



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 14, Issue 6, June 2025

Fuzzy Logic-Based Terrain Following and Collision Avoidance System for Unmanned Aerial Vehicles

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ABSTRACT: Unmanned Aerial Vehicles (UAVs) are widely used due to their small size, cost-effectiveness, and ability to operate without risking human lives. This paper proposes a fuzzy logic-based approach for terrain following (TF) and collision avoidance to ensure safe low-level flights. Traditional optimization methods face computational challenges and are unsuitable for real-time use. The proposed fuzzy logic controller determines altitude and airspeed adjustments using linguistic variables such as altitude error and airspeed categories. Simulation results show that the controller effectively maintains safe distances from terrain with quick response times, making it suitable for real-time autonomous UAV operations. This approach enhances UAV safety and reliability in complex environments.

KEYWORDS: Fuzzy Logic Control, Unmanned Aerial Vehicles (UAVs), Terrain Following (TF), Collision Avoidance, Autonomous Flight Control, Real-Time Systems, Airspeed Regulation, Trajectory Planning, Vision Sensors, Artificial Intelligence in UAVs.

AMS Classification: 93C42, 93C85, 68T37

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), also known as drones, aerial torpedoes, and pilotless aircraft, have transformed multiple sectors including military surveillance, environmental monitoring, precision agriculture, and disaster management. Their ability to operate autonomously in hazardous environments without risking human lives makes them a critical technological advancement.

Conventional optimization techniques for trajectory planning, such as dynamic programming, are computationally intensive and not feasible for real-time applications in rapidly changing terrains. To address these challenges, fuzzy logic provides a robust alternative by enabling rule-based decision-making under uncertainty, suitable for real-time terrain following and collision avoidance. UAVs require significant energy and thrust to effectively survey vast terrain areas..

II. LITERATURE REVIEW

Menon and Kim. (1988)[6] demonstrated optimal trajectory synthesis for TF flight but highlighted its limitations in computational feasibility. Kendoul et al. (2012)[2] discussed advances in UAV guidance and navigation, emphasizing the need for adaptive control systems for dynamic environments. Recent studies by Nickolos et al. (2006). [1] showed the effectiveness of fuzzy logic in UAV roll control, but comprehensive integration with vision-based terrain tracking remains unexplored, forming the motivation for this research.

III. METHODS TO SOLVE THE SITUATION

This method can reliably support offline trajectory design and planning tasks.

- 1) Strategy
- 2) Perceive
- 3) Implementation Consequence
- 4) Creativity
- 5) Action

Strategy:

To accomplish this objective, the method efficiently integrates the aircraft's dynamic behaviour. In essence, the mathematical approach utilizes the relationships between terrain slope, its rate of change, aircraft speed, and altitude to formulate appropriate fuzzy rules.

Perceive:

Various case studies were carried out involving aircraft flight scenarios. Show the effectiveness of the method as compared to other existing methods. The results illustrate a good tracking based on fuzzy approach and only minor changes in the solution.

Implementation Consequence:

The current works offers a new approach in low-level flights where maintaining a suitable height above the ground is essential. This becomes particularly critical for civil aircraft landing at airports under poor visibility conditions or when executing a go-around.

The domain of the current work is however confined to only planning of TF manoeuvres. Nevertheless, the work could be expanded onto TF / terrain avoidance and three-dimensional manoeuvres which are not in the scope of the current work.

Creativity:

The current work addresses the problems associated with low-level flight; such as TF using artificial intelligence and fuzzy logic. The provided intelligence helps the aircraft conduct TF manoeuvres by understanding the general patterns of the existing terrain. The method is fast energy to be applied for real-time applications.

Action:

Using above things consider as an input vector. Generally, a fuzzy system consists of four main components: the fuzzifier, rule base, inference engine, and defuzzifier.

$$F_C = \frac{V \times h}{S \times T_P}$$

IV. EXPERIMENTAL RESULTS

Case i)

$$V = 23.12,$$

$$h = 150,$$

$$T_P = 34 \text{ and}$$

$$S = 128.17$$

$$F_C = \frac{23.12 \times 150}{34 \times 128.17}$$

$$F_C = \frac{3468}{4357.78}$$

$$F_C = 0.79$$

Case ii)

$$V = 46.24 ,$$

$$h = 300 ,$$

$$T_P = 72.12 \text{ and}$$

$$S = 256.34$$

$$F_C = \frac{46.24 \times 300}{72.12 \times 256.34}$$

$$F_C = \frac{13872}{18487.24}$$

$$F_C = 0.75$$

Case iii)

$$V = 82.32 ,$$

$$h = 750 ,$$

$$T_P = 250.27 \text{ and}$$

$$S = 632.5$$

$$F_C = \frac{82.32 \times 750}{250.27 \times 632.5}$$

$$F_C = \frac{61740}{158295.78}$$

$$F_C = 0.39$$

If the F_C value is above 0.5 the UAV is in safe but the value is below 0.5 the UAV is in danger position.

The fuzzy inference engine uses the fuzzy if-then rules to perform a mapping from an input vector to an output scalar. In the present paper, a terrain is recognized based on fuzzy logic so the small changes in terrain are omitted automatically.

The following figure 1 shows a decision-making algorithm which commands the aircraft based on the existing terrain profile together with the aircraft speed, its position and orientation.

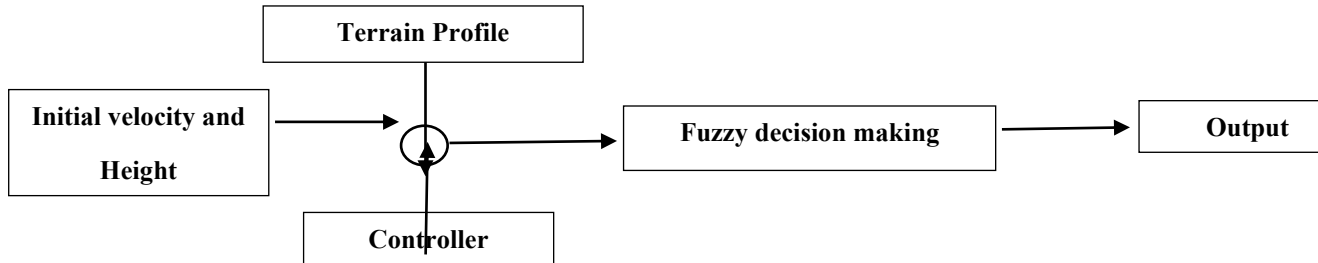


Figure 1

The aircraft should perform a TF manoeuvre in vertical plane, but based on some conditions the vehicle can perform a TA manoeuvre in horizontal plane automatically.

V. CONCLUSION

Using fuzzy controllers, the difficult design process is avoid nevertheless stable control and fast reaction time over conventional autonomous UAVs can be achieved.

The capability to do a dynamic planning of the desirable flight pattern is also important and this is done by using the current position of the moving UAV and the stationary target positions. The paper introduces a fuzzy logic-driven autonomous controller for UAV operations. The conducted simulations demonstrate that, despite having basic controllers, the UAV is able to track the predefined paths effectively.

A fuzzy controller has three inputs. The initial scaling factors has a default values, equal to one fast give the input values to the fuzzy logic controller then receive the output value between 0 to 1. If the value is 0 the flight is in risk but the value is 1 the flight is unsafe. In between 0 to 1 below 0.5 is due to risk but above 0.5 is safe.

Fuzzy logic controllers are also implemented to prevent collisions with the ground. This system determine if the aircraft is in danger or flying too close to the terrain, or obstacles and then to react automatically.

The UAV are used in security, search and rescue, monitoring disaster management, crap management communication and survey application and whether detection. Not only the above application but also the importance one is military services, wars for future will be with use UAV to do their task without any risk on human.

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