Drone Turbulence Detector and Monitoring System

Problem Description

Turbulence poses significant challenges to the safety and efficiency of drone operations, particularly for delivery drones. Unanticipated turbulent conditions can lead to hardware malfunctions, destabilization, and increased power consumption, jeopardizing mission success and safety. While turbulence's impact on manned aircraft is well-documented, its effects on smaller unmanned aerial vehicles (UAVs) like drones are profound due to their lighter weight and susceptibility to atmospheric disturbances. Efficient tracking and detection of turbulence are essential to mitigate these risks, ensuring that drones can either avoid turbulent areas or adjust their flight parameters accordingly. Although this project's primary focus is on delivery drones, the developed solutions have potential applications in larger aircraft systems in the future.

Solution Description and Research Methodologies

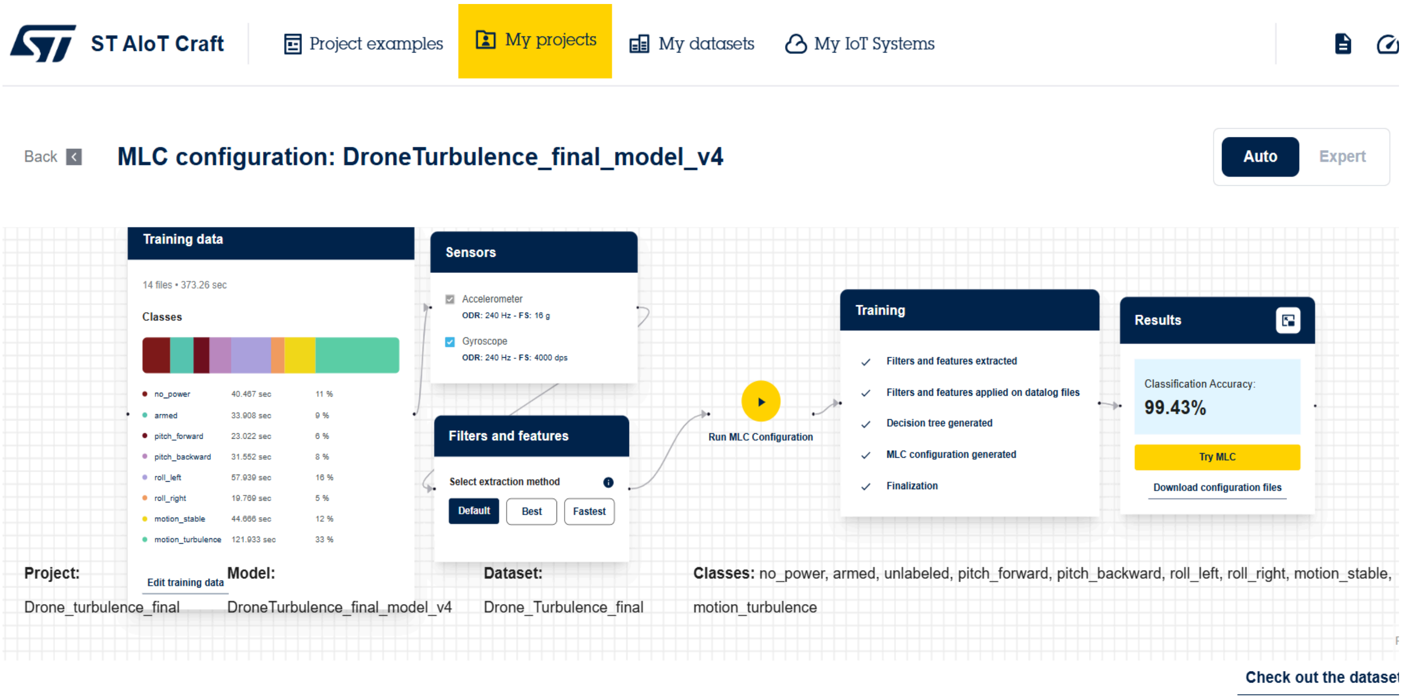
To address the challenges posed by turbulence, we propose a comprehensive system that integrates sensor-based turbulence detection with machine learning classification to enhance flight stability and control.

<u>System Overview</u>:-

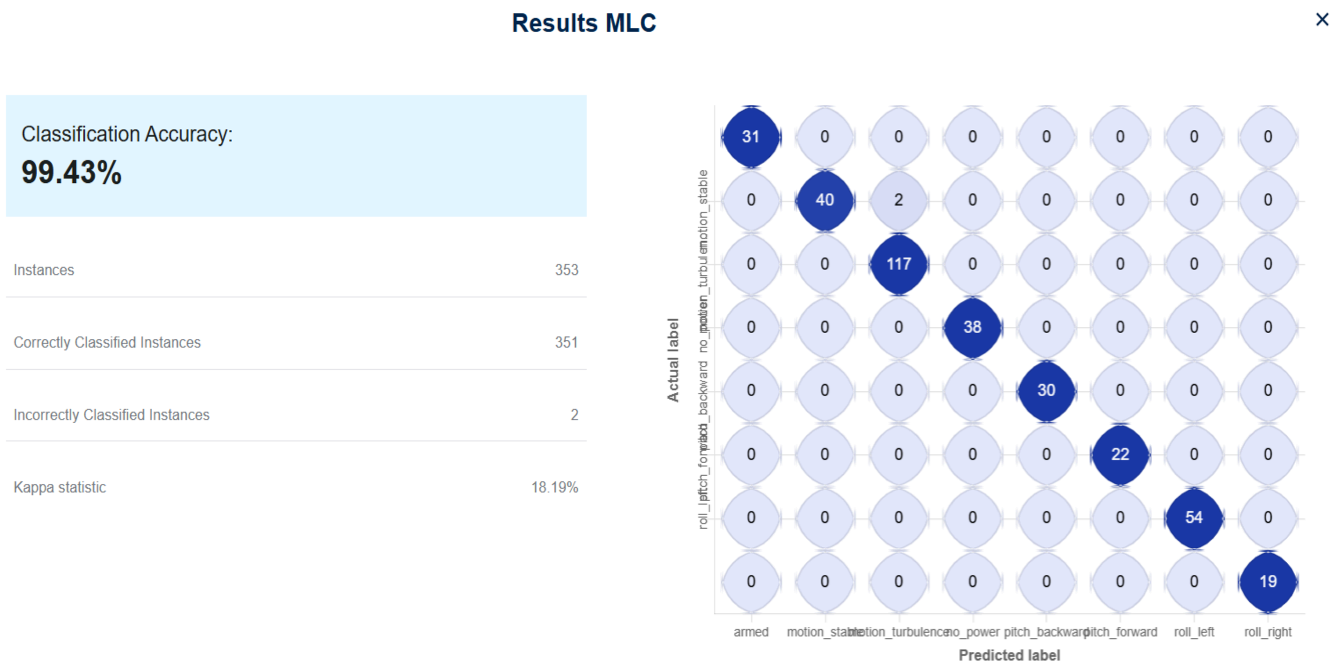
The Drone Turbulence Detector and Monitoring System is designed to improve drone stability by detecting turbulence in real-time and providing categorized output to assist in monitoring flight patterns and maneuverability. The system consists of an onboard STEVAL-MKBOXPRO module mounted on an FPV Drone that logs motion data and classifies flight conditions based on a trained model.

- *Real-Time Sensor Data Acquisition:* The system continuously records data at 240Hz ODR from an onboard STEVAL-MKBOXPRO module, which includes an accelerometer and gyroscope (LSM6DSV16X).
- *MLC Configuration and Classification:* The collected data is used to generate a dataset, which is then processed using the ST AIoT Craft tool to generate a Machine Learning Core (MLC)

configuration. This configuration enables the board to classify different flight conditions, distinguishing between turbulence, stable flight, and various tilt states.



- *Validation and Output Display:* The MLC configuration is flashed onto the sensor module, and the classified output is displayed via Bluetooth on the ST AIoT Craft mobile application for real-time validation.



Key Features:-

1. *Real-Time Turbulence Detection & Classification:* Detects and classifies turbulence affecting drone stability in real-time, and can differentiate between stable flight, turbulence, and various tilt states.
2. *Multi-State Flight Classification:* Categorizes drone flight into different states like no_power (System is off or disconnected), Armed (Drone is powered but stationary), motion_stable (Smooth flight with minimal disturbances), motion_turbulence (Flight is unstable due to wind or other external factors), Tilted states - pitch_forward, pitch_backward, roll_left, roll_right (Drone is experiencing directional tilts due to imbalance or maneuvering)

3. *AI-Powered Model for Improved Accuracy:* Utilizes machine learning core for turbulence and motion classification and has automated feature selection and model training.
4. *Data Logging & Analysis:* Logs real-time flight data for further analysis and model improvements which allows for performance evaluation and refinement of classification models or further maintenance of drones.
5. *Wireless Model Validation & Deployment:* Enables seamless testing of the trained model via Bluetooth using the ST AIoT Craft mobile app, which flashes the trained MLC onto the onboard module for real-time execution.
6. *Customizable Dataset Creation:* Supports dataset creation for different flight conditions, therefore allowing retraining the model for improved classification accuracy.
7. *Scalable for Future Applications:* Can be extended to larger UAVs or aircrafts for turbulence mitigation. Can also be integrated with autopilot systems for automated corrections.

Research Methodologies

Our approach encompasses several key research methodologies:

- *Data Collection:* Custom datasets were created by conducting controlled flight tests under various conditions. This approach was necessary due to the lack of existing datasets tailored to our specific sensor configuration and application.
- *Feature Extraction and Model Training:* The ST AIoT Craft tool offers various feature extraction methods, including Analysis of Variance (ANOVA), Ada Boost (ADA), Random Forest (RF), and Recursive Feature Elimination (RFE). For this project, the default mode was selected, which excludes Sequential Feature Selection (SFS).
- *Turbulence Research:* Turbulence, characterized by irregular air movements, significantly affects both manned and unmanned aircraft. For drones, turbulence can lead to instability, increased energy consumption, and potential hardware failure. Studies have shown that certain bio-inspired designs, such as feather-like flaps, can enhance aircraft stability by adjusting to airflow changes, thereby improving lift and reducing drag. (Wired.com)
- *Existing Equipment & Cost-Effective Solution*: Research was conducted on existing flight modules used for turbulence detection in aviation.
  Most solutions, like TAMDAR sensors, are designed for commercial aircraft and are not affordable for drone applications.Our goal is to develop a low-cost, efficient turbulence detection system for drones using ML-enabled embedded devices. Drone Flight Instability Analysis Various drone parameters affecting stability were analyzed, including Temperature, humidity, and wind turbulence. Vibrations and sudden movements (e.g., up/down shifts, left/right tilts, forward/backward tilts). This research guided the sensor data collection strategy to ensure accurate turbulence detection.

Role of ST AIoT Craft Tool

The ST AIoT Craft tool played a pivotal role in this project by providing a no-code, block-based web application that facilitated the entire process from data processing to model deployment. Its capabilities include dataset creation, labeling, class definition, feature extraction, model training, and MLC configuration generation. This comprehensive functionality was particularly beneficial given our limited prior experience with AI model training and MLCs, enabling an efficient and streamlined development process.

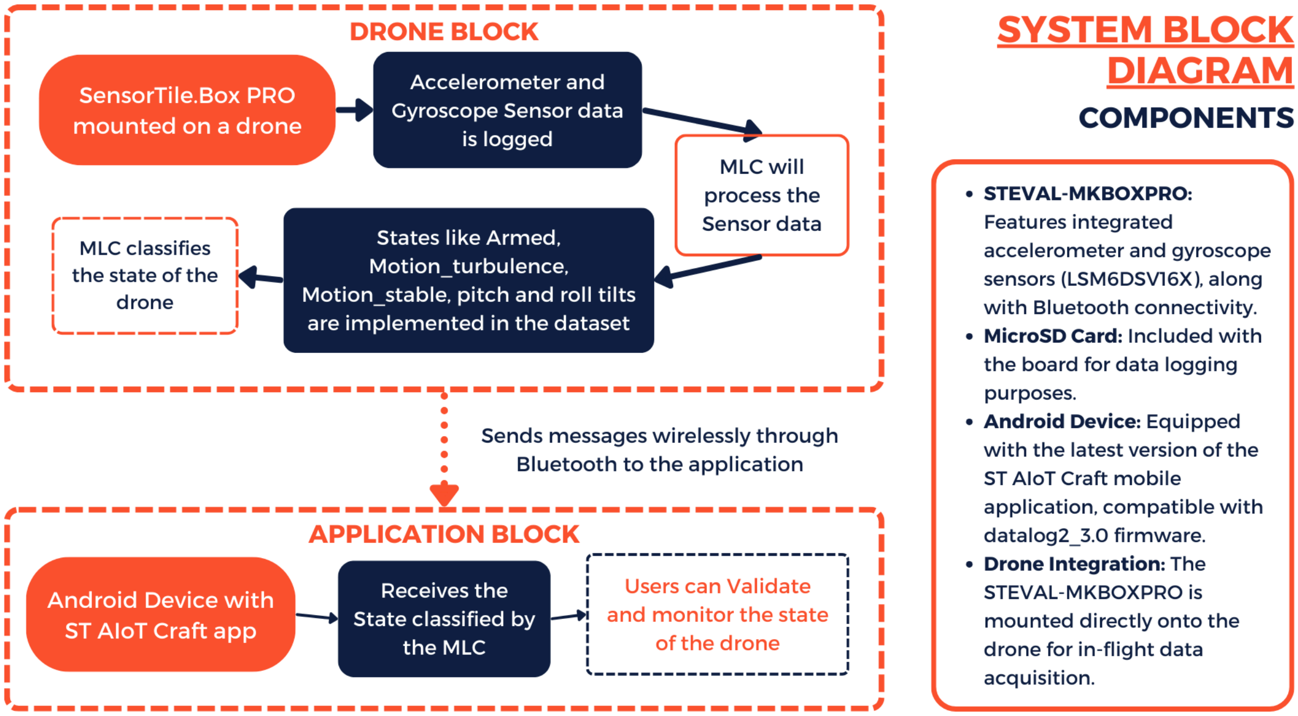
Detailed Solution Description with Block Diagram

The system detects turbulence by utilizing the STEVAL-MKBOXPRO board mounted on the drone, which features an accelerometer (LSM6DSV16X) and a gyroscope. The board logs motion data onto a MicroSD

card during flight. This data is later uploaded to the ST AIoT Craft web platform, where it is used to create a dataset and train a model.
Using the extracted features, an MLC configuration is generated, which is then flashed onto the board. Once deployed, the MLC processes real-time sensor data and classifies the drone's state into multiple categories:

- *No_power:* This signifies the drone being turned off or not receiving sufficient power to operate.
- *Armed:* The Drone is now stationary on the ground with its blades powered on, with no active flight movement (on standby).
- *Motion_stable:* The drone is flying smoothly without significant disturbances (turbulence).
- *Motion_turbulence:* The drone is experiencing unstable airflow, leading to erratic motion and increased power consumption.
- *Pitch_forward:* The drone is leaning forward, possibly due to acceleration or external forces.
- *Pitch_backward:* The drone is tilting backwards, which may indicate deceleration or wind resistance.
- *Roll_Left:* The drone is leaning to the left, which could be caused by maneuvering or external factors.
- *Roll_right:* The drone is leaning towards the right, which could be caused by the turning or external factors.

The classified state is transmitted via Bluetooth to the ST AIoT Craft mobile app, allowing users to validate and analyze the system's performance in different flight conditions.



<u>Hardware Components:</u>

- *STEVAL-MKBOXPRO:* Features integrated accelerometer (LSM6DSV16X) and gyroscope sensors, along with Bluetooth connectivity.
- *MicroSD Card:* Included with the board for data logging purposes.
- *Android Device:* Equipped with the latest version of the ST AIoT Craft mobile application, compatible with datalog2_3.0 firmware.
- *Drone Integration:* The STEVAL-MKBOXPRO is mounted directly onto the drone for in-flight data acquisition.

Conclusion

The Drone Turbulence Detector and Monitoring System successfully classifies Real-time Turbulence using machine learning based feature extraction and model training. Utilizing the STEVAL-MKBOXPRO module and the ST AIoT Craft tool, the system effectively categorizes flight states, allowing for improved maneuverability and response to turbulent environments. The implementation of sensor-based data acquisition, AI-driven classification, and wireless validation ensures a cost-effective and scalable solution for UAV operations.

This project demonstrates the potential of AI-powered turbulence detection not only for delivery drones but also for broader applications in aviation, including larger UAVs and autopilot integration. Future work can focus on refining classification accuracy, expanding dataset diversity, and integrating adaptive flight control mechanisms for real-time turbulence mitigation.

References

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