Gesture-Controlled UAV System

CS528 Final Project Report

Quan Vo, Van Vo, Vani Korepu

Abstract

This project presents a gesture-controlled Unmanned Aerial Vehicle (UAV) system that replaces traditional remote controllers with intuitive hand gestures for UAV navigation. By leveraging ESP32 MPU6050 sensor data (accelerometer and gyroscope) and machine learning, the system interprets hand movements in real time and maps them to UAV control commands. A Support Vector Machine (SVM) model was trained on gesture data and achieved an accuracy of 96.93%. Gestures such as Up, Down, Left, Right, Front, Back, Clockwise, and Counterclockwise were successfully integrated for altitude and directional control. The system improves UAV usability and accessibility, particularly in critical applications such as search and rescue operations, disaster control, agricultural monitoring, and hands-free operations. Real-time testing demonstrated the system's effectiveness in providing stable and accurate UAV control. Future work includes expanding the gesture set to include advanced movements and optimizing real-time responsiveness.

1. Introduction

The development of Unmanned Aerial Vehicles (UAVs) has enabled significant advancements across diverse fields, including disaster response, precision agriculture, and entertainment. However, traditional UAV control methods rely on manual remote controllers, which present challenges such as complexity, requiring specialized expertise, and limited accessibility for inexperienced users. Additionally, manual controls are impractical in scenarios where hands-free operation is necessary, such as search and rescue missions where situational awareness is critical.

To address these limitations, we propose a gesture-based UAV control system. By utilizing hand gestures as an alternative input method, the system enables intuitive, efficient, and hands-free UAV navigation. Gesture recognition is achieved using an ESP32 MPU6050 Inertial Measurement Unit (IMU) sensor, which captures accelerometer and gyroscope data corresponding to predefined hand movements. A machine learning model is trained to classify these gestures accurately and map them to UAV commands, such as increasing altitude, descending, and moving laterally.

The primary objectives of this project include:

- Collecting and preprocessing gesture data from the ESP32 MPU6050 sensor.
- Training a machine learning model to classify hand gestures based on sensor readings.
- Integrating the gesture recognition system with UAV control for real-time navigation.

This system significantly improves UAV usability, as hand gestures provide a natural and accessible way to control UAVs. The system is particularly relevant for applications requiring intuitive and hands-free operation, such as emergency response, field monitoring, and user-friendly recreational UAV control.

The following sections describe the project workflow, implementation, evaluation, and contributions of each team member.

2. Project Overview

The gesture-controlled UAV system consists of a series of steps that transform raw sensor input into actionable UAV commands. The system combines hardware data acquisition, machine learning-based gesture recognition, and UAV integration to create a robust and dynamic control mechanism.

System Workflow

The project workflow can be broken down into five key phases:

1. Data Acquisition:
    - Hand gesture data is collected using the ESP32 MPU6050 sensor, which measures accelerometer (x, y, z) and gyroscope (x, y, z) values.
    - A total of 400 samples were collected for eight predefined gestures: Up, Down, Left, Right, Forward, Backward, Clockwise, and Counterclockwise.

2. Data Preprocessing:
    - Raw data was cleaned, converted to a usable CSV format, and normalized using StandardScaler to ensure feature consistency.

3. Machine Learning Model:
    - A Support Vector Machine (SVM) classifier was trained to classify hand gestures based on the sensor data.
    - The model achieved a classification accuracy of 96.93%.

4. Real-Time Implementation:
    - The trained model was deployed to process real-time sensor data every 3 seconds.

  - Predictions were stabilized using majority voting to filter out inconsistencies caused by sensor noise.

5. UAV Control Mapping:
   - Recognized gestures were mapped to specific UAV movements:
     - Up → Increase altitude.
     - Down → Decrease altitude.
     - Left → Move UAV left.
     - Right → Move UAV right.
     - Front → Move UAV front.
     - Back → Move UAV back.
     - Clockwise → Rotate UAV clockwise.
     - Counterclockwise → Rotate UAV counterclockwise.

The system bridges the gap between machine learning and physical control by dynamically translating hand gestures into UAV navigation, making the system intuitive and accessible.

3. Project Implementation

3.1 Data Collection

Sensor data was collected using the ESP32 MPU6050 IMU sensor, which captured acceleration and gyroscopic movements. The dataset consisted of:

- Gestures: Eight gestures were recorded, each representing a unique motion.
- Sample Duration: Each sample spanned approximately 4 seconds.
- Sample Size: 400 samples were collected to ensure sufficient training data for the machine learning model.
- Data was saved as raw text files and subsequently converted into structured CSV files for further processing.

3.2 Data Preprocessing

The collected data was preprocessed to ensure it was clean, consistent, and ready for training:

Cleaning: Irrelevant or incomplete sensor readings were removed.
Normalization: Data features were standardized using StandardScaler, ensuring uniform scale for all axes.
Feature Selection: Accelerometer and gyroscope data (x, y, z) were selected as the primary inputs for the model.

3.3 Model Training

A Support Vector Machine (SVM) model was trained to classify hand gestures. The following steps were undertaken:

Training and Testing: The data was split into 70% training and 30% testing sets.
Performance: The SVM model achieved an accuracy of 91.67%, indicating strong performance for gesture recognition.
Challenges:
Misclassifications were observed, particularly between Backward and Forward gestures, due to overlapping patterns in accelerometer readings.

3.4 Real-Time Implementation

The trained SVM model was deployed to process real-time data from the ESP32 sensor:

Sensor Integration: Data was captured every 3 seconds from the MPU6050 sensor using serial communication.
Prediction Stabilization: Majority voting was used to improve prediction stability and reduce sensor noise.
Command Mapping: Recognized gestures were mapped to UAV movements:
Up: Increase altitude.
Down: Decrease altitude.
Left: Move left.
Right: Move right.

3.5 Challenges

Data Noise: Some sensor readings were inconsistent and required significant preprocessing.
Misclassifications: Overlapping gesture patterns caused occasional errors in prediction.
Real-Time Delays: The integration of serial communication with gesture recognition initially caused slight delays, which were mitigated through majority voting.

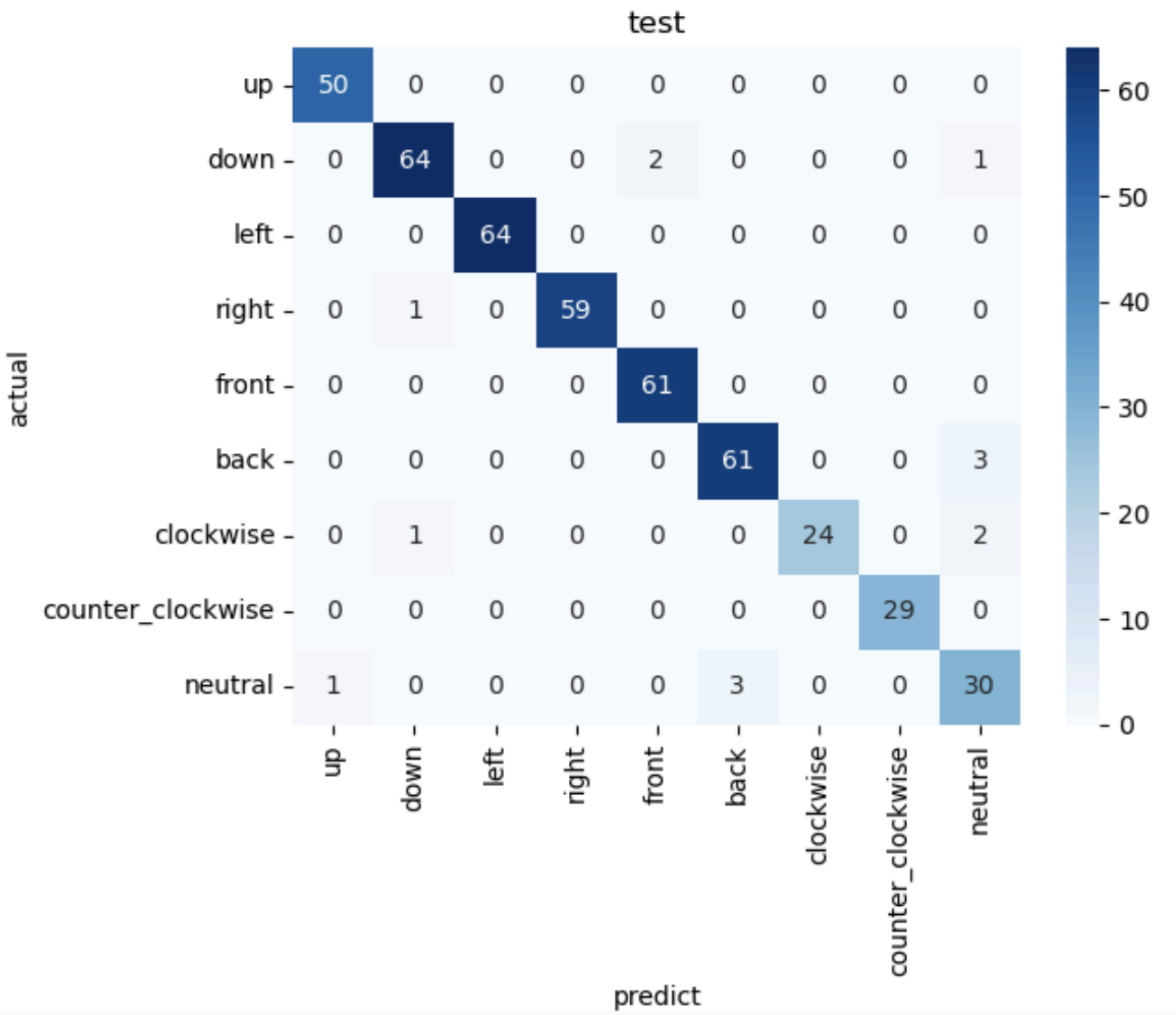
4. Evaluation and Demonstration

4.1 Evaluation Metrics

The system was evaluated based on the following metrics:

Model Accuracy:
The trained SVM model achieved a 96.93% accuracy on the test set.

Confusion Matrix:



4.2 Real-Time Testing

The system was tested with live gestures to verify its real-time performance. The UAV successfully executed the following commands:

Up: Increased altitude as expected.
Down: Decreased altitude smoothly.
Left and Right: Demonstrated consistent lateral movement based on predictions.
Front and Back: The UAV shows consistent movement.
Clockwise and Counter-Clockwise: The UAV works with Counter-Clockwise movement, but not Clockwise. There may be errors in training data for Clockwise.

4.3 Demonstration

FinalDemo.MOV
https://youtu.be/n5tGuT7H8Gs (alternatively)

5. Task Assignment and Contributions

Team Member Contributions

Quan Vo	Data Collection, Contribute to training model and real-time running code.
Van Vo	
Vani Korepu	

6. Conclusion

This paper presents a robust gesture-controlled UAV system that replaces manual controls with intuitive hand gestures. The system leverages accelerometer and gyroscope data collected from the ESP32 MPU6050 sensor and achieves real-time UAV control using a trained Support Vector Machine (SVM) model.

Key Contributions:
Collected and processed high-quality IMU sensor data for eight gestures.
Achieved an accuracy of 96.93% for gesture recognition using machine learning.
Successfully integrated the system for real-time UAV navigation with stable and accurate gesture predictions.

Future Work

Expand the gesture set to include complex movements, such as Flip and Rotate.
Improve the model to handle overlapping gestures and reduce misclassification errors.
Optimize real-time processing for smoother UAV control and faster response times.
The proposed system has significant potential in fields requiring hands-free and intuitive UAV operations, such as emergency response, precision agriculture, and recreational UAV use.