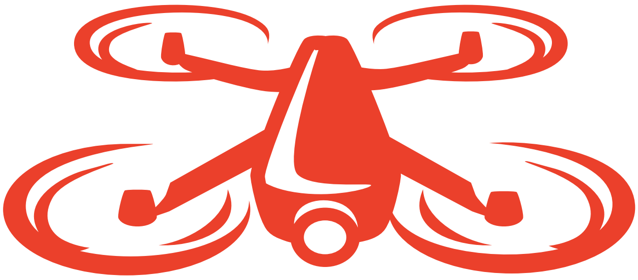

Tafila Technical University
College of Information Technology and Communication

FUZZY LOGIC
DRONE LANDING CONTROLLER
ADVANCED AI PROJECT REPORT

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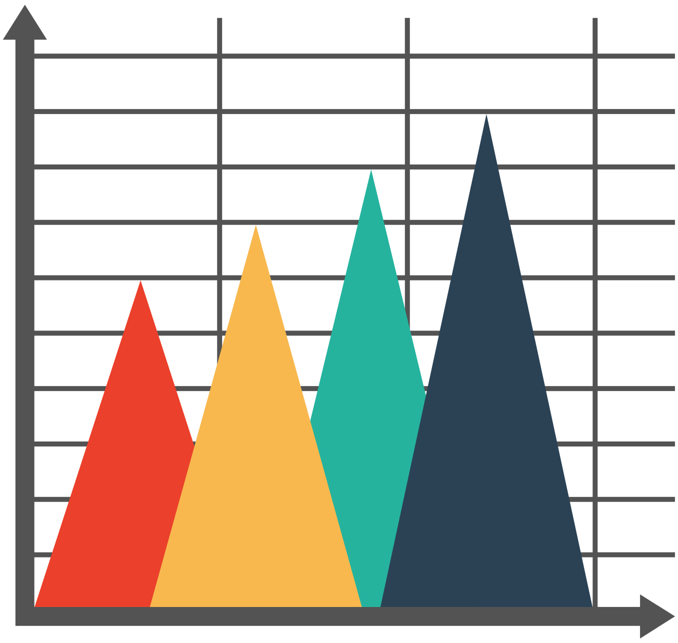
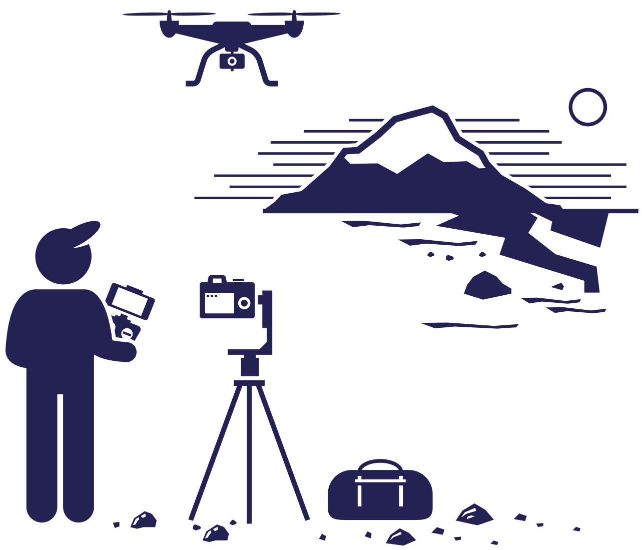


introduction

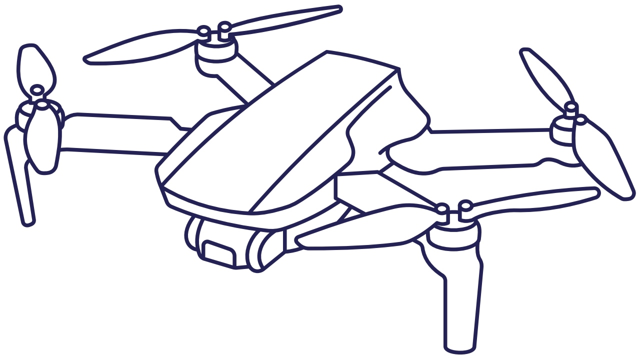
Unmanned aerial vehicles (UAVs), commonly known as drones, are increasingly deployed across various domains such as delivery systems, surveillance, agriculture, and disaster response. A crucial aspect of drone autonomy is the ability to land safely and precisely, especially in environments characterized by uncertainty, such as fluctuating wind conditions or uneven surfaces. Traditional control systems often rely on rigid, physics-based models that may not adapt well to imprecise or rapidly changing input data.

Fuzzy logic, inspired by the way humans make decisions based on vague or qualitative information, provides a powerful alternative for modeling such uncertain environments. Rather than relying on exact numerical thresholds, fuzzy logic systems interpret linguistic descriptions—like “low altitude” or “slightly misaligned”—to make control decisions through a set of intuitive, rule-based structures.

This project proposes a fuzzy logic-based landing controller for drones, aimed at ensuring a smooth and safe descent under various environmental conditions. The controller processes multiple input parameters—such as altitude, vertical speed, landing pad alignment, and wind stability—and outputs appropriate throttle and position correction commands. By simulating various landing scenarios and designing a robust rule base, the system demonstrates how fuzzy logic can be used to adaptively manage the complexities involved in drone landing operations.



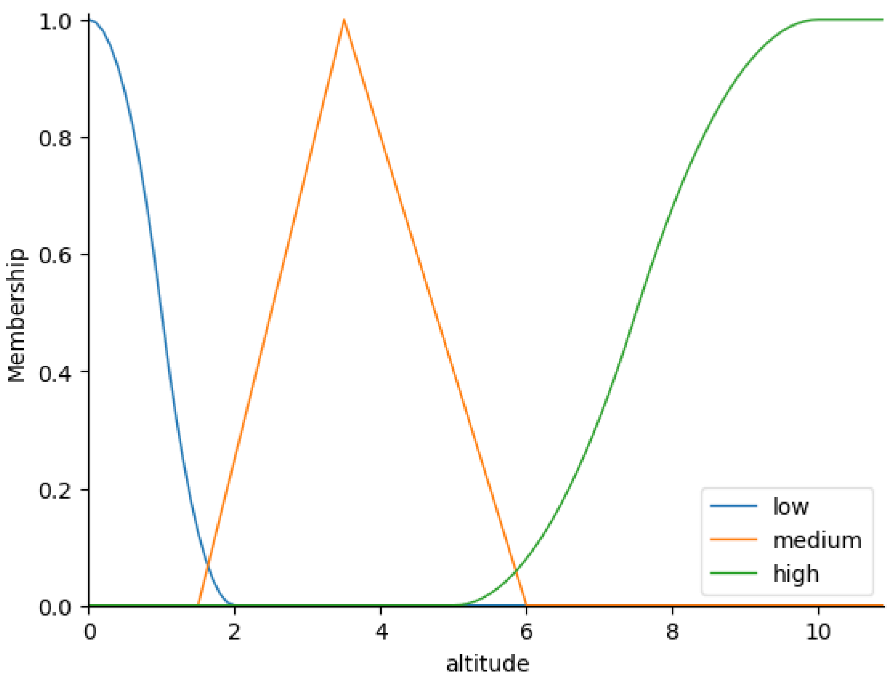
Input Variables and Their Fuzzy Sets:



Altitude

This input represents the vertical distance between the drone and the ground, ranging from 0 to 10 meters. It is categorized into three fuzzy sets:

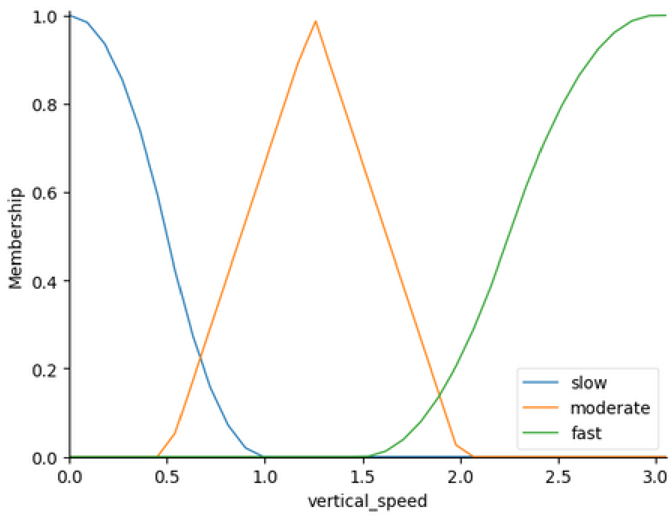
- Low: Z-shaped membership function, spanning from 0 to 2 meters.
- Medium: Triangular membership function with a peak at 3.5 meters and base from 1.5 to 6 meters.
- High: S-shaped membership function, starting at 5 and saturating at 10 meters.



Vertical Speed

This input indicates how fast the drone is descending, ranging from 0 to 3 meters per second. It is divided into three fuzzy sets:

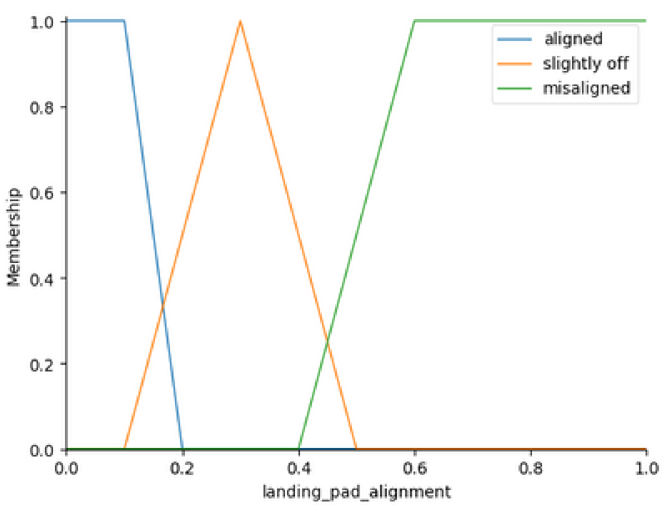
- Slow: Z-shaped, covering 0 to 1 m/s.
- Moderate: Triangular, peaking at 1.25 m/s with a base from 0.5 to 2 m/s.
- Fast: S-shaped, from 1.5 to 3 m/s.



Landing Pad Alignment

This input reflects how well-centered the drone is over the landing pad, with values between 0 (perfectly centered) and 1 (completely misaligned). It is divided into three fuzzy sets:

- Aligned: Trapezoidal, sharply covering 0 to 0.2 with full membership up to 0.1.
- Slightly Off: Triangular, centered at 0.3 with a base from 0.1 to 0.5.
- Misaligned: Trapezoidal, starting around 0.4–0.6 and beyond.



Why Trapezoidal for Aligned and Misaligned?

Trapezoidal functions are used to ensure stable classification at the edges of the input range:

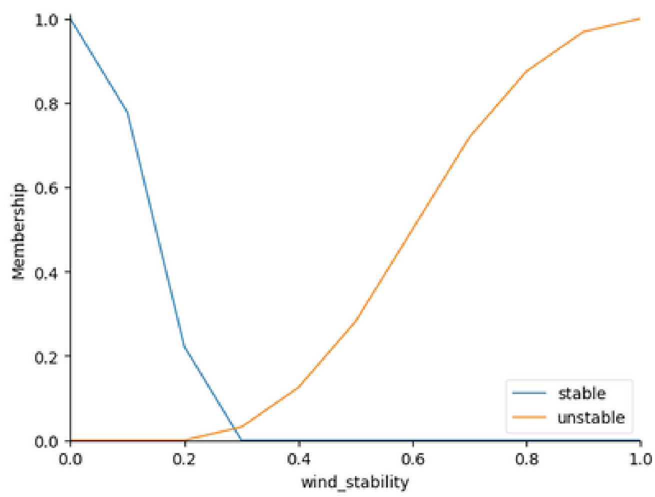
- Aligned: Covers near-perfect alignment (0 to ~0.2) with full membership, avoiding overreaction to minor shifts.
- Misaligned: Captures strong misalignment (e.g., 0.6 to 1), ensuring consistent correction when the drone is far off-center.

This reduces sensitivity to small variations and improves control stability.

Wind Stability

This input assesses how stable the wind conditions are during landing, ranging from 0 (completely stable) to 1 (very unstable). It is modeled using two fuzzy sets:

- Stable: Z-shaped, ranging from 0 to 0.3.
- Unstable: S-shaped, covering from 0.2 to 1.

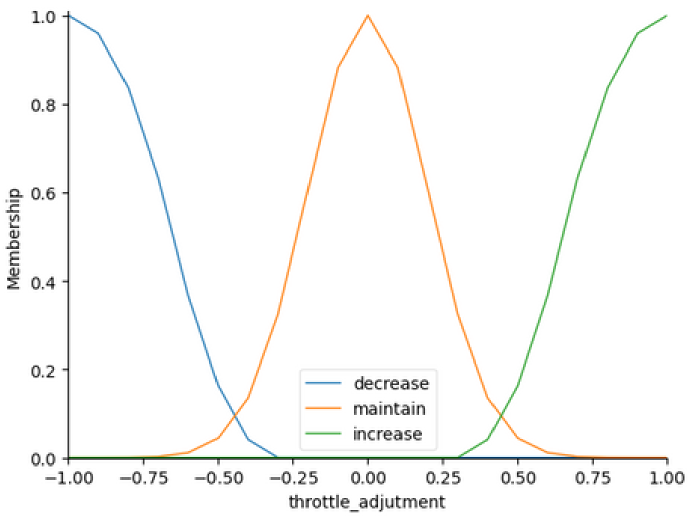


output Variables and Their Fuzzy Sets:

Throttle Adjustment

This output controls how the drone's vertical speed is adjusted during landing. The range is from -1 (strong throttle reduction) to 1 (throttle increase). It is divided into three fuzzy sets:

- Decrease: Z-shaped membership function, from -1 to -0.3.
- Maintain: Gaussian, centered at 0 for smooth, symmetric response around neutral throttle.
- Increase: S-shaped, from 0.3 to 1.

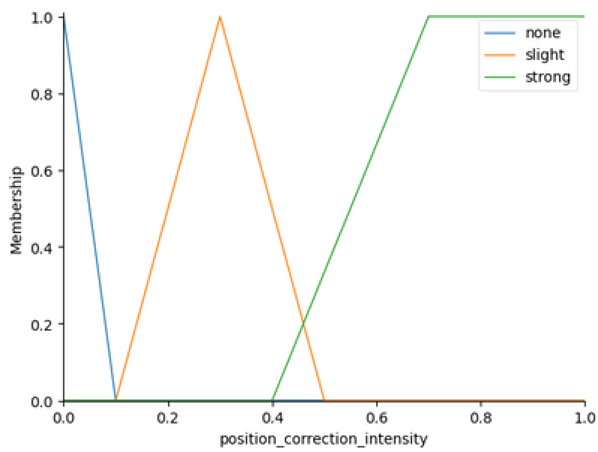


Position Correction Intensity

This output controls the intensity of horizontal (x/y axis) adjustments needed to re-center the drone over the landing pad. Range: 0 (no correction) to 1 (maximum correction).
It is divided into three fuzzy sets:

- None: Z-shaped, from 0 to 0.1 — no lateral movement needed when the drone is well centered.
- Slight: Triangular, peaking at 0.3 with a base from 0.1 to 0.5 — small corrections for minor misalignments.
- Strong: Trapezoidal, from 0.4 to 1 — full correction applied when the drone is significantly off-center.

This output ensures smooth, proportional x/y movement based on how far the drone deviates from the landing pad center.



Fuzzy Rules

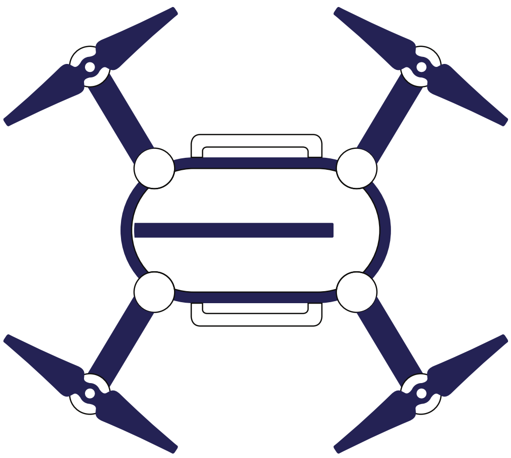
To control the landing behavior of the drone, 54 fuzzy rules were defined. Each rule maps a unique combination of the four input variables—altitude, vertical speed, landing pad alignment, and wind stability—to appropriate output values for throttle adjustment and position correction intensity.
The rules are designed to cover all possible combinations:

- 3 levels of altitude
- × 3 levels of vertical speed
- × 3 levels of landing pad alignment
- × 2 levels of wind stability = 54 unique rules, ensuring full input space coverage.

Logic Behind the Rules

- Low altitude, slow descent, aligned, and stable wind → maintain throttle, no position correction.
- Low altitude but misaligned → increase throttle to hover and apply strong correction.
- High altitude with fast descent → reduce throttle, apply correction depending on alignment.
- Medium conditions generally maintain throttle, with position correction intensity adjusted based on alignment accuracy.

This rule base ensures the controller adapts smoothly and safely across varying descent conditions, using human-like reasoning for decision making.



Experiments and Results

To evaluate the effectiveness of the fuzzy logic landing controller, two simulated experiments were conducted using contrasting conditions. The results demonstrate how the system dynamically adapts based on real-time input values.

Experiment 1: Smooth and Safe Conditions

Input Parameters

- **Altitude: 1 (Low)**
- **Vertical Speed: 0.5 m/s (Slow)**
- **Landing Pad Alignment: 0.1 (Well Aligned)**
- **Wind Stability: 0.1 (Stable)**

Expected Behavior

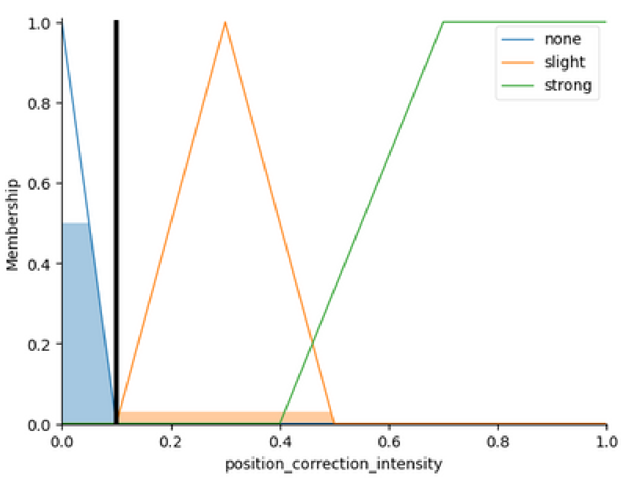
Minimal adjustment required—gentle throttle behavior and almost no position correction.

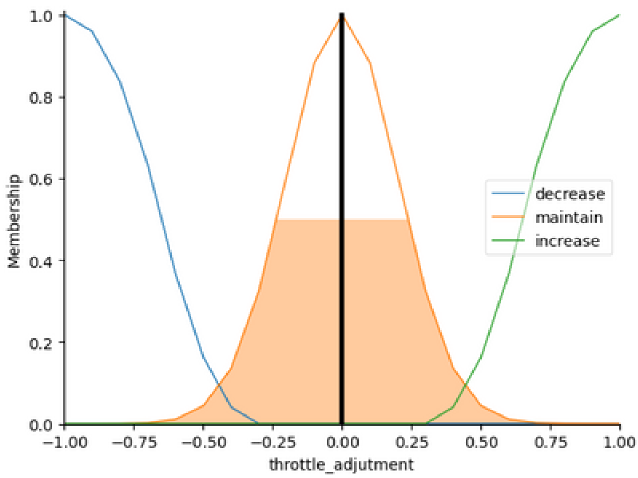
Controller Output

- **Throttle Adjustment: ~0 (−8.32e−18, effectively neutral)**
- **Position Correction Intensity: 0.1009**

Interpretation

The drone is already well-positioned for landing. The controller maintains steady descent with minimal lateral movement, as intended.





Experiment 2: Challenging Scenario

Input Parameters

- Altitude: 9 (High)
- Vertical Speed: 2.8 m/s (Fast)
- Landing Pad Alignment: 0.8 (Misaligned)
- Wind Stability: 0.9 (Unstable)

Expected Behavior

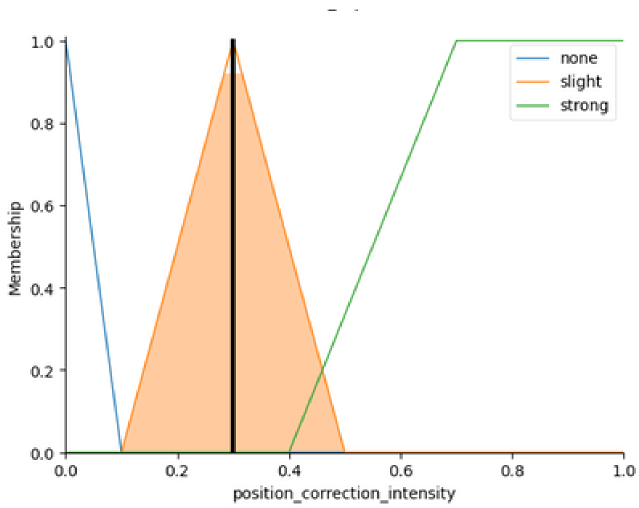
Throttle should reduce significantly, and position correction should be strong to safely guide the drone.

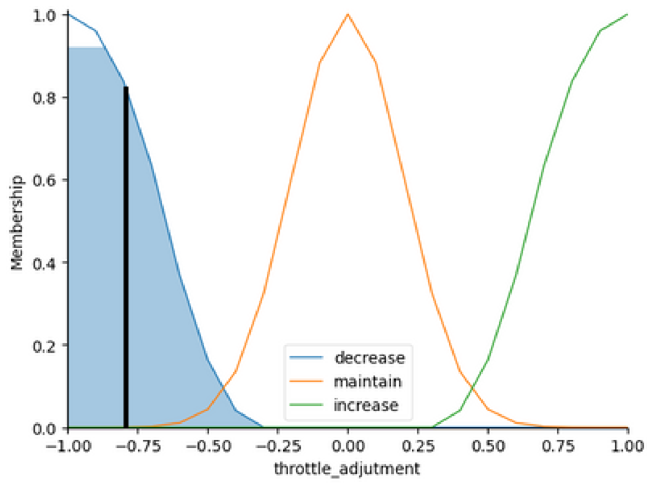
Controller Output

- Throttle Adjustment: −0.7905
- Position Correction Intensity: 0.3

Interpretation

The system responds aggressively to reduce descent speed and apply moderate lateral correction, helping the drone regain stability before touchdown.





Conclusion

The experiments demonstrate that the fuzzy logic-based landing controller responds effectively to varying conditions. In safe scenarios, it maintains stability with minimal adjustments. Under challenging inputs, it reacts appropriately by reducing descent speed and increasing lateral corrections. Overall, the controller shows strong adaptability, handling uncertainty and imprecision in real-time, making it a reliable approach for autonomous drone landing.