METHOD FOR PRECISE LANDING OF UNMANNED AERIAL VEHICLE

Jamolova Gulbanbegim Muzaffar qizi
p.f.f.d (PhD),
Karshi branch of Tashkent University of Information Technologies
E-mail: Gulbanbegim_jamolova@gmail.com,

Bo'riyev Sardor Norovich
assistent,
Karshi branch of Tashkent University of Information Technologies

Akhmadjon Tursunov
student
Karshi branch of Tashkent University of Information Technologies
E-mail: akhmadjontursunov1@gmail.com

ABSTRACT

An aircraft landing is a very challenging problem. Due to the risks involved, pilots practice touchdowns for a long time during the landing phase. Over the past ten years, research on the development of autonomous landing technologies has been vigorous. This article gives a general overview of landing procedures, covering everything from vision-based landings to GPS-based ones, and basic controls to sophisticated ones. It aims to give a comprehensive overview of the landing control problem's current state and controller design. The comparison presented in this paper is based on factors including vehicle type, problem design assumptions, methodological approaches, and algorithm performance in real-world scenarios.

Keywords: UAVs, Neural network-based control, Fuzzy logic, Backstepping control, Sliding mode control, Feedback linearization, INS systems, GPS

INTRODUCTION

Unmanned aerial vehicles (UAVs) are very effective in remote operations. These vehicles are used in various fields such as surveillance, search, agriculture, border patrol, scientific experiments, and mapping. Over the past few decades, communications, sensor, and control technologies have evolved, resulting in a wide range of UAVs varying in shape, size, configuration, and characteristics. Common types of UAVs are fixed-wing UAVs, quadcopters, and helicopters of different scales (large UAVs, miniature vehicles, or micro drones). Fixed-wing UAVs have a simple design, fly at high speeds, and have a longer flight time compared to rotary-wing UAVs. However, some fixed-wing UAVs may require a runway to take off and land, while those that are manually launched or catapulted can land without a runway. On the other hand, rotary-wing UAVs have the advantage of hovering, which is useful for monitoring certain regions of interest. Rotary-wing UAVs are maneuverable, but at the same time they have high mechanical complexity, low speed, and a short range. Landing is an integral part of any reusable unmanned aerial vehicle (UAV) application, regardless of its functional purpose. This stage is characterized by a high level of technical implementation complexity and largely determines such important characteristics of an unmanned aerial vehicle as acceptable application conditions, flexibility, mobility, maneuverability, autonomy, all-weather capability, and reusability. Therefore, the search for and development of new methods, schemes, and means of landing UAVs is one of the most urgent tasks, whose successful solution ultimately determines the expansion of the UAV application field and the development of unmanned aviation as a whole.

BASIC UAV LANDING PATTERNS

- Landing by plane (runway); landing by helicopter (pad);
- Helicopter landing (pad landing);
- Parachute landing;
- Landing into a catching device.

The first three schemes use the standard navigation equipment of the UAV to solve the problem of terminal control. The second task is solved by running the UAV along the runway until it comes to a complete stop, as well as by using a parachute or a parachute system consisting of a brake parachute and a main parachute [1], and, if necessary, inflatable landing cylinders (cushions, shock absorbers) located under the fuselage and wings, which protect the UAV from damage when touching the ground. In helicopter landing, the second problem does not need to be solved, as an unmanned helicopter ensures landing with zero landing speed.

Landing into a catching device requires high accuracy of UAV coordinates relative to this device, which is usually not provided by standard UAV navigation equipment. Therefore, implementation of this scheme implies the development of special-purpose equipment to bring the UAV into the catching device and often manual control of the UAV during landing. At that point, the main advantage of the landing in the catching device scheme is the compactness of the landing site (area of space), which allows it to be performed, for example, on the deck of the ship, on small open areas of terrain.

The main disadvantage of the UAV landing method is the low autonomy of landing due to mandatory binding to the supporting ground infrastructure (airfields with a landing strip, course gliders, and other landing equipment), which significantly limits the acceptable conditions, flexibility, and efficiency of UAV applications.

The main disadvantage of the parachute method is its low landing accuracy; as a result, its implementation may require a landing site of large dimensions (up to tens of kilometers and more), free of obstructing objects, a collision with which may result in the loss of the UAV. Additional expenses of time for the search of UAVs over a considerable area and the subsequent evacuation of UAVs to the area of start cause low operability of repeated applications of UAVs. The necessity of search and evacuation by UAV requires the attraction of additional equipment (transport), which reduces the degree of autonomy of the method. Besides, the probability of UAV damage is high, which sharply reduces the multiplicity of its applications. The total weight of UAV parachute landing system units can reach 12–15%. According to other sources [1], the weight of only one parachute (without shock-absorbing devices), providing a safe landing speed of about 4 m/s, can reach 26% of the UAV mass. This significantly limits the mass reserve for payload or fuel (to increase range or flight time).

Different variants of landing schemes for the catching device differ in the type (design) of the latter. The most known are schemes using an aero-finisher [2] and landing schemes with entrapment in catching devices in the form of vertical and horizontal cables, rods, and nets [3]. The main limiting factor in the selection of such a landing scheme is the UAV weight, which, as a rule, should not exceed 100–120 kg, except for landing with the use of an air finisher. At the same time, as the UAV weight decreases, the variety of landing schemes and catching device designs grows to "exotic" variants [4].

The most typical and practical method of using a catching device is landing with a catch in a vertical net. Let us consider an example of the implementation of this landing method in the Aquila unmanned system [2]. The method consists of forming a narrow sectoral zone of UAV approach and setting a landing support trajectory, for which purpose two infrared cameras are installed at a given landing site on the structure of the catching vertical network attachment, whose fields of view set a narrow sectoral zone of UAV approach in lateral and vertical planes and the optical axis-supporting trajectory of UAV landing. Ground control stations provide radar tracking of UAVs by range and angular coordinates. Based on the radar tracking data, control commands are generated for entering the UAV into the narrow sector approach zone. These commands are transmitted via a radio link to the UAV and processed by the onboard control system. The lateral and vertical angular deviations of the UAV from the landing reference track are detected by the on-board infrared source by means of infrared cameras. These deviations are transmitted via radio link to the UAV and are used by the onboard control system to keep the UAV on the landing reference path until it hits the catch net.

The main disadvantage of the vertical net landing method is its low autonomy, due to the fact that a significant part of the actions are performed on the ground with the use of appropriate ground equipment. Besides, it does not provide all-angle UAV approach and all-weather landing, which is caused by the formation of narrow sectoral zones of UAV approach and the use of infrared wavelength range in the landing equipment. Landing requires an open, unobstructed area of considerable size (radius of at least 200–250 m).

In order to increase the autonomous performance of UAV landing, provide an all-angle approach and all-weather performance of landing, and reduce the size of the landing site to units of meters in cross-section, the method of accurate landing of small-sized UAVs in the horizontal catching net is proposed [5]. The method consists of the following: In order to form a circular approach zone, an isotropic radio emission source (radio beacon) is installed at the given landing point, and a radio direction finder is installed onboard the UAV. With the help of standard onboard navigation equipment, autonomous entry of the UAV into the landing approach zone is performed. The onboard direction finder receives signals from the radio beacon and provides its angular tracking in the horizontal and vertical planes. Based on the radio direction finder data, the onboard control system generates homing commands for the UAV to locate the radio beacon in the horizontal plane. Simultaneously with the homing of the UAV to the radio beacon in the horizontal plane, the UAV performs its flight at a given altitude until reaching a predetermined angle of sighting of the radio beacon in the vertical plane. Then the UAV is dived and self-targeted to the radio beacon in the vertical and horizontal planes until it hits the catching network installed horizontally above the radio beacon.

Figure 1 shows the scheme of implementation of the proposed method of precise landing of a small UAV.

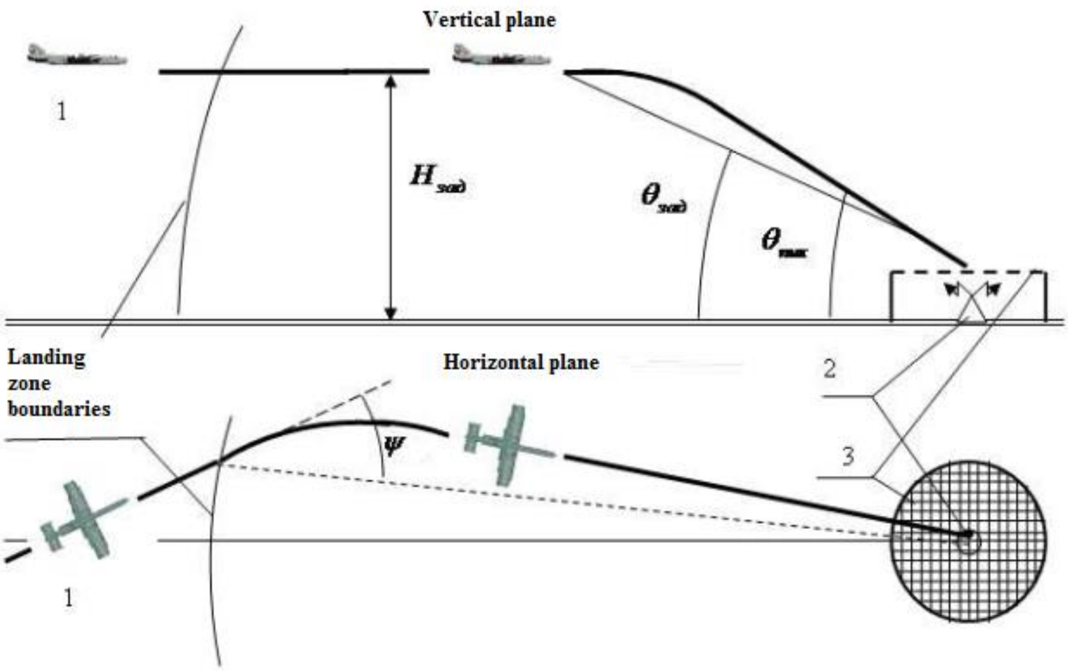

Figure 1 - Scheme of the implementation of the method of accurate landing of a small-sized UAV in a horizontal network: 1 - UAV with standard on-board navigation equipment, an on-board control system and an on-board radio direction finder; 2 - isotropic radio beacon installed at a given landing point; 3 - horizontal catching network

LANDING CONTROLLERS

A typical landing system uses GPS (global positioning system) and INS (inertial navigation sensors). Altitude measurement with GPS is inaccurate, so in combination with GPS, a close-range sensor such as a radar altimeter or barometric pressure sensor is also used. However, GPS signals are not always available, so an automatic landing may not be possible in many remote areas. In the case of unmanned helicopters, GPS and INS systems are suitable for long-range and low-accuracy flights but are not suitable for accurate and close flights [6]. Thus, there is a need to integrate these systems to improve accuracy and reliability.

NON-LINEAR CONTROL METHODS

An aircraft model can be either a linearized or non-linearized aircraft model. In a linearized model, the longitudinal and transverse dynamics of the aircraft are decoupled, allowing the use of separate controllers and loops. Control techniques such as feedback linearization, sliding mode control, and backstepping are often used for the nonlinear aircraft model [7].

1) Feedback linearization: Feedback linearization is a technique used to control non-linear systems. It attempts to introduce an auxiliary non-linear feedback so that the system can be treated as linear for control design purposes. Prasad and Pradeep [8]

used this technique to control the landing of a fighter jet. Voos and Nourghassemi [9] proposed a stabilized flight and landing strategy for quadrotor UAVs, where they used a nonlinear feedback linearization technique to linearize and decouple three of the six degrees of freedom. Burchett [10] applied feedback linearization to the point mass dynamics of a vehicle to control the approach and landing of a reusable launch vehicle. The result was a linear system with inputs that were combinations of lift, drag, and roll angle. Applying a simple aerodynamic model, the lift and drag were mapped to negative z-axis acceleration and deceleration commands. The direct application of feedback linearization requires second- and third-order derivatives from uncertain aerodynamic systems, which does not guarantee stability. To overcome this, the flight dynamics can be divided into slow and fast dynamics with sufficient time separation [6].

2) Sliding mode control: The sliding mode control method is a non-linear control method that modifies the non-linear dynamics by applying an intermittent control signal. In this method, the trajectories are forced to reach a sliding manifold in a finite amount of time and remain at that manifold for all future time. These trajectories in sliding control mode are defined as solutions of a set of sliding functions, where the number of variables to track the trajectory must be equal to the number of available control inputs [12]. The main problems in sliding mode control are jitter and high control requirements. Therefore, an appropriate choice of sliding functions and attainment laws must be developed.

3) Backstepping control: Backstepping control is another non-linear method that can be used to design a landing controller. The backstepping method provides a recursive method of stabilizing the start of the system in the form of strict feedback. In such a system, the designer can start with a basic, stable system and ‘fall back’ on new controllers that gradually stabilize each external subsystem. For an autonomous UAV landing, the subsystems could be a rotation subsystem and a linear translation subsystem [13]. Using the backstepping approach, a control law can be synthesized to force the system to follow the desired trajectory. Ahmed and Pota [14] presented the application of a backstepping controller to land a rotary-wing aircraft (RUAV) using a tether. This approach was extended in [15], where the backstepping-based controller takes advantage of the ‘decoupling‘ of translation dynamics and rigid body rotation, resulting in a two-step procedure for obtaining control inputs for the UAV. Lee and Kim [11] proposed flight and landing control using backstepping and neural networks, where the backstepping controller monitored the angle of attack, side slip angle, and roll commands, assuming the aerodynamic model is fully known. Yoon et al. [16] proposed an adaptive backstepping controller for landing an aircraft with wind disturbances and actuator failures using hedging techniques. A nonlinear aircraft model

with six degrees of freedom was considered to design a backstepping controller that tracked the desired glide slope to the runway. In order to estimate the modeling errors of the aerodynamic coefficients in the nonlinear model, adaptive parameter estimation of the nonlinear function was adopted.

INTELLIGENT CONTROL METHODS

Intelligent control is a category of control methods that use various computational approaches to artificial intelligence, such as fuzzy logic, neural networks, and machine learning.

1) Fuzzy logic: Fuzzy logic is a form of multi-valued logic. It operates on the concept of partial truth, where the truth value can range from completely true to completely false. A fuzzy control system is a system that uses fuzzy logic. It accepts analog continuous input values from 0 to 1 instead of the discrete values 0 and 1. The process of converting an input value into a fuzzy value is called "phasing" [17]. Fuzzy logic is used in the landing task because it can account for non-linearities caused by aerodynamics, actuators, sensors, and environmental perturbations. In addition, fuzzy logic controllers can be combined with conventional controllers, such as PIDs, for more realistic system modeling. Nho and Aggarwal [18] developed a fuzzy logic controller like PD and tested it on simulations using linear and non-linear models. Miguel et al. [19] presented a fuzzy logic-based UAV landing system using 3D position estimation.

2) Neural network-based control: Neural network-based control involves two steps: system identification and control. Neural networks have the ability to learn. Given the specific problem to be solved and the class of function F, learning means using a set of observations to find f F, which controller, in the presence of different wind patterns, will extend the flight safety zone. Four different types of controllers have been developed: PID, neuro, hybrid neuro PID, and ANFIS-PID [21]. The neurocontroller was designed to control the aircraft in glide and flare modes. The hybrid neurocontroller was designed to control the aircraft in very high wind conditions. Fuzzy logic was used as it allows the system to be developed without a model. solves the problem in some optimal sense. Malayek et al. [20] have considered the problem of designing an intelligent auto-landing system.

HYBRID CONTROL METHODS

A system that exhibits both continuous and discrete behavior is a hybrid system. The state of the hybrid control system is defined by a set of continuous variables and a discrete control mode. In order to perform an autonomous landing, a sequence of complex tasks must be performed, especially if there are obstacles on the runway. Koo and Sastry [22] presented a hybrid control scheme for the landing task, modeling the external-internal loop of the vehicle as a hybrid system. The packet controller controlled the discrete state of the system based on the continuous state. The hybrid controller encoded the phase switching sequences in the landing scenario.

REFERENCES:

1. Лобанов Н.А. Основы расчета и конструирования парашютов. – М.: Машиностроение,1965.

2. Системы адаптивного управления летательными аппаратами. / А.С. Новоселов, В.Е. Болнокин, П.И. Чинаев, А.Н. Юрьев. - М. Машиностроение, 1987.

3. Овинов А.В. Способы взлета и посадки летательных аппаратов и взлетно-посадочная система для осуществления этих способов. Патент РФ № 2466913, 2010.

4. Николаев Р.П., Григорьев Д.В., Весельев А.В. и др. Способ посадки летательного аппарата. Патент РФ № 2208555, 2001.

5. Агеев А.М., Волобуев М.Ф., Михайленко С.Б. и др. Способ точной посадки беспилотного летательного аппарата. Патент РФ № 2539703, 2013.

6. A. Cesetti, E. Frontoni, A. Mancini, P. Zingaretti, and S. Longhi, “A vision-based guidance system for uav navigation and safe landing using natural landmarks,” in Selected papers from the 2nd International Symposium on UAVs, Reno, Nevada, USA June 8–10, 2009. Springer, 2010, pp. 233–257.

7. H. Khalil, Nonlinear Systems. Prentice Hall PTR, 2002. [Online]. Available: http://books.google.co.in/books?id=t\ d1QgAACAAJ

8. B. Prasad B and S. Pradeep, “Automatic landing system design using feedback linearization method,” in AIAA Infotech@ Aerospace 2007 Conference and Exhibit.

9. H. Voos and B. Nourghassemi, “Nonlinear control of stabilized flight and landing for quadrotor uavs,” in 7th Workshop on Advanced Control and Diagnosis, Zielona Gora, Poland ´ , 2009.

10. B. T. Burchett, “Feedback linearization guidance for approach and landing of reusable launch vehicles,” in American Control Conference, 2005. Proceedings of the 2005. IEEE, 2005, pp. 2093–2097.

11. T. Lee and Y. Kim, “Nonlinear adaptive flight control using backstepping and neural networks controller,” Journal of Guidance, Control, and Dynamics, vol. 24, no. 4, pp. 675–682, 2001.

12. D. Venkateswara Rao and T. H. Go, “Automatic landing system design using sliding mode control,” Aerospace Science and Technology, vol. 32, no. 1, pp. 180–187, 2014.

13. S. Bouabdallah and R. Siegwart, “Backstepping and sliding-mode techniques applied to an indoor micro quadrotor,” in Robotics and Automation, 2005. ICRA 2005.

Proceedings of the 2005 IEEE International Conference on. IEEE, 2005, pp. 2247–2252.
14. B. Ahmed and H. R. Pota, “Backstepping-based landing control of a ruav using tether incorporating flapping correction dynamics,” in American Control Conference, 2008. IEEE, 2008, pp. 2728–2733.
15. B. Ahmed, H. R. Pota, and M. Garratt, “Flight control of a rotary wing uav using backstepping,” International Journal of Robust and Nonlinear Control, vol. 20, no. 6, pp. 639–658, 2010.
16. S. Yoon, Y. Kim, and S. Park, “Constrained adaptive backstepping controller design for aircraft landing in wind disturbance and actuator stuck,” International Journal of Aeronautical and Space Sciences, vol. 13, no. 1, pp. 74–89, 2012.
17. M. Livchitz, A. Abershitz, U. Soudak, and A. Kandel, “Development of an automated fuzzy-logic-based expert system for unmanned landing,” Fuzzy Sets and Systems, vol. 93, no. 2, pp. 145–159, 1998.
18. K. Nho and R. K. Agarwal, “Automatic landing system design using fuzzy logic,” Journal of Guidance, Control, and Dynamics, vol. 23, no. 2, pp. 298–304, 2000.
19. M. A. Olivares-Mendez, I. F. Mondrag ´ on, P. Campoy, and C. Martinez, ´ “Fuzzy controller for uav-landing task using 3d-position visual estimation,” in Fuzzy Systems (FUZZ), 2010 IEEE International Conference on. Ieee, 2010, pp. 1–8.
20. S. Malaek, N. Sadati, H. Izadi, and M. Pakmehr, “Intelligent autolanding controller design using neural networks and fuzzy logic,” in Control Conference, 2004. 5th Asian, vol. 1. IEEE, 2004, pp. 365–373.
21. J.-S. Jang, “Anfis: adaptive-network-based fuzzy inference system,” Systems, Man and Cybernetics, IEEE Transactions on, vol. 23, no. 3, pp. 665–685, 1993.
22. T. J. Koo and S. Sastry, “Hybrid control of unmanned aerial vehicles for autonomous landing,” in Proceedings of 2nd AIAA Unmanned Unlimited, AIAA, systems, technologies, and operationsaerospace, land, and sea conference, 2003.