Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 04, April-2025

Precision Drone Control using MPU6050 Sensor Integration

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***Abstract*— This project focuses on developing a wireless control system for a drone using an MPU6050 sensor and ESP32 microcontrollers. The system is designed to capture the orientation and movement data of the drone through the MPU6050, which measures pitch, roll, and yaw. This data is processed by an ESP32 transmitter and communicated wirelessly to an ESP32 receiver onboard the drone using the ESP-NOW protocol. The flight controller on the receiver side interprets the transmitted data to control the drone's movement. By employing real-time data from the sensor, this setup ensures efficient and responsive drone control, providing a flexible and cost-effective solution for Drone navigation systems.**

Keywords: **Drone Control, MPU-6050, ESP32, ESP-NOW, Real-time Processing, Wireless Communication, Flight Stability.**

I. INTRODUCTION

Drone technology achieved rapid advancement that now powers delivery services alongside agricultural and surveillance operations as well as recreational drone applications. Performance of drones heavily depends on their control system because this system needs to operate in real time while maintaining accuracy and stability together with instant response capabilities. Researchers along with enthusiasts and small-scale developers cannot access the high accuracy levels of commercial drone navigation systems because these solutions are both expensive and rigid. The proposed solution builds an affordable drone control system based on the ESP32 microcontroller and MPU-6050 motion sensor to deliver effective and flexible real-time control functions.

The MPU-6050 sensor provides comprehensive orientation data through its 3-axis accelerometer and gyroscope that helps drones maintain stability while enabling precise maneuvers. The ESP-NOW protocol operates through the ESP32 microcontroller to process real-time sensor data from the motion sensor to establish wireless connections with drone reception units. Drone operators benefit from this system because it enables them to customize their designs while maintaining cost-effectiveness because it avoids prpriety requirements.

Creating controllers that unite sensors with creating wireless interconnections between the flight controllers and sensors represents the leading project goals. The system provides precise drone control through successful connections between its operational elements suitable for industrial work fields as well as leisure activities.

Scientists created an open-source adaptable system platform for low-cost drone development to enable broad technological distribution. The development of advanced UAV automation and control systems is possible because experimental research demonstrated similar performance results as commercial drone systems. The project demonstrates potential as a fundamental technology base to enhance sophisticated drone functions through real-time processing capabilities alongside strong communications platforms with automated flight modes and autonomous navigation features.

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II. EASE OF USE

The designed drone control system places emphasis on user-friendly operation allowing both expert and beginner-level users to utilize the system effectively. Researchers and hobbyists and students can easily start because the system relies on popular research-based components including ESP32 microcontrollers and MPU-6050 sensors. The hardware setup requires no complicated soldering process because its simple configuration uses standard I²C communication wires with jumper wires for prototype connections that do not require specialist tools. Basic users can create the system on their own with minimum support thanks to its plug-and-play construction.

The project operates with the user-friendly Arduino IDE software because of its popular reputation for community-aligned programming simplicity. People who utilize prewritten MPU-6050 and ESP-NOW protocol libraries through their development process benefit from faster development and superior focus on system functionality instead of complex implementation mechanics. The supplied firmware demonstrates modular design with proper documentation which enables users to modify their system by adding sensors or altering PID parameters. Customers experience enhanced usability through serial monitor feedback because the feature delivers real-time sensor data and system performance output necessary for calibration and debugging processes.

Users can easily operate the wireless communications through the ESP-NOW protocol. The main feature distinguishing ESP-NOW from conventional Wi-Fi is its peer-to-peer functionality that relies on device MAC addresses only to establish wireless connections without requiring network configuration access to the internet. Network management becomes straightforward because of this system which maintains reliable low-latency connectivity despite lacking infrastructure. The system features scalable properties because users can integrate cameras or GPS modules while keeping the design unchanged.

Both usability and low expenses combined with maintenance-friendly features provide additional ease of use for the system. The system lowers long-term expenses because its off-the-shelf hardware combined with open-source software does not require licensing payments nor proprietary limitations. The system maintains reasonable costs and eco-friendliness because ESCs and LiPo batteries function as interchangeable parts. The platform serves as an excellent platform for teaching and research activities and do-it-yourself drone enthusiasts because it combines advanced capabilities with simple operation. Users advantage from the modular construction and extensive documentation to modify and increase the system for their individual needs.

III. SYSTEM DESIGN AND ARCHITECTURE

The distributed architecture of the precision drone control system combines wireless communication, sensor data collection, and flight control into a unified system. A ground-based transmitter unit and an onboard receiver unit installed on the drone make up the system's two main subsystems. An ESP32 microcontroller is linked to an MPU6050 inertial measurement unit (IMU) by I²C communication in the transmitter unit. In order to increase accuracy, this subsystem uses sensor fusion algorithms to process real-time orientation data, such as pitch, roll, and yaw. After processing, the ESP-NOW protocol—which offers dependable, low-latency communication without the need for external network infrastructure—is used to wirelessly send the data to the drone.

Another ESP32 microcontroller makes up the drone's receiver unit, which decodes incoming orientation data and converts it into control signals for the fly stabilization system. Through electronic speed controllers (ESCs), the microcontroller dynamically modifies the speed of four brushless motors using a PID (Proportional-IntegralDerivative) control method. Each motor's thrust is individually controlled to accomplish the appropriate attitude modifications in the motor mixing logic, which is based on a conventional quadcopter arrangement. Through the use of suitable voltage regulation circuits, a LiPo battery provides a steady voltage to the propulsion system and control electronics.

The software architecture of the system is built for real-time performance and modularity. The MPU6050 sensor is initialized on the transmitter side by code running on the ESP32, which also continuously samples motion data, filters it to cut down on noise, and packages it into a small data structure for transmission. The receiver firmware calculates PID corrections, manages incoming data via callback functions, and produces pulse-width modulation (PWM) signals to power the ESCs. By continuously observing and adjusting the drone's attitude in response to transmitted sensor data, this closed-loop control system guarantees steady flying.

The ESP-NOW protocol enables data transmission between the drone system and base station station while providing several advantages for this application. ESP-NOW offers instant data exchanges without connection protocols since it removes conventional Wi-Fi network overhead while decreasing latency levels. The data packets contain minimal essential orientation data while their design achieves maximum bandwidth conservation while ensuring precision accuracy. The system implements core fault-tolerance methods to enhance dependability which integrate communication timeout analysis and sensor maintenance routines.

The selection of hardware components focused on achieving high performance alongside availability and cost effectiveness. The ESP32 microcontrollers provide wireless functions and complete processing abilities to process sensor inputs and execute control algorithms.

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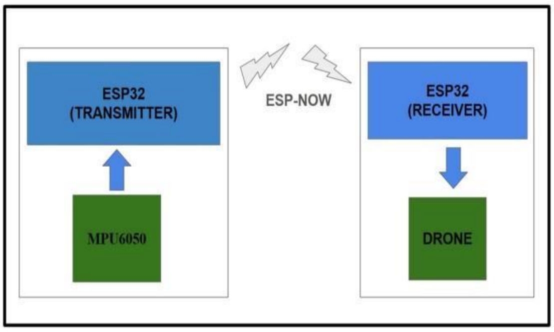
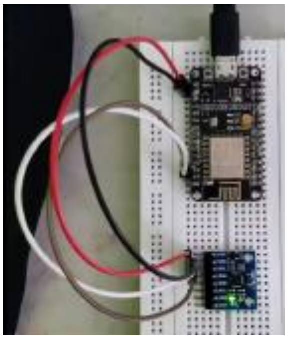
The MPU-6050 delivers sufficient measurement accuracy for stabilization functions despite offering basic features that lower its cost compared to complex IMUs. Positioning the motors properly across the drone body while using a robust frame base ensures the F450 drone frame functions predictably. Through proper integration of hardware components and software programs this system operates with functionality alongside easy usage which suits drone research applications as well as educational purposes and actual field operations.

Modern complex control systems evolve through the integration of different components to stay within their original design boundaries according to architectural principles. When integrated independently the sensor subsystem ignores communication subsystem and actuation subsystem operations because of their distinct separation. The modular structure enables better development and debugging processes together with future system upgrades such as autonomous navigation functions and higher-level control system compatibility. The platform originated from well-considered system design to meet its purpose as an investigation tool for advanced unmanned aerial vehicle control theories.

Architecture Diagram Overview



1. Transmitter Unit (Ground Station)
   - ESP32 Microcontroller: Processes sensor data and handles wireless transmission
   - MPU-6050 IMU: Measures 6-axis motion data (accelerometer + gyroscope)
   - Data Processing: Filters raw sensor data to calculate pitch, roll, and yaw angles
   - Wireless Transmission: Sends orientation data via ESP-NOW protocol



2. Communication Layer
   - ESP-NOW Protocol: Enables direct peer-to-peer communication between ESP32 devices
   - Low Latency: Achieves <20ms transmission delay
   - Reliable: Includes automatic packet retransmission for robustness

3. Receiver Unit (On Drone)
   - ESP32 Flight Controller: Receives and interprets orientation data
   - PID Control System: Computes motor adjustments for stabilization
   - Motor Mixing Logic: Converts control signals into individual motor commands

4. Actuation System
   - Electronic Speed Controllers (ESCs): Translate control signals into motor speeds
   - Brushless Motors (x4): Provide thrust based on PID-corrected inputs
   - Frame (F450): Standard quadcopter platform with symmetrical motor layout

5. Power Management
   - LiPo Battery (3S, 11.1V): Powers both electronics and propulsion system
   - Voltage Regulation: 5V BEC for ESP32 and 3.3V for sensors

International Journal of Engineering Research & Technology (IJERT)
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6. Key Features ○ Real-time sensor data processing
○ Wireless control without Wi-Fi dependency
○ Modular design for easy upgrades
○ Hardware safety mechanisms (PWM timeout)

7. Data Flow

MPU-6050 → ESP32 (Tx) → ESP-NOW → ESP32 (Rx) → PID → ESCs → Motors

IV. IMPLEMENTATION

The MPU-6050 sensor and ESP32 microcontrollers are used in the project's implementation to accomplish precise drone control through a methodical combination of hardware and software components. To regulate the drone's flight dynamics, the system is made to wirelessly communicate, process, and record motion data in real time. A thorough explanation of the implementation procedure may be found below.

Hardware Setup

The drone frame (F450), which acts as the structural base, is assembled first in the hardware setup process. The frame is equipped with four brushless motors, each of which is linked to an Electronic Speed Controller (ESC) to control motor speed. The entire system is powered by a Li-Po battery, which guarantees there is enough energy for flying. The transmitter unit, which is made up of an ESP32 microcontroller, is connected to the MPU-6050 sensor. The sensor measures acceleration and angular velocity to record orientation data (pitch, roll, and yaw). Another ESP32 serves as the drone's receiver, interacting with the flight controller to modify motor speeds in response to data transmission.

Sensor Integration and Data Acquisition

To guarantee precise data gathering, the MPU-6050 sensor is initialized and calibrated. It determines the drone's orientation in three dimensions using its integrated gyroscope and accelerometer. The sensor provides real-time motion updates for the drone by utilizing the I2C protocol to interact with the transmitter ESP32. In order to reduce noise and increase accuracy, the ESP32 combines accelerometer and gyroscope signals using complimentary filter techniques. After processing, the data is structured for wireless transmission, taking into account the pitch, roll, and yaw angles.

Wireless Communication Using ESP-NOW

For low-latency communication between the transmitter and receiver ESP32 modules, the ESP-NOW protocol is utilized. Without a Wi-Fi router, this protocol allows direct peer-topeer connection by functioning on the data-link layer. With the least amount of delay possible, the transmitter ESP32 delivers the processed orientation data to the receiver's MAC address. After decoding the incoming data, the ESP32 receiver sends it to the flight controller for additional processing. This configuration guarantees quick control and real-time updates, which are essential for preserving drone stability while in flight.

Flight Control and Motor Adjustment

The drone's flight controller creates control signals for the ESCs by interpreting the data it has received. Pitch, roll, and yaw adjustments are computed using a PID (ProportionalIntegral-Derivative) control algorithm. By modifying the speed of every brushless motor, these adjustments guarantee that the drone stays in the intended orientation. For example, in order to restore balance, the flight controller will raise the speed of motors on one side while decrease the speed on the other if the sensor detects a tilt in the roll axis. Even in changing environmental conditions, precise and stable flight is made possible by this dynamic adjustment.

V..RESULTS AND DISCUSSION

The project effectively illustrated how ESP32 microcontrollers and the MPU-6050 sensor may be combined to provide precise drone control. Pitch, roll, and yaw are among the real-time orientation data that the MPU6050 accurately and efficiently recorded. Reliable data for flight control were ensured by minimizing noise using sensor calibration and complementing filtering techniques. With a low latency (about 10–20 milliseconds), the ESPNOW protocol enabled smooth wireless communication between the transmitter and receiver ESP32 modules. During flight, this low-latency connection was essential for making adjustments in real time.

By analyzing sensor data and modifying motor speeds through the ESCs, the PID control system was important in stabilizing the drone. Stable hovering and smooth corrections for controlled maneuvers like tilting and rotation were verified during flight tests. The system demonstrated its resilience by remaining stable even in the face of slight wind disturbances. Another significant accomplishment was power efficiency, as the Li-Po battery allowed for roughly ten to fifteen minutes of continuous flight. These outcomes confirmed that the system can function dependably under real-world circumstances.

Although noise was occasionally created by external vibrations, the MPU-6050 sensor demonstrated exceptional efficacy in motion tracking. Although this problem was lessened by software filtering techniques, future improvements might include more sensors, like a magnetometer, for better orientation accuracy. Although the ESP-NOW protocol's range was only around 100 meters in open spaces, it guaranteed quick and dependable connection. To increase flexibility for long-range applications, a hybrid communication strategy that combines Wi-Fi and ESPNOW could be investigated.

International Journal of Engineering Research & Technology (IJERT)
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Stability was effectively maintained by the PID controller, however vigorous maneuvers showed a small amount of overshooting. Reducing integral windup and modifying the PID gains could improve the system's responsiveness even further. Weight and power efficiency were balanced in the F450 chassis and component choices, however adding payloads like cameras might require improvements to the motor or battery. To increase the drone's capabilities, future research might concentrate on incorporating autonomous functions like obstacle avoidance or GPS-based navigation.

VI. FUTURE SCOPE

1. Enhanced Sensor Fusion for Improved Stability
   - Integrating additional sensors like a magnetometer (HMC5883L) or barometer (BMP280) could provide more accurate heading and altitude data, reducing drift and improving flight stability.
   - Implementing Kalman filters or machine learning-based sensor fusion could further refine motion tracking and noise reduction.
2. Extended Communication Range & Reliability
   - Testing LoRa (Long Range) modules alongside ESP-NOW could increase the drone's operational range beyond 100 meters, making it suitable for long-distance applications like agricultural monitoring or search-and-rescue.
   - Adding mesh networking capabilities would allow multiple drones to communicate and coordinate autonomously.
3. Autonomous Flight Modes
   - Incorporating GPS modules (e.g., NEO6M) would enable waypoint navigation, return-to-home functions, and geofencing for safer operations.
   - Implementing computer vision (OpenCV on Raspberry Pi/ESP32-CAM) could facilitate obstacle avoidance, object tracking, and automated landing.
4. Advanced Control Algorithms
   - Replacing the PID controller with adaptive or fuzzy logic control could improve the drone's ability to handle dynamic environments (e.g., wind gusts, payload changes).
   - Adding AI-driven flight optimization could enable the drone to learn from flight patterns and adjust PID gains in real time.
5. Energy Efficiency & Battery Optimization
   - Exploring solar-powered charging or hybrid battery systems could extend flight time for surveillance or delivery applications.
   - Implementing power management algorithms to optimize motor usage based on flight conditions (e.g., hovering vs. high-speed maneuvers).
6. Payload & Application-Specific Upgrades
   - Mounting thermal cameras (e.g., FLIR Lepton) for firefighting or nighttime surveillance.
   - Adding mechanical arms or delivery mechanisms for precision agriculture (e.g., seed planting, pesticide spraying) or medical supply delivery.
7. Swarm Intelligence & Multi-Drone Coordination
   - Developing swarm algorithms to enable multiple drones to work collaboratively (e.g., for 3D mapping, disaster response, or light shows).
   - Using UWB (Ultra-Wideband) positioning for precise relative localization in drone swarms.
8. Edge Computing for Real-Time Processing
   - Offloading sensor data processing to edge devices (e.g., NVIDIA Jetson Nano) for real-time AI tasks like facial recognition or anomaly detection.
   - Implementing onboard data logging for post-flight analysis and performance tuning.
9. Regulatory Compliance & Safety Features
   - Adding fail-safe mechanisms (e.g., parachute deployment, emergency landing protocols) to meet aviation regulations.
   - Integrating RFID/remote ID systems for airspace compliance and anti-collision in urban environments.
10. Open-Source Community & Scalability
    - Publishing the project as an open-source framework to encourage collaboration and customization for educational or commercial use.
    - Designing modular hardware (e.g., plug-and-play sensor mounts) to simplify upgrades for different use cases.

VII. CONCLUSION

By utilizing the MPU-6050 IMU sensor and ESP32 microcontrollers, the Precision Drone Control Using MPU6050 Sensor Integration project effectively demonstrated a low-cost, effective, and highly functional drone control system. Successful hover testing and maneuverability trials confirmed that steady and responsive flight control was made possible by the combination of real-time motion tracking and ESP-NOW wireless communication. The hardware configuration proved sturdy enough for real-world applications, and the PID-based control system successfully modified motor speeds to preserve stability.

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This project demonstrates the promise of opensource, reasonably priced UAV technology solutions, enabling small businesses, researchers, and enthusiasts to have access to sophisticated drone control. Although the current system accomplishes its primary goals, the suggested future improvements—autonomous navigation, AI-driven control, and increased communication range—offer even more adaptability for uses in disaster relief, logistics, agriculture, and surveillance..

This study opens the door for more innovation in do-ityourself drone systems by bridging the gap between cost and performance. Its versatility for a variety of use cases is ensured by its modular design, which promotes experimentation. In the end, this project not only provides a working prototype but also acts as a precursor to future drone technologies that are more intelligent, self-governing, and scalable.

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