Real-Time Tilt and Acceleration Monitoring System using ESP32 and MPU6050

1. System Analysis

Introduction

This project focuses on building a real-time tilt and acceleration monitoring system using the ESP32 microcontroller, MPU6050 gyroscope + accelerometer sensor, and SSD1306 OLED display. The system reads acceleration and angular tilt data, displays it on an OLED screen, and serves it via a web interface.

Functional Requirements

- Read acceleration and gyroscopic data in real time.
- Compute tilt angles (pitch and roll) using sensor fusion.
- Display sensor readings on a local OLED display.
- Serve sensor readings on a real-time HTML web interface.

System Purpose and Significance

The system is designed for applications where real-time movement or tilt monitoring is essential, such as in drone orientation systems, wearable fall detection, or robotic stability platforms. The ability to visualize sensor data both locally and over a network adds flexibility and practical use.

2. System Diagram

System Diagram Description

The system consists of the following interconnected components:

- **ESP32**: Acts as the central processing unit. It reads data from the sensor, processes it, displays it on the OLED, and hosts a web server.

- **MPU6050 Sensor**: Provides raw accelerometer and gyroscope data.
- **SSD1306 OLED (128x64)**: Displays real-time temperature, acceleration (X, Y, Z), and tilt (pitch, roll).
- **WiFi Interface**: Used to serve a web page displaying sensor data.

Diagram Functions

- **MPU6050** → **ESP32**: I2C communication to read sensor data.
- **ESP32** → **OLED**: I2C communication to display sensor output.
- **ESP32** → **WiFi**: Hosts a web page with JSON/HTML sensor data.

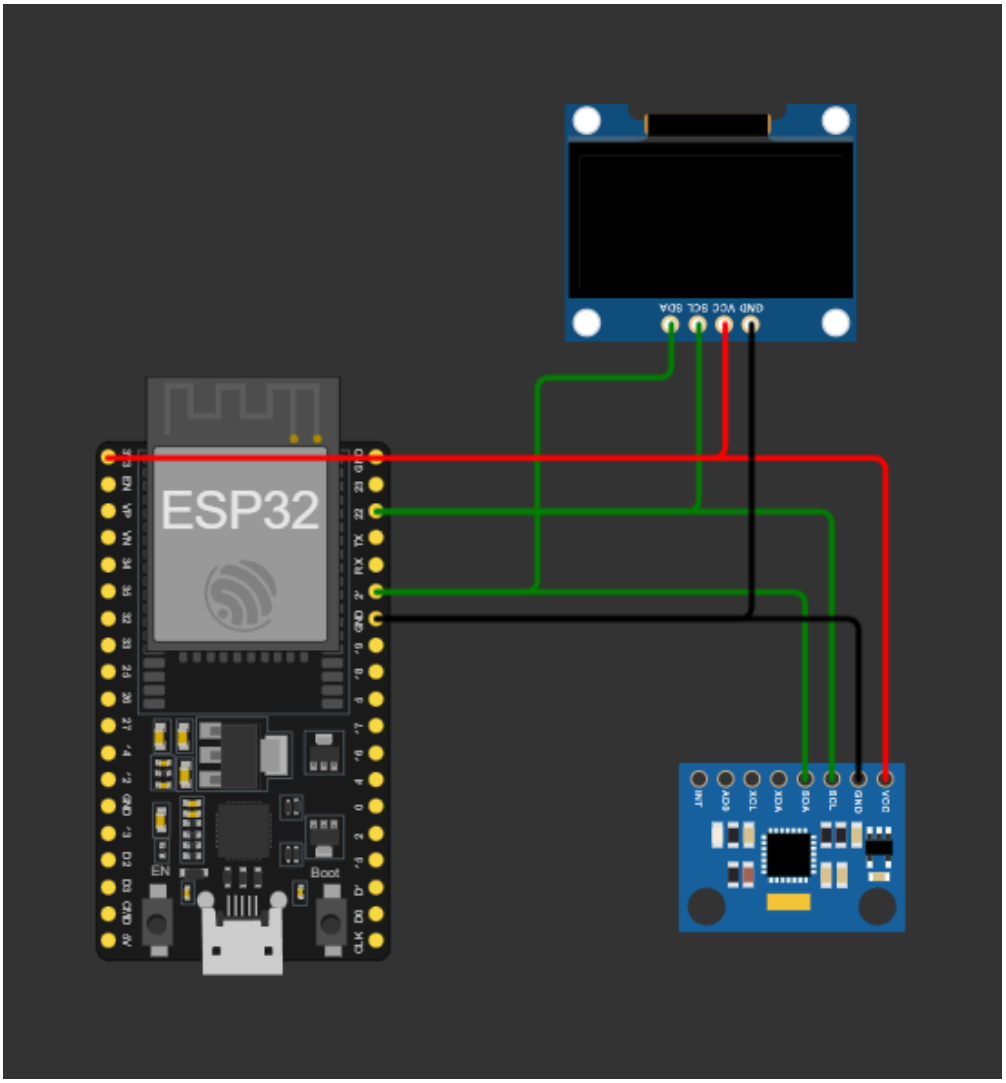

Figure 1: System Diagram of the ESP32 IMU Monitoring System

3. Codes

Client/Server Code Highlights

- Initializes essential components including WiFi, I2C communication, and the server endpoint.
- Utilizes the Adafruit MPU6050 library to acquire real-time accelerometer and gyroscope data.
- Computes pitch and roll angles using the `atan2` function for accurate orientation estimation.
- Displays sensor readings on the OLED using the `Adafruit_SSD1306` library.
- Hosts an HTML webpage over WiFi that dynamically presents temperature, acceleration, and tilt data.

Client Code Overview and Explanation

1. WiFi Setup

```
WiFi.begin(ssid, password);
while (WiFi.status() != WL_CONNECTED) {
  delay(500);
  Serial.print(".");
}
```

Explanation: Connects the ESP32 to a local WiFi network using the given SSID and password. A loop waits until the connection is successfully established.

2. MPU6050 Initialization

```
if (!mpu.begin()) {
  Serial.println("Failed to find MPU6050 chip");
  while (1) { delay(10); }
}
```

Explanation: Initializes the MPU6050 sensor. If not detected, the system enters an infinite loop and halts.

3. Tilt Computation

```
float tiltx = atan2(ay, az) * (180.0 / PI);
float tilty = atan2(-ax, sqrt(ay * ay + az * az)) * (180.0 / PI);
```

Explanation: Calculates tilt angles (pitch and roll) using the `atan2` function for stable angle estimation, converting results from radians to degrees.

4. HTML Web Page Handler

```
void handleRoot() {
  ...
  <meta http-equiv='refresh' content='1'/>
  ...
  <span>%.2f</span>  // Temperature
  <span>%s</span>    // Acceleration
  <span>%s</span>    // Tilt
  ...
}
```

Explanation: This function serves a simple auto-refreshing HTML page that displays temperature, acceleration, and tilt data. Styling is applied using embedded CSS and icons via FontAwesome.

5. OLED Display Output

```
display.print("Acc X:"); display.print(accX, 2);
display.print(" Y:");    display.print(accY, 2);
...
display.print("tiltx:"); display.print(tiltx, 1);
```

Explanation: This section formats and displays acceleration and tilt values on the OLED. The display is cleared before each update to prevent overlap.

6. Sensor Event Retrieval

```
mpu.getEvent(&a, &g, &temp);
```

Explanation: Polls the MPU6050 sensor and retrieves the latest accelerometer, gyroscope, and temperature data into the corresponding event structures.

7. Web Server Setup

```
server.on("/", handleRoot);
server.begin();
```

Explanation: Maps the root URL (‘/‘) to the function that sends HTML sensor data and starts the web server to begin handling HTTP requests.

Snapshots

- **OLED Display Output:** Real-time data including temperature, acceleration (X, Y, Z), and calculated tilt (pitch and roll) are displayed on a 0.96” OLED screen connected to the ESP32.
- **Compact Breadboard Setup:** The ESP32, MPU6050 IMU, and OLED are connected via I2C and powered on a single breadboard layout.

- **Live Sensor Reading Snapshot:** OLED display showing readings with updated temperature and accelerometer data.
- **Web UI Snapshot:** A minimal web interface hosted by the ESP32 displaying sensor data using FontAwesome icons, color styling, and auto-refresh every 1 second.

System Working

The system is powered by an ESP32 which reads real-time data from the MPU6050 IMU sensor over I2C. The sensor provides temperature and 3-axis acceleration data, from which the pitch and roll are calculated using trigonometric functions.

This data is:

- Displayed on a local OLED screen in a readable format.
- Simultaneously served over WiFi through an asynchronous web server.
- Presented on a styled HTML page using icons from FontAwesome, with auto-refresh implemented via a meta-refresh tag.

This system is modular and suitable for applications like drone orientation tracking, fall detection in elderly care systems, or real-time monitoring tools in robotics.

5. References, Presentation, and Vodcast

References

- Adafruit Industries (2020) *MPU6050 6-DOF Accelerometer and Gyroscope*. Available at: `https://learn.adafruit.com/mpu6050-6-dof-accelerometer-and-gyroscope/overview`.
- Adafruit Industries (2021) *Adafruit SSD1306 OLED Library*. Available at: `https://github.com/adafruit/Adafruit_SSD1306` .
- Arduino (2018) *atan2() - Arduino Reference*. Available at: `https://www.arduino.cc/reference/en/language/functions/math/atan2/`.
- InvenSense (2013) *MPU-6000 and MPU-6050 Product Specification*. Available at: `https://invensense.tdk.com/wp-content/uploads/2015/02/MPU-6000-Datasheet1.pdf` .
- Solomon Systech Limited (2019) *SSD1306 OLED Display Driver Datasheet*. Available at: `https://solomon.jp/wp-content/uploads/2016/03/SSD1306-1.pdf` .

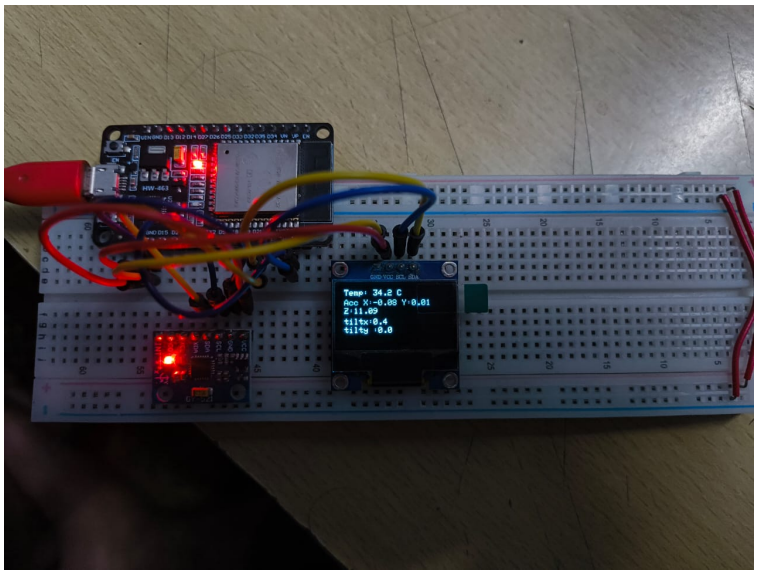

Figure 1: Live data on OLED (horizontal layout)

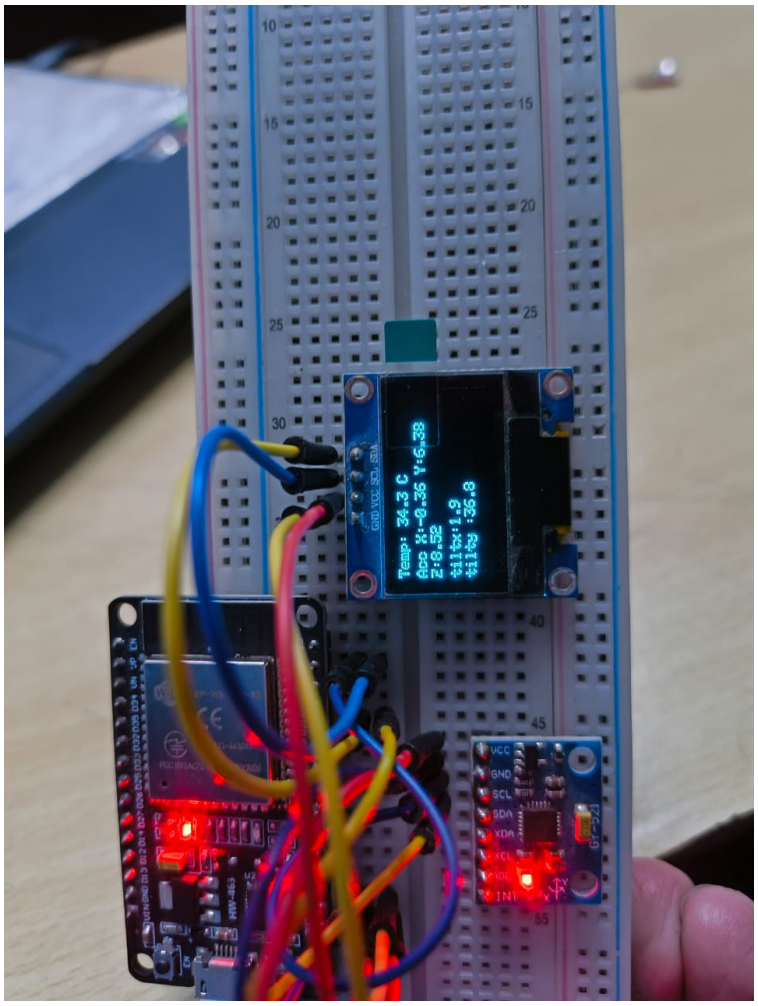

Figure 2: Vertical breadboard configuration

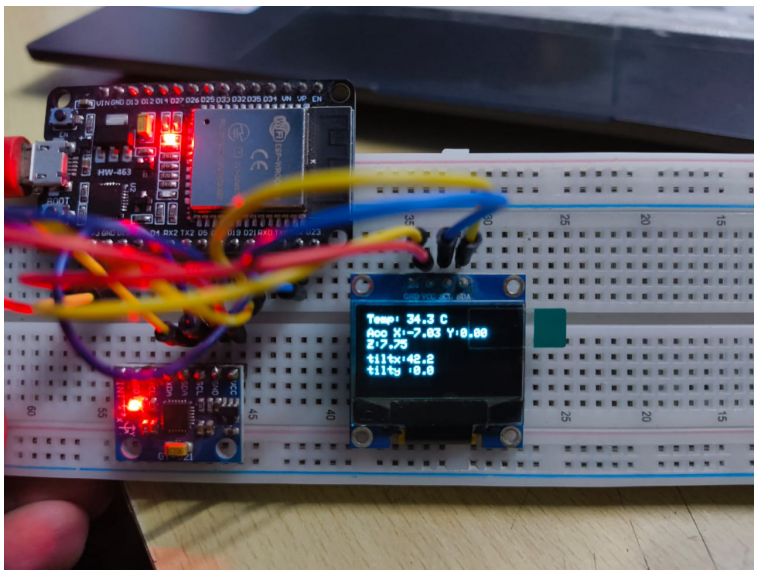

Figure 3: Updated sensor values displayed

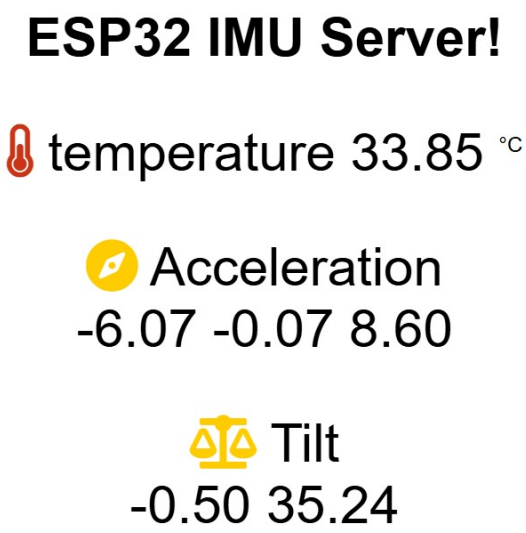

Figure 4: ESP32 Web Server UI