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Development of a Control Algorithm for the Landing Approach Process of Fixed-Wing UAVs

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ABSTRACT
The paper provides a detailed account of the development process of a control algorithm for unmanned aerial vehicles (UAVs) using fuzzy logic controllers. The research focuses on the design and implementation of the control algorithm to optimize the UAV landing approach. After determining the optimal landing trajectory, the study analyzes and simulates landing processes based on the developed algorithm. The landing trajectory begins at the point when the UAV receives the landing command and ends at the parachute deployment position an essential phase for ensuring safe and accurate touchdown. Determining the optimal landing trajectory is carried out by considering various factors such as real-world operating conditions, UAV technical specifications, and safety constraints. Once the trajectory is established, the fuzzy logic control algorithm is applied to adjust the UAV dynamics, ensuring it maintains the desired trajectory even when faced with environmental factors such as wind, turbulence, or sensor errors. The entire algorithm development and simulation process is conducted using MATLAB, a powerful tool for control system analysis and design. With MATLAB, researchers not only design the algorithm but also perform testing and fine-tuning to optimize system performance. This study offers a comprehensive view of applying fuzzy logic controllers in UAV control while opening up potential for practical applications, especially in high-precision missions such as reconnaissance, surveillance, or rescue operations. The results demonstrate that combining an optimal landing trajectory with fuzzy logic control significantly enhances the accuracy and safety of modern UAV systems.

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I. INTRODUCTION

The landing methods for fixed-wing UAVs have been diversely developed to suit various operational conditions and mission requirements, including runway landing, recovery net systems, vertical take-off and landing (VTOL), and other specialized designs. Runway landing is the most common method, mimicking the procedures of conventional aircraft. This method requires a long, flat, obstacle-free runway, making it suitable for large UAVs and areas with well-established infrastructure. However, the demand for ample space renders this method impractical in narrow or complex terrains. In contrast, the recovery net method does not require a runway but instead employs a tensioned net system to reduce the UAV's kinetic energy upon contact, thereby ensuring a safe stop. This method is particularly advantageous in space-constrained environments, such as on ships or rugged terrains. Nevertheless, it necessitates high precision in UAV control and a carefully designed and installed net system, increasing operational complexity. Additionally, vertical take-off and landing (VTOL) technology is increasingly applied due to its ability to enable UAVs to take off and land in confined spaces. This method typically employs rotors or lift mechanisms to generate vertical thrust, eliminating the need for a runway or recovery net. While providing high flexibility, VTOL is often limited by low payload capacity and requires specialized UAV structural designs to optimize both fixed-wing flight and vertical landing capabilities. Furthermore, some UAVs employ innovative methods such as cables or aerodynamic braking systems tailored for specific mission objectives. Overall, each landing method has distinct advantages and disadvantages, selected based on factors such as UAV size, terrain conditions, and mission characteristics. The continuous development of landing technologies plays a crucial role in expanding UAV applications across various fields.

UAV-70V is a small UAV (70 kg) designed for remote surveillance, with broad applicability in socio-economic and security-defense needs. It is powered by a small propeller engine. The selected landing method for UAV-70V is parachute landing. Upon receiving a landing signal, the UAV is automatically guided by the algorithm to the parachute deployment position, following a predefined beneficial landing trajectory. This trajectory is the shortest path and is oriented against the wind direction. The control algorithm chosen for UAV-70V is flight control using fuzzy logic controllers. UAV parameters during control are determined by solving flight dynamics equations. Landing control for the UAV requires the use of four control channels: Yaw control channel; Altitude control channel; Speed control channel, and Roll angle control channel.

II. MATERIAL AND METHODS

Yaw control channel

The simulation results on the computer indicate that for the rudder control channel, it is sufficient to use the proportional control algorithm: $\delta_h^* = k.n_z$

Where: δ_h^* - The desired value of the rudder deflection angle is provided by the onboard computer.

k - Proportional coefficient.

n_z - The value of lateral overload (determined in the body-fixed coordinate system).

Altitude control channel

Using a fuzzy controller, the desired value of the elevator deflection angle δ_c^* is a nonlinear function of the altitude error Δy and the vertical velocity component ΔV_y, with the addition of two components to the control law.

The first additional component is the (approximate) equilibrium value of the elevator deflection angle δ_{cbb}, obtained by solving the familiar system of linear algebraic equations for force and moment equilibrium during level flight at a given altitude and airspeed, taking into account the pitching moment caused by the propeller. This component is necessary because, in the absence of error, a conventional fuzzy controller would result in a zero elevator deflection angle, leading to an imbalance of forces and moments. Due to the continuous correction of the elevator deflection angle, the UAV would oscillate in pitch.

The second additional component is a damping term (proportional to the angular velocity ω_z).

Thus, the algorithm for the modified fuzzy controller in the altitude control channel is as follows:

$$\delta_c^* = fuzzy1(\Delta_y, \Delta_{V_y}) + \delta_{cbb} + k_{cd}.\omega_z$$

Where: fuzzy1 – A nonlinear function of altitude error and vertical velocity component, derived using fuzzy logic.

δ_{cbb} - The equilibrium value of the elevator deflection angle during level flight.

k_{cd} - The damping coefficient of the longitudinal channel.

It is evident that δ_c^* is constrained by a certain maximum value $\delta_{c\max}$, enforced through the angle of attack limit implemented via the normal overload sensor channel n_y, and by simultaneously adjusting the desired value of the vertical velocity component V_y^* according to a time-based law:

$$V_y^* = f(t, n_y)$$

The desired altitude value H^* is obtained by integration:

$$H^* = H_o + \int_0^t V_y^*.dt$$

Velocity control channel

The velocity control of the UAV is also performed by a fuzzy controller for the thrust force T of the propeller, with the "neutral" thrust value adjusted depending on whether level flight, climbing, or descending is required, meaning it depends on the altitude change V_y^*.

Where, a modified fuzzy control algorithm for the thrust force T is used as follows:

$$T = fuzzy2(\Delta V) + mg.\theta^*$$

$$\theta^* = V_y^* / V$$

Where: fuzzy2 - A nonlinear function of the velocity error is obtained using fuzzy logic.

mg –The weight of the UAV.

θ^* - The desired trajectory orbital angle.

V - The flight velocity of the UAV.

It is clear that $T_{\max}, T_{\min}$ is limited by maximum and minimum values. These values depend on the current altitude and flight velocity.

The control of the thrust force T of the propeller (through throttle position) is considered instantaneous, without any time delay.

Roll control channel

A fuzzy controller is used, where the desired aileron deflection angle δ_l^* is a nonlinear function of the error in the roll angle $\Delta\gamma$ and the angular velocity $\Delta\omega_x$, combined with a damping roll component in the control law.

$$\delta_l^* = fuzzy3(\Delta\gamma, \Delta\omega_x) + k_{cl}.\omega_x$$

$$|\ \delta_l^*\ | \le \delta_{l\max}$$

Flowchart of the algorithm

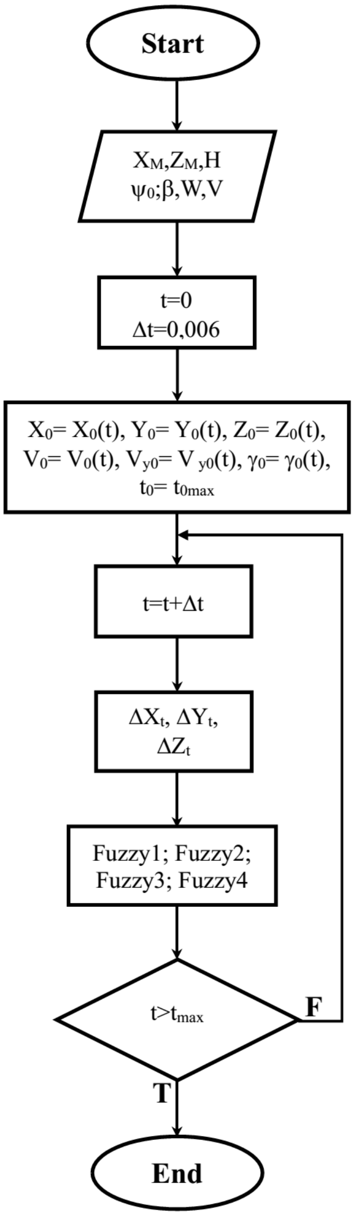

Figure 1. Flowchart of the UAV-70V control algorithm

The input signals are the parameters at the moment when the UAV receives the landing signal:

X_M, Z_M, H - UAV coordinates

ψ_0 - Heading angle, V - Velocity, W - Wind speed, β -Wind direction

$X_0, Y_0, Z_0, V_0, V_{y0}, \gamma_0$ -Parameters of the aircraft defined in the predefined trajectory, which have been calculated in reference [1]

$t_{0\max}$ - Flight time from the moment the landing command is received to the parachute deployment position when flying in the predefined trajectory with theoretical flight parameters, as determined in reference [1]

$\Delta X_t, \Delta Y_t, \Delta Z_t$ - Deviation of the actual trajectory from the theoretical trajectory at corresponding time intervals Δt, which serve as the basis for comparison for the fuzzy functions to issue control commands, ensuring the aircraft follows the predefined trajectory.

III. RESULTS

Case 1. Landing approach against the wind

Input data:

Wind direction 60°, wind speed 3 m/s, landing approach against the wind

Current position of the aircraft in space:

Coordinates (X, Y, Z) = (2000, 500, 750) meters

Heading angle 30°

Initial velocity V_0= 40 m/s

Survey Results:

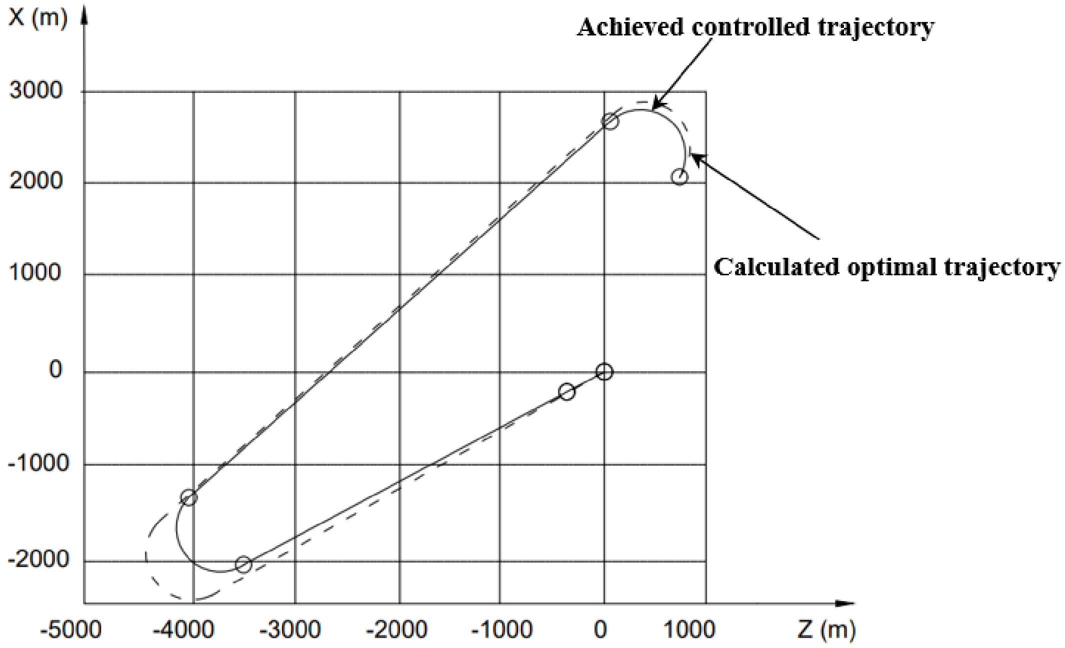

Figure 2. Landing approach against the wind

Remarks:

In the first turning phase: The trajectory deviation error starts from "0," and the roll control channel (fuzzy gamma) begins to work, influenced by crosswind W. The velocity control channel (fuzzy V) also starts working, but due to the small deviation parameters, the trajectory deviation remains small.

During the straight flight phase, maintaining the initial altitude: The heading control and velocity control channels work simultaneously. The trajectory parameters remain mostly unchanged.

In the second turning phase: Due to a larger deviation in the input speed (to maintain the straight flight trajectory), the velocity control channel, combined with the roll angle control channel, works simultaneously, resulting in a significantly larger trajectory deviation compared to the first turning phase.

In the descent phase: The heading control and altitude control channels (fuzzy V_y) work together, and the trajectory deviation is small.

Case 2. Landing approach along the predetermined direction

Input data:

North wind ($0°$), wind speed 3m/s , landing approach along the predetermined direction (Heading $60°$)

Current position of the aircraft in space:

Coordinates $(X,Y,Z)=(2000,500,750)$ meters

Heading angle $30°$

Initial velocity $V_0 = 40\text{m/s}$

In this case, the UAV is approaching the landing point along a predefined direction, with wind coming from the north. The analysis would focus on how the UAV adjusts its path and handles the wind during the landing approach, with the fuzzy control system making necessary adjustments for stable flight and accurate landing.

Survey Results:

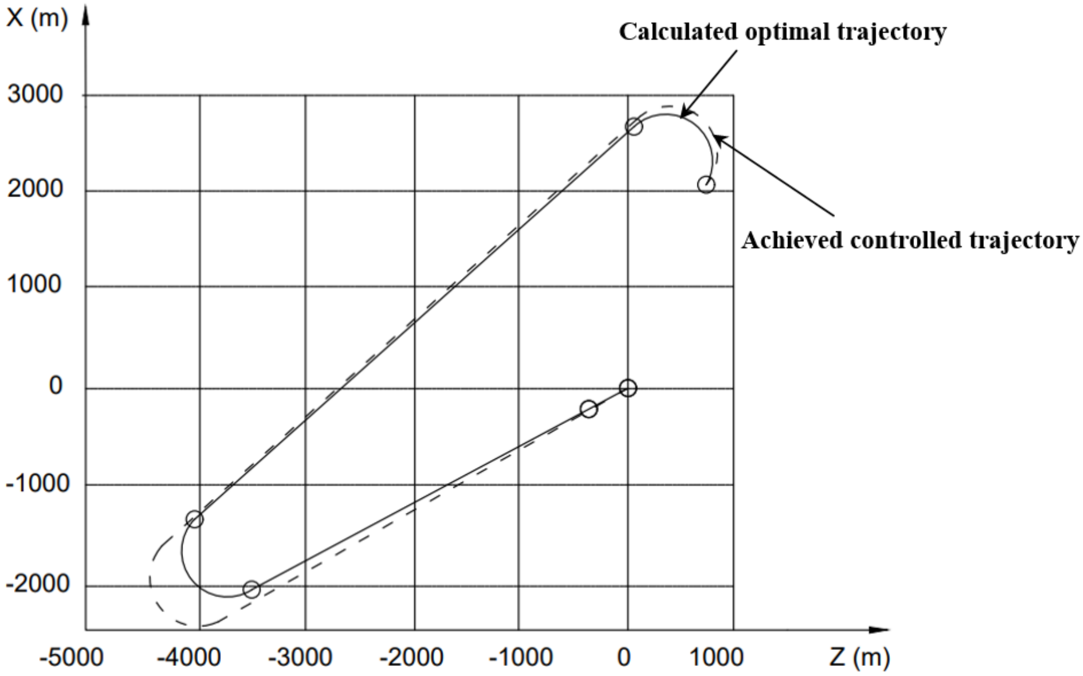

Figure 3. Landing approach along the predetermined direction

Remarks:

In this case, the input parameters are the same as in Case 1, with the only difference being the wind direction. However, since the landing direction is chosen to be along the wind direction (which was the opposite in Case 1), the following observations are made:

The predetermined landing approach trajectoryremains the same.

The actual trajectory is also the same.

This demonstrates that the software runs stably and accurately, adapting to the chosen landing direction and the wind conditions effectively.

IV. DISCUSSION AND CONCLUSION

Thus, with the control programs for the control surfaces, it is entirely possible to guide the aircraft to the intended parachute deployment landing point. The results obtained serve as a foundation and are an indispensable part of the design, development, and improvement of unmanned aerial vehicles (UAVs). The control algorithm for the landing approach process plays a crucial role in building an overall control program to ensure the stable and effective operation of the UAV. Through investigation and analysis, this control program has calculated and determined the actual flight trajectory of the UAV during the landing approach phase. It also provides detailed information about the variation of other dynamic parameters of the UAV in space over time. These results not only clarify the difference between the actual landing approach trajectory and the desired one but also visually represent the oscillation amplitude of the UAV in real-world conditions. The amplitude of the oscillation of the actual landing approach trajectory is influenced by many important factors, including the control channels, the number of channels used, and the speed and direction of wind in the operational area. This enables researchers to comprehensively assess the control effectiveness of the UAV according to the developed program.

These results not only demonstrate the accuracy of the control algorithm but also help identify factors that need improvement to enhance the system's performance. Specifically, the control program for the UAV’s control surfaces has proven its ability to guide the aircraft to the desired parachute landing position. This is an essential factor because ensuring the UAV's safe and precise landing depends not only on the projected trajectory but also on the ability to adjust flexibly during the landing approach. With the ability to accurately calculate the trajectory and effectively control external factors, this control program provides a solid technical foundation for the design, development, and refinement of modern UAVs.

Overall, the results obtained not only contribute to a better understanding of the dynamics and control effectiveness of UAVs during the landing phase but also serve as a basis for developing more advanced algorithms to meet increasingly demanding requirements for precision, stability, and safety in UAV operations. These achievements are not only technically significant but also open up vast potential for applications in various fields, from military, industry, to search and rescue and environmental monitoring.

REFERENCES

[1]. Anh Tu Hoang, Van Quang Pham, Calculation and Determination of Landing Trajectory for UAVs Considering Wind Effects, Proceedings of the 10th National Mechanics Conference, p.372.
[2]. Luong Hoang, Flight Dynamics, Volume 1, 1998.
[3]. Nuke Newcome, “News Room,” UAV Forum, SRA International, 4 Oct. 2003.
[4]. http://www.uavforum.com/library/news.htm.
[5]. UAV Flight Systems, AP50 Autopilot, Colorado, 2003.