precise time measurements with sub-microsecond resolution using the external interrupt (EXTINT0). Rising and falling edges of these signals are time-stamped to the GPS or UTC time and counted. The Time Mark functionality can be enabled with the UBX-CFG-TM2 message

Parameter	Specification	
Antenna Type		Passive and active antenna
Active Antenna Recommendations	Minimum gain	15 dB (to compensate signal loss in RF cable)
	Maximum gain	50 dB
	Maximum noise figure	1.5 dB

Table 5: Antenna table

Raw data:
Raw data output is supported at an update rate of 5 Hz on the NEO-6T and NEO-6P. The UBX-RXM-RAWmessage includes carrier phase with half-cycle ambiguity resolved, code phase and Doppler measurements, which can be used in external applications that offer precision positioning, real-time kinematics (RTK) and attitude sensing.

Power Management:

U-blox receivers support different power modes. These modes represent strategies of how to control the acquisition and tracking engines in order to achieve either the best possible performance or good performance with reduced power consumption.

Maximum Performance Mode:
During a Cold start, a receiver in Maximum Performance Mode continuously deploys the acquisition engine to search for all satellites. Once the receiver has a position fix (or if pre-positioning information is available), the acquisition engine continues to be used to search for all visible satellites that are not being tracked.

Eco Mode:
During a Cold start, a receiver in Eco Mode works exactly as in Maximum Performance Mode. Once a position can be calculated and a sufficient number of satellites are being tracked, the acquisition engine is powered off resulting in significant power savings. The tracking engine continuously tracks acquired satellites and acquires other available or emerging satellites. Note that even if the acquisition engine is powered off, satellites continue to be acquired.

Power Save Mode:
Power Save Mode (PSM) allows a reduction in system power consumption by selectively switching parts of the receiver on and off.

Boot Time Configuration:

NEO-6 modules provide configuration pins for boot-time configuration. These become effective immediately after start-up. Once the module has started, the configuration settings can be modified with UBX configuration messages. The modified settings remain effective until power-down or reset. If these settings have been stored in battery-backup RAM, then the modified configuration will be retained, as long as the backup battery supply is not interrupted.

NEO-6 modules include both CFG_COM0 and CFG_COM1 pins and can be configured as seen in the Table.

CFG_COM1	CFG_COM0	Protocol	Messages	UARTBaud rate	USB power
1	**1**	**NMEA**	**GSV, RMC, GSA, GGA, GLL, VTG, TXT**	**9600**	**BUS Powered**
1	0	NMEA	GSV, RMC, GSA, GGA, GLL, VTG, TXT	38400	Self Powered
0	1	NMEA	GSV[9], RMC, GSA, GGA, VTG, TXT	4800	BUS Powered
0	0	UBX	NAV-SOL, NAV-STATUS, NAV-SVINFO, NAV-CLOCK, INF, MON-EXCEPT, AID-ALPSERV	57600	BUS Powered

Table 6: Raw data

Neo 6M Electrical specification:

Absolute maximum rating:

Parameter	Symbol	Module	Condition	Min	Max	Units
Power supply voltage	VCC	NEO-6G		-0.5	2.0	V
		NEO-6Q/ NEO-6M		-0.5	3.6	V
Backup battery voltage	V_BCKP	All		-0.5	3.6	V
USB supply voltage	VDDUSB	All		-0.5	3.6	V
Input pin voltage	Vin	All		-0.5	3.6	V
	Vin_usb	All		-0.5	VDDUSB	V
DC current trough any digital I/O pin (except supplies)	Ipin				10	mA
VCC_RF output current	ICC_RF	All			100	mA
Input power at RF_IN	Prfin	All	source impedance = 50 Ω, continuous wave		15	dBm
Storage temperature	Tstg	All		-40	85	°C

Table 7: Absolute max ratings

.Operating Conditions:

Parameter	Symbol	Module	Min	Typ	Max	Units	Condition
Power supply voltage	VCC	NEO-6G	1.75	1.8	1.95	V	
		NEO-6Q, NEO-6M	2.7	3.0	3.6	V	
Supply voltage USB	VDDUSB	All	3.0	3.3	3.6	V	
Backup battery voltage	V_BCKP	All	1.4		3.6	V	
Backup battery current	I_BCKP	All		22		µA	V_BCKP = 1.8 V, VCC = 0V
Input pin voltage range	Vin	All	0		VCC	V	
Digital IO Pin Low level input voltage	Vil	All	0		0.2*VCC	V	
Digital IO Pin High level input voltage	Vih	All	0.7*VCC		VCC	V	
Digital IO Pin Low level output voltage	Vol	All			0.4	V	Iol=4mA
Digital IO Pin High level output voltage	Voh	All	VCC -0.4			V	Ioh=4mA
USB_DM, USB_DP	VinU	All	Compatible with USB with 22 Ohms series resistance				
VCC_RF voltage	VCC_RF	All		VCC-0.1		V	
VCC_RF output current	ICC_RF	All			50	mA	
Antenna gain	Gant	All			50	dB	
Receiver Chain Noise Figure	NFtot	All		3.0		dB	
Operating temperature	Topr	All	-40		85	°C	

Table 8: Operating conditions

SPI

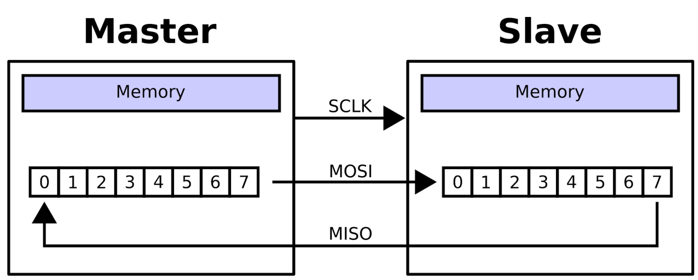


Figure 11: SPI

SPI, which stands for Serial Peripheral Interface, is a synchronous serial communication protocol commonly used to transfer data between a master device and one or more peripheral devices. It is a full-duplex communication protocol, meaning that data can be transmitted in both directions simultaneously. SPI is widely employed in embedded systems, microcontrollers, sensors, and other electronic devices where a fast and efficient data transfer method is required.

Here are the key features and components of SPI:

1.Communication Basics:
Master-Slave Architecture: In SPI communication, there is typically one master device that initiates and controls the communication, and one or more slave devices that respond to the master's commands.

Multiple Slaves: SPI supports multiple slave devices on the same bus, each with a unique slave select (SS) or chip select (CS) line. The master activates the SS/CS line corresponding to the intended slave to initiate communication with that specific device.

2.Physical Connections:

Four Conductors/Wires:

MOSI (Master Out Slave In): The master sends data to the slave on this line.
MISO (Master In Slave Out): The slave sends data back to the master on this line.
SCLK (Serial Clock): This clock signal is generated by the master and synchronizes data transmission.
SS/CS (Slave Select/Chip Select): Activated by the master to select the specific slave device for communication.

3.Data Transfer:

Bit-wise Serial Communication: SPI transfers data one bit at a time, with a specified word length (8, 16, or more bits).

Full-Duplex Communication: Data can be sent and received simultaneously, enhancing communication speed and efficiency.

SPI timing diagrams:
In order to avoid a faulty usage of the SPI, the user needs to comply with certain timing conditions. The following signals need to be considered for timing constraints:

Figure 12: SPI timing

ESP8266 Module:

The ESP8266 is a low-cost, Wi-Fi-enabled microcontroller module that has gained widespread popularity in the maker and electronics communities. It was developed by Espressif Systems, a company based in China, and it is part of the ESP series of modules. The ESP8266 module is known for its simplicity, ease of use, and capability to provide Wi-Fi connectivity to embedded systems and Internet of Things (IoT) devices.

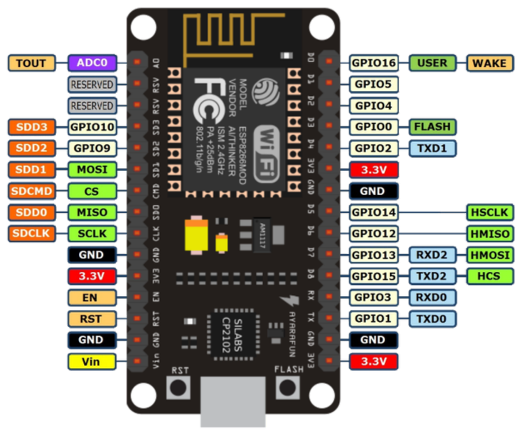


Figure 13: ESP8266 Module

Specifications

CPU:

The ESP8266EX integrates a Tensilica L106 32-bit RISC processor, which achieves extralow power consumption and reaches a maximum clock speed of 160 MHz. The Real-Time Operating System (RTOS) and Wi-Fi stack allow 80% of the processing power to be available for user application programming and development. The CPU includes the interfaces as below:

• Programmable RAM/ROM interfaces (iBus), which can be connected with memory controller, and can also be used to visit flash.
• Data RAM interface (dBus), which can be connected with memory controller.
• AHB interface which can be used to visit the register.

Memory:

ESP8266EX Wi-Fi SoC integrates memory controller and memory units including SRAM and ROM. MCU can access the memory units through iBus, dBus, and AHB interfaces. All memory units can be accessed upon request, while a memory arbiter will decide the running sequence according to the time when these requests are received by the processor. According to our current version of SDK, SRAM space available to users is assigned as below.

• RAM size < 50 kB, that is, when ESP8266EX is working under the Station mode and connects to the router, the maximum programmable space accessible in Heap + Data section is around 50 kB.
• There is no programmable ROM in the SoC. Therefore, user program must be stored in an external SPI flash.

External Flash:
ESP8266EX uses external SPI flash to store user programs, and supports up to 16 MB memory capacity theoretically. The minimum flash memory of ESP8266EX is shown below:

• OTA disabled: 512 kB at least
•OTA enabled: 1 MB at least

High Frequency Clock:
The high frequency clock on ESP8266EX is used to drive both transmit and receive mixers. This clock is generated from an internal crystal oscillator and external crystal. The crystal frequency ranges from 24 MHz to 52 MHz.

The internal calibration inside the crystal oscillator ensures that a wide range of crystals can be used, nevertheless the quality of the crystal is still a factor to consider to have reasonable phase noise and good Wi-Fi sensitivity.

External Clock:
An externally generated clock is available with the frequency ranging from 24 MHz to 52 MHz.

Power Management:

Power Mode	Description	Power Consumption
Active (RF working)	Wifi TX/RX Packet	400mA

Modern-sleep	CPU is working	15mA
Light sleep	-	0.9mA
Deep sleep	Only RTC is working	20uA
Shutdown	-	0.5uA

Table 9: power consumption

ESP8266EX is designed with advanced power management technologies and intended for mobile devices, wearable electronics and the Internet of Things applications. The low-power architecture operates in the following modes:

• Active mode: The chip radio is powered on. The chip can receive, transmit, or listen.
• Modem-sleep mode: The CPU is operational. The Wi-Fi and radio are disabled.
• Light-sleep mode: The CPU and all peripherals are paused. Any wake-up events (MAC, host, RTC timer, or external interrupts) will wake up the chip.
• Deep-sleep mode: Only the RTC is operational and all other part of the chip are powered off.

I2C Interface:

I2C, which stands for Inter-Integrated Circuit, is a widely used synchronous serial communication protocol that enables communication between various electronic components, such as microcontrollers, sensors, and peripherals. Developed by Philips (now NXP Semiconductors), I2C is a multi-master, multi-slave protocol, allowing multiple devices to communicate with each other on the same bus.

ESP8266EX has one I2C, which is realized via software programming, used to connect with other microcontrollers and other peripheral equipment such as sensors. I2C is illustrated in the figure.

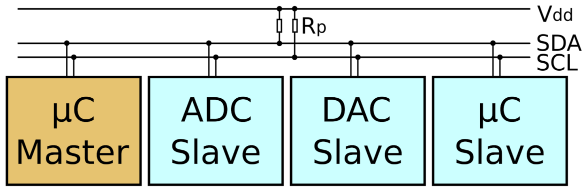


Figure 14: I2C

Software Used

Arduino IDE:

The Arduino IDE (Integrated Development Environment) is an open-source software platform used for programming and developing applications for Arduino microcontrollers. Arduino is an open-source electronics platform that provides a range of hardware and software tools for creating interactive and programmable projects. The Arduino IDE serves as the software interface through which users can write, compile, and upload code to Arduinos and other boards with familiar firmware like the expressif's ESP8266.

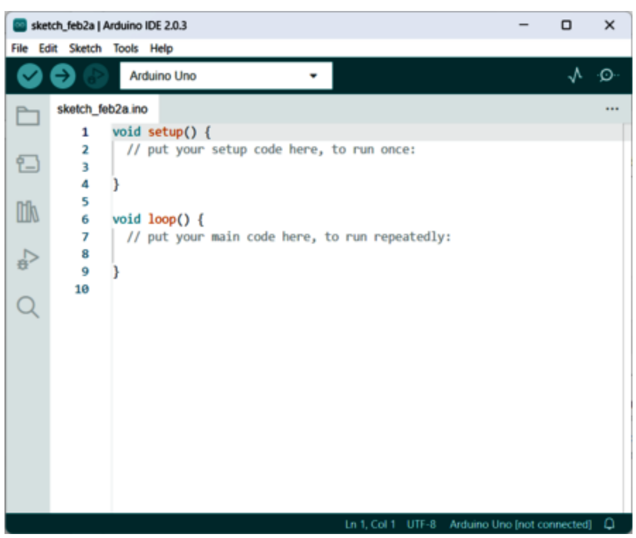


Figure 15: Arduino IDE

Cloud Services:

A cloud service refers to any service made available to users on-demand via the internet from a cloud computing provider's servers as opposed to being provided from a company's own on-premises servers. These services can include infrastructure resources (such as computing power and storage), software applications, and other resources delivered over the internet.

Infrastructure as a Service (IaaS):
IaaS provides virtualized computing resources over the internet. Users can rent virtual machines, storage, and networks on a pay-as-you-go basis. Popular IaaS providers include Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform

Platform as a Service (PaaS)
Platform as a Service (PaaS) is a cloud computing service model that provides a comprehensive platform allowing developers to build, deploy, and scale applications without the complexity of managing the underlying infrastructure. PaaS offerings include tools, development frameworks, and runtime environments that streamline the application development process. In the context of big data, PaaS plays a crucial role in simplifying the creation and deployment of large-scale data processing and analytics applications.Google Cloud Platform (GCP).

Key Characteristics of PaaS:

Abstraction of Infrastructure:
PaaS abstracts the complexities of managing servers, networks, and storage. Developers can focus on writing code and designing applications without being burdened by infrastructure management tasks.

Development Frameworks:
PaaS platforms provide development frameworks and tools that facilitate the creation of applications. This includes programming languages, libraries, and pre-built components to accelerate the development process.

Automated Deployment:
PaaS automates the deployment process, allowing developers to easily deploy and scale their applications. This simplifies tasks such as version control, testing, and continuous integration.

Scalability:
PaaS platforms offer built-in scalability features, enabling applications to handle varying workloads. Automatic scaling ensures that resources are allocated efficiently based on demand.
PaaS in Big Data:

Data Processing Frameworks:
PaaS environments support popular big data processing frameworks like Apache Hadoop, Apache Spark, and Apache Flink. These frameworks allow developers to process and analyze massive datasets in a distributed and parallelized manner.

Database Services:
PaaS provides managed database services that support the storage and retrieval of large volumes of data. These databases are often designed to handle the specific requirements of big data applications, such as NoSQL databases for unstructured data.

Analytics and Machine Learning:
PaaS platforms often integrate analytics and machine learning services. These services enable developers to build and deploy advanced analytics models and machine learning algorithms without deep expertise in these domains.

Stream Processing:
For real-time data processing, PaaS platforms offer stream processing services. These services allow developers to process and analyze data in motion, making them suitable for applications requiring low-latency responses.
Integration with Data Sources:

PaaS facilitates integration with various data sources, including data lakes, cloud storage, and external APIs. This allows big data applications to ingest, process, and analyze data from diverse origins.
Collaboration and Version Control:

PaaS platforms often include collaboration tools and version control systems. This ensures that development teams can work collaboratively on big data projects, manage code versions, and track changes efficiently.

Benefits of PaaS in Big Data Applications:

Rapid Development:

PaaS accelerates the development of big data applications by providing pre-built components and development frameworks, allowing developers to focus on application logic.
Scalability and Flexibility:
PaaS platforms automatically scale resources based on demand, ensuring that big data applications can handle varying workloads and scale horizontally as needed.

Cost-Efficiency:
PaaS models often follow a pay-as-you-go pricing model, optimizing costs by charging only for the resources consumed during application development and deployment.

Simplified Maintenance:
PaaS handles infrastructure maintenance tasks, such as security updates and patches, freeing developers from routine operational tasks and allowing them to concentrate on building features and improving application functionality.
In conclusion, PaaS plays a vital role in simplifying the development, deployment, and management of big data applications. By abstracting infrastructure complexities and providing a rich set of tools and services, PaaS empowers developers to harness the power of big data technologies efficiently and accelerates the innovation and delivery of data-intensive applications.

Python Programming:

Python is a versatile and widely-used programming language known for its simplicity, readability, and extensive community support. It is used for various applications, including web development, data analysis, machine learning, artificial intelligence, automation, and more.

Python, with libraries like TensorFlow, PyTorch, and scikit-learn, is extensively used for machine learning model inference. Once a machine learning model is trained, it can be deployed, and Python is often the language of choice for implementing the inference process. Frameworks like TensorFlow Serving and Flask can be used to create APIs for serving machine learning model

Results:

The IMU angles are sent to the cloud terminal and inturn stored in a cointainer using a stream analytics job (SAJ)

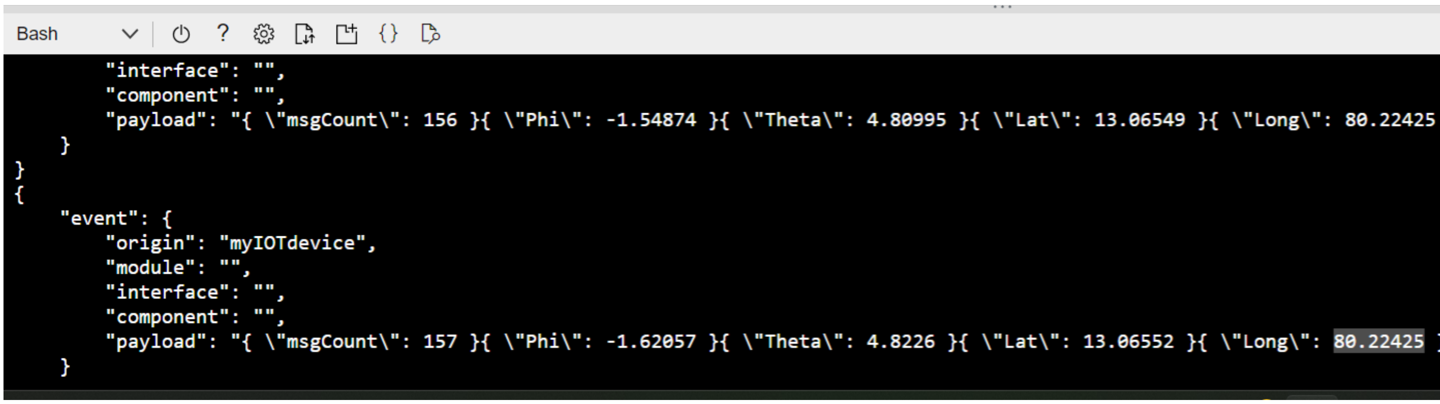


Figure 16: telemetry updates

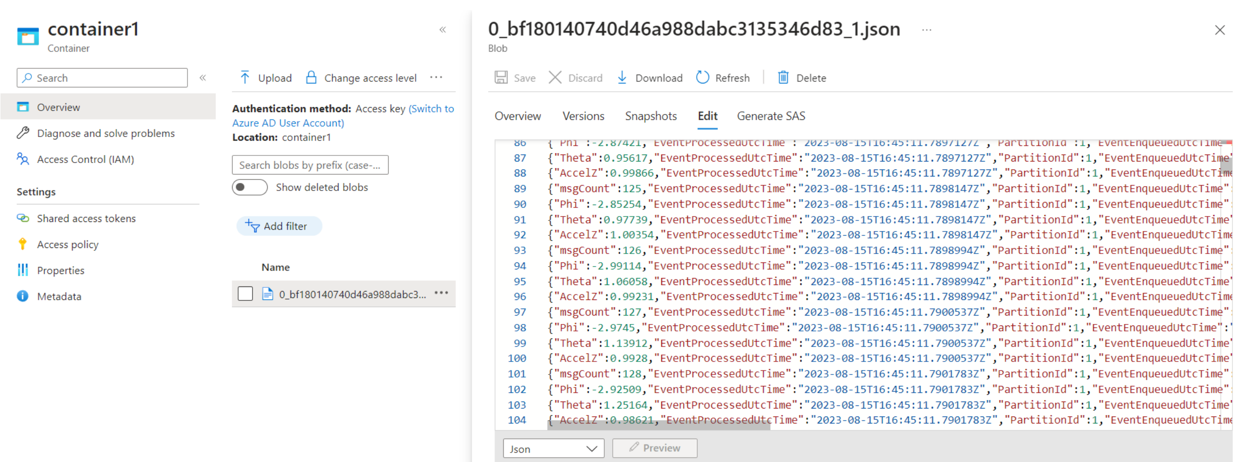


Figure 17: Output in container

Conclusion

The data that is generated from the system is processed and able to provide a live inference that is used in the selection of optimal routes. With internet connectivity, live inferences can be made and the most optimal route be selected. Thus the raw stream data and inferred data is available to view in real-time.

Applications:

1. Route selection for logistics/freight companies:
   Can be used to determine the best route for shipping with time constraints and breakable/fragile cargo.

2. Route selection for Delivery Personnel:
   Reduces congestions in traffic and prevents accidents

3. Research:
   Provides large amounts and highly accurate data that is very useful in predicting accident prone areas.

4. Municipal roadway maintenance:
   Employed as a tool by the Government for monitoring and maintaining the quality of roadways.

Future Scope:

Smartphone Replaced Hardware

Can be implemented by further minimizing hardware by obtaining and processing inertial and GPS data through smartphones on a stable platform that is immune to vibrations and drift. By doing this, there is internet connectivity, inertial data, location data with no hardware overhead. GPS allows smartphones to accurately determine their location by receiving signals from satellites, enabling applications such as mapping, navigation, and location-based services. It plays a pivotal role in daily activities, from finding directions to tracking fitness activities. The ubiquitous nature of smartphones and the population's growing dependence on it lead to better Gyroscopes are integral for applications like augmented reality, where precise understanding of the device's position is crucial. These sensors often work in conjunction with accelerometers and magnetometers, creating a sensor fusion approach that enhances the overall accuracy and reliability of the smartphone's spatial awareness. The improving performance, more accurate GPS and gyroscope on the device can be used to fetch and throw data from the cloud, leading to a very cost effective solution.

Edge Computing:

Edge computing is a distributed computing paradigm that brings computational resources closer to the data source, reducing latency and improving the efficiency of data processing. Unlike traditional cloud computing, where data is sent to a centralized cloud server for processing, edge computing processes data locally on devices or in edge servers situated near the data source. This decentralized approach is particularly beneficial for applications that require real-time processing, low-latency responses, and reduced reliance on a centralized cloud infrastructure

For applications that are not suitable with the bulky hardware can use a light version of the same device with lesser capability but data that can still be used to generate a favorable output. The inference happens on the hardware rather than the cloud, although the model is trained in the cloud

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K. A. Kalpoma, G. M. R. K. Robin, J. Ferdaus, M. M. R. Mitul and A. Rahman, "Satellite Image Database Creation for Road Quality Measurement of National Highways of Bangladesh," IGARSS 2022 - 2022 IEEE International Geoscience and Remote Sensing Symposium, Kuala Lumpur, Malaysia, 2022, pp. 3047-3050, doi: 10.1109/IGARSS46834.2022.9883389.

Qihui Qin, Meiling Feng, Junqing Sun and Bin Sun, "Prediction of road resistance based on historical/real-time information and road quality," 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD), Zhangjiajie, 2015, pp. 1073-1077, doi: 10.1109/FSKD.2015.7382091.

H. Tariq, S. Mazhar and H. Hameed, "Poster Abstract: Road Quality Classification for Road Repair Authorities and Regular Drivers, Using an On-Board Data Logger," 2018 17th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN), Porto, Portugal, 2018, pp. 142-143, doi: 10.1109/IPSN.2018.00034. No inference and vulnerable to vibrations

A. El-Kady, K. Emara, M. H. ElEliemy and E. Shaaban, "Road Surface Quality Detection using Smartphone Sensors: Egyptian Roads Case Study," 2019 Ninth International Conference on Intelligent Computing and Information Systems (ICICIS), Cairo, Egypt, 2019, pp. 202-207, doi: 10.1109/ICICIS46948.2019.9014721.

N. T. Sy, M. Avila, S. Begot and J. C. Bardet, "Detection of defects in road surface by a vision system," MELECON 2008 - The 14th IEEE Mediterranean Electrotechnical Conference, Ajaccio, France, 2008, pp. 847-851, doi: 10.1109/MELCON.2008.4618541.

S.no	**Year of Publishing**	**Paper Name**	**Advantages**	**Disadvantages**	**Technology Used**
1	2008	N. T. Sy, M. Avila, S. Begot and J. C. Bardet, "Detection of defects in road surface by a vision system," MELECON 2008 - The 14th IEEE Mediterranean	Cost effective	Vulnerable to changes in light	Computer Vision

		Electrotechnical Conference, Ajaccio, France, 2008, pp. 847-851, doi: 10.1109/MELCON.2008.4618541.			
is	2019	A. El-Kady, K. Emara, M. H. ElEliemy and E. Shaaban, "Road Surface Quality Detection using Smartphone Sensors: Egyptian Roads Case Study," 2019 Ninth International Conference on Intelligent Computing and Information Systems (ICICIS), Cairo, Egypt, 2019, pp. 202-207, doi: 10.1109/ICICIS46948.2019.9014721.	Accurate	Inference is not available in real time	Smartphone sensors
3	2018	H. Tariq, S. Mazhar and H. Hameed, "Poster Abstract: Road Quality Classification for Road Repair Authorities and Regular Drivers, Using an On-Board Data Logger," 2018 17th ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN), Porto, Portugal, 2018, pp. 142-143, doi: 10.1109/IPSN.2018.00034.	Effective	Vulnerable to vibrations	Sensor Network
4	2015	Qihui Qin, Meiling Feng, Junqing Sun and Bin Sun, "Prediction of road resistance based on historical/real-time information and road quality," 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD), Zhangjiajie, 2015, pp. 1073-1077, doi: 10.1109/FSKD.2015.7382091. a	Can use for predictio n	Does not provide road data	Fuzzy System
5	2022	K. A. Kalpoma, G. M. R. K. Robin, J. Ferdaus, M. M. R. Mitul and A. Rahman, "Satellite Image Database Creation for Road Quality Measurement of National Highways of Bangladesh," IGARSS 2022 - 2022 IEEE International Geoscience and Remote Sensing Symposium, Kuala Lumpur, Malaysia, 2022, pp. 3047-3050, doi: 10.1109/IGARSS46834.2022.9883389.	Stable training data	Low Accuracy and lack of sectional data	Satellite

6	2016	L. Israel Pinto and P. Bertemes Filho, "New Quantitative Indicator for Measuring the Quality of Road," in IEEE Latin America Transactions, vol. 14, no. 2, pp. 582-585, Feb. 2016, doi: 10.1109/TLA.2016.7437196.	Can Indicate quality of road	No inference tool	Quantitative analysis
7	2018	Y. -L. Jeng, S. -B. Huang and C. -F. Lai, "Inspect Road Quality by Using Anomaly Detection Approach," 2018 International Conference on System Science and Engineering (ICSSE), New Taipei, Taiwan, 2018, pp. 1-4, doi: 10.1109/ICSSE.2018.8520151.	Can show the paramete rs of raod	No bigdata implement ation	Anomaly detection
8	2019	T. Guo, K. Iwamura and M. Koga, "Towards high accuracy road maps generation from massive GPS Traces data," 2007 IEEE International Geoscience and Remote Sensing Symposium, Barcelona, Spain, 2007, pp. 667-670, doi: 10.1109/IGARSS.2007.4422884.	Provides map data	Does not provide road data	GPS traces
9	2009	Tiehu Fan and Guihe Qin, "GPS/MAP based road parameters acquirement for automotive control system," 2009 2nd International Conference on Power Electronics and Intelligent Transportation System (PEITS), Shenzhen, China, 2009, pp. 213-218, doi: 10.1109/PEITS.2009.5406918.	Implemn table	Does not provide means of compariso n	GPS/MAP based road parameters acquirement
10		S. Kamijo, K. Okumura and A. Kitamura, "Digital road map database for vehicle navigation and road information systems," Conference Record of papers presented at the First Vehicle Navigation and Information Systems Conference (VNIS '89), Toronto, Ontario, Canada, 1989, pp.	Provides Map data	Does not indicate road usability	Map Database

		319-323, doi: 10.1109/VNIS.1989.98783.			

Table 10: Literature survey