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Fuzzy Logic Based Approach to Design of Autonomous Landing System for Unmanned Aerial Vehicles

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Abstract This paper is concerned with autonomous flight of UAVs and proposes a fuzzy logic based autonomous flight and landing system controller. Besides three fuzzy logic controllers which are developed for autonomous navigation for UAVs in a previous work as fuzzy logic based autonomous mission control blocks, three more fuzzy logic modules are developed under the main landing system for the control of the horizontal and the vertical positions of the aircraft against the runway under a TACAN (Tactical Air Navigation) approach. The performance of the fuzzy logic based controllers is evaluated using the standard configuration of MATLAB and the Aerosim Aeronautical Simulation Block Set which provides a complete set of tools for rapid development of 6 degree-of-freedom nonlinear generic manned/unmanned aerial vehicle models. Additionally, FlightGear Flight Simulator and GMS aircraft instruments are deployed in order to get visual outputs that aid the designer in evaluating the performance and the potential of the controllers. The simulated test flights on an Aerosonde indicate the capability of the approach in achieving the desired performance despite the simple design procedure.

Keywords UAV · Autonomous flight control · Autonomous landing system · Fuzzy logic controller

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1 Introduction

For unmanned aerial vehicle systems to achieve full autonomy, smarter airplanes need to be developed. Full autonomy means performing takeoffs, autonomous waypoint navigation and, especially landings while the craft is hardest to control under computer control autonomously. In recent years, the usage of Unmanned Air Vehicles (UAVs) in different application areas has considerably increased, with a corresponding increase in the expectations from their autopilot systems. Capabilities of autopilot systems are important to successfully complete the mission of an UAV. A number of different autonomous capabilities may be required to be exhibited during a flight, like autonomous take off, navigation and autonomous landing.

Navigation is the topic which is most studied about. Autonomous navigation can be achieved by using several different techniques and technologies like fuzzy control, adaptive control, neural networks and genetic algorithms. In this work, fuzzy logic based approach to design of flight navigation task will be used which is developed in [1]. There are three fuzzy logic based controller in the navigation computer design which are used to control the speed, the altitude and the position of the UAV in 3D space while UAV is navigating from one point to another.

Landing is one of the most critical parts of a flight, because, like in traditional aircrafts, UAVs aim to land at minimum air speed, consequently the stability conditions are severe and the maneuvering abilities are limited. A total of 65 Predators have crashed to date, including three during Jan.–Oct. 2009. Thirty-six of the crashes were attributed to human error, and half of those occurred during landing [2]. Air Force Research laboratory has reported that 71% of Predator crashes between 2003 and 2006 resulted from human error. US Air Force is about to field a laser altimeter that could make its Predators and Reapers easier to fly until the automated take-off and landing systems are ready for Reapers in 2012 [2]. For now, personnel inside launch and recovery stations continue to guide the UAVs in with joysticks at the end of each mission. UAV operators must be local teams in the landing airfields of the UAVs because, otherwise, the signal delays would make them impossible to control. The difficulties in taking off and landing arise mostly from instinctual factors, because pilots use their feelings in these periods of flight, such as feeling the ground rush and having peripheral vision. Cross check is one of the most important procedures. For a kite pilot, landing is a process which aims to see the wings inside of runway, but when a pilot is not in the cockpit, such feelings do not exist any longer. Because of these reasons, the manual control of an UAV from the ground is not a good alternative in the case of an emergency, especially during takeoff and landing.

The basic parts of a UAV mission flight can be seen in Fig. 1. The UAV is controlled by human manually in the initial part of the flight and after the low altitude flight missions the flight computer becomes active. In the part of the flight until landing the UAV is controlled by the mission computer. When the UAV reaches the initial approach point, the landing system takes the control of the UAV to complete the mission flight.

This paper is concerned with the final approach and the touch-down periods of UAVs and proposes a fuzzy logic based autonomous landing system controller. The navigation system needs are met a fuzzy logic based autonomous navigation system. Three fuzzy logic modules are developed under the main landing system for the control of the horizontal and the vertical positions of the aircraft against the runway

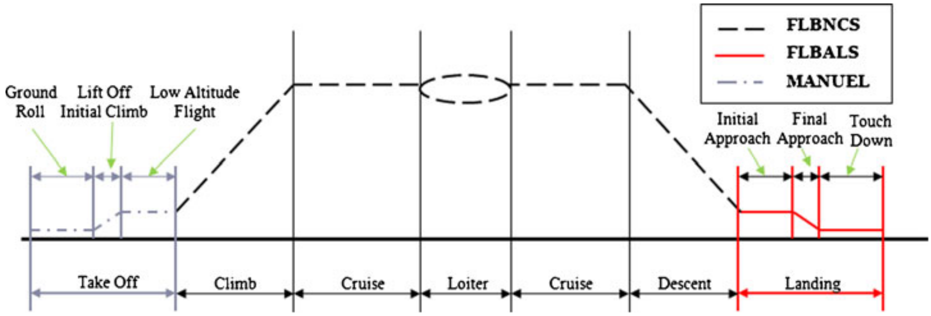


Fig. 1 Basic parts of UAV mission flight

under a TACAN (Tactical Air Navigation) approach. In Section 2 the autonomous landing model is defined by using landing parameters and landing path definitions. In Section 3, fuzzy logic based lateral position, altitude and speed controllers are described. In Section 4, the fuzzy logic based autonomous landing system is tested under simulated conditions. The conclusions and the work planned for the future are given in the last chapter.

2 Autonomous Landing Model

To accomplish a successful landing, there are three main attributes which must be under control. First of them is the lateral position of the UAV with reference to the runway. As has already been stated, the goal is to touchdown on the lateral middle point of the runway like in Fig. 2. The second attribute is the vertical position, which is the AGL (above ground level) altitude of the UAV. It is a dynamic value since it changes according to the distance to the runway, but the usual glide path angle is 3 degree in aviation literature as in Fig. 2. The glide path angle is 3 degrees in nearly all the airfields in the world if there is no obstacle in this 3° path. The last main attribute is the speed. The speed value is a static value and it depends on the aircraft characteristics. The main aim is keep the desired speed value during the period of the final approach.

In order to obtain the lateral position of the UAV with reference to the runway, different techniques can be used, like image processing [3] or radio based position calculators [4] and ILS (instrument landing systems) [5, 6]. To measure the altitude

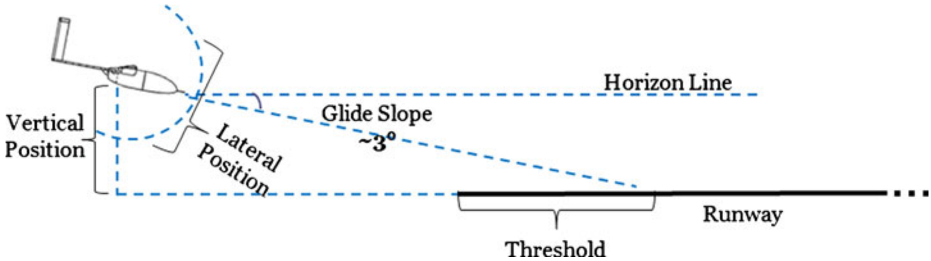


Fig. 2 Desired final approach path

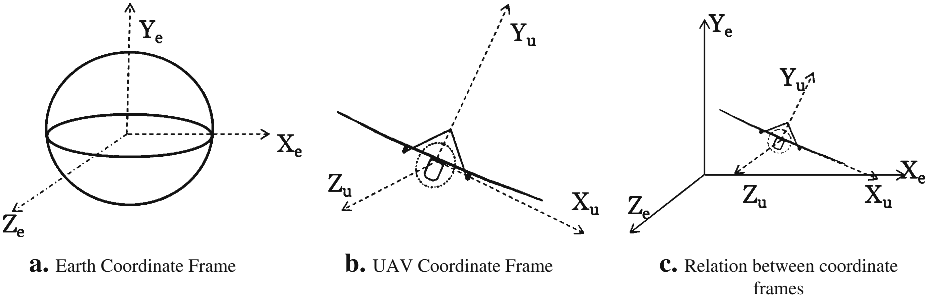


Fig. 3 Coordinate frames and relations

and the speed of the UAV, laser altimeters and pito systems can be used respectively [7]. In this work, it is assumed that accurate measurements of these three parameters are available.

In order to design the autonomous controller, the state of the aircraft has to be described by using 6-DOF Model of the aircraft and the Equations of Motion (EOM) [7]. For this purpose, two coordinate systems are used. The first one is the body coordinates of the UAV. The noninertial body coordinate system is fixed both in origin and orientation to the moving craft. The craft is assumed to be rigid. The second one is the Earth coordinate frame. The relation between the earth and the UAV body frames indicate the basic attitudes of the UAV like in Fig. 3. One of the ways to detect the attitudes of the UAV is the use of inertial measurement equipments (IMU).

3 Fuzzy Logic Based System Design

In literature, many different approaches can be seen related to the autonomous control of UAVs; some of the techniques proposed include fuzzy control [1, 8],

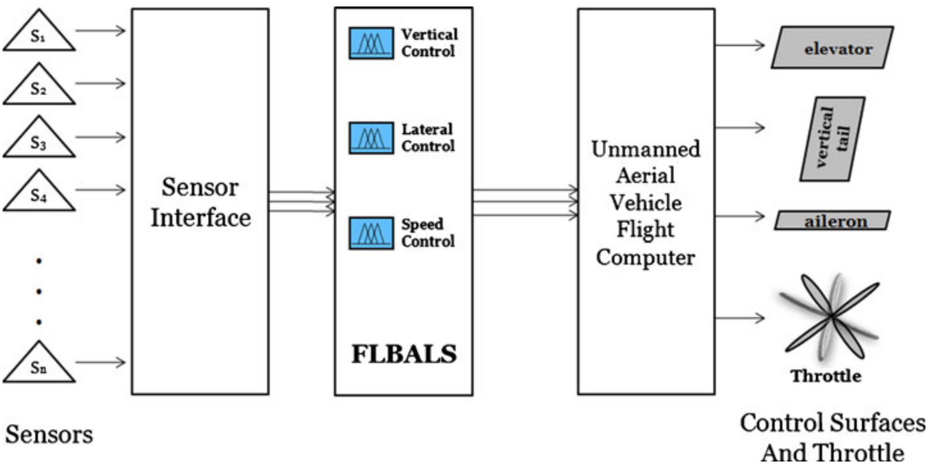


Fig. 4 Autonomous landing system architecture

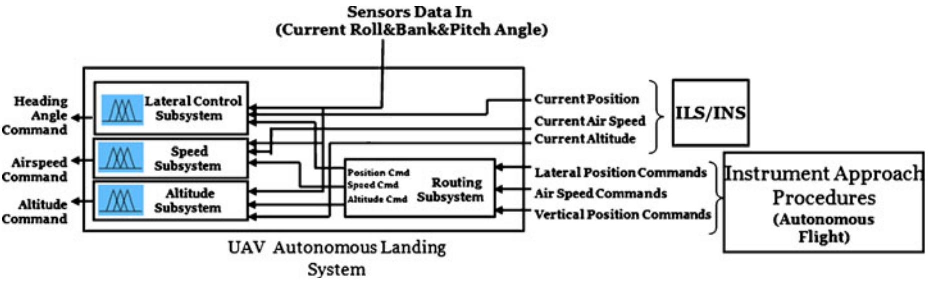
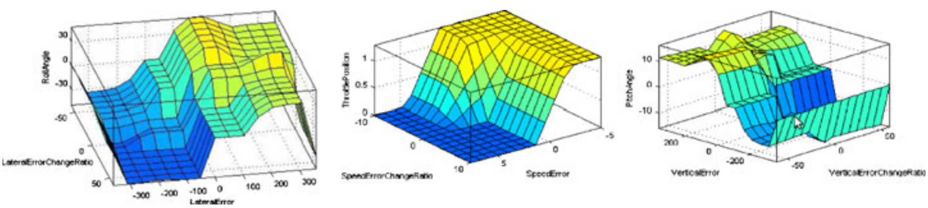


Fig. 5 Fuzzy logic based autonomous landing system design

adaptive control [9, 10], neural networks [11, 12], genetic algorithms [13] and Lyapunov Theory [14]. The architecture used by the authors in [7] for their work on a Fuzzy Logic Based Navigation Control System (FLNCS) forms the basis of the architecture for the Fuzzy Logic Based Autonomous Landing System (FLANS). This is shown in Fig. 4. After getting the sensor values from the sensor interface, both FLNCS and FLANS calculate the desired attitude of the UAV attitudes which must be achieved by the flight computer. Then flight computer selects the correct commands between the navigation computer and the landing system commands. If UAV is in the final approach pattern it uses the landing systems commands, else it uses the navigation computer commands as inputs. The flight computer then calculates the control surfaces and the throttle positions by using its direct sensor inputs and the command inputs to reach the desired attitudes. The flow of this process can be seen in Fig. 4.

The fuzzy logic based autonomous landing system uses the position inputs to calculate the exact location against the runway. It then determines the error and calculates the corrective maneuvers by using three fuzzy logic subsystem blocks. First fuzzy block is the lateral fuzzy logic controller which resolves the lateral errors. The second block is the vertical fuzzy logic controller which resolves the altitude errors and the last one is the speed fuzzy logic controller which tries to achieve the desired speed for the current conditions.

The inputs to these fuzzy logic blocks are provided by different systems like ILS/INS and GPS [3, 4], laser based systems [5] or by vision based algorithms [2]. Other inputs of these blocks are landing pattern flight plan or Ground Control Station (GCS) manual commands. These inputs of blocks can be seen in Fig. 5 and the surface diagrams of these blocks can be seen in Fig. 6.



a. Lateral Fuzzy Control Surface **b.** Speed Fuzzy Control Surface **c.** Vertical Fuzzy Control Surface

Fig. 6 Control surfaces

Weight	27-30 lb,
Wing Span	10 ft
Engine	24 cc, 1.2 kw
Flight	Fully Autonomous / Base Command
Speed	18 – 32 m/s
Range	>1800 miles
Altitude Range	Up to 20,000 ft
Payload	Maximum 5 lb with full fuel

Fig. 7 The aerosonde and its specifications

4 Simulation Studies

The performance of the proposed system is evaluated by simulating a number of test flights, using the standard configuration of MATLAB and the Aerosim Aeronautical Simulation Block Set [15], which provides a complete set of tools for rapid development of detailed 6 degree-of-freedom nonlinear generic manned/unmanned aerial vehicle models. As a test air vehicle, a model which is called Aerosonde UAV [16], shown in Fig. 7 together with its characteristics is utilized. The great flexibility of the Aerosonde, combined with a sophisticated command and control system, enables deployment and command from virtually any location.

In order to get visual outputs that aid the designer in the evaluation of the controllers, a number of aircraft instruments which are developed by using Delphi programming Active X components are deployed as shown in Fig. 8. Additionally, Flightgear open source flight simulator [17] is used to visualize the flight, like shown in Fig. 9. The details of these visual aids can be found in [18]. In order to be able to visualize the position of the UAV in GPS coordinate system, diagrams like the one shown in Fig. 12 are also plotted.

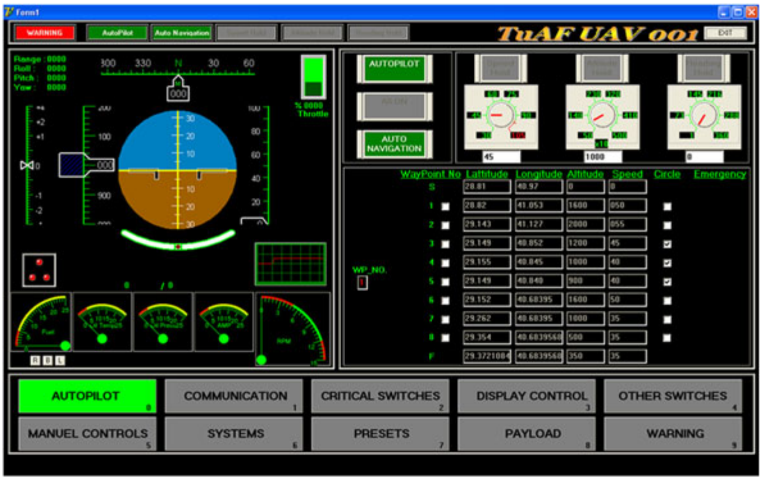


Fig. 8 UAV aircraft instruments to get visual outputs of UAV parameters and mission planning

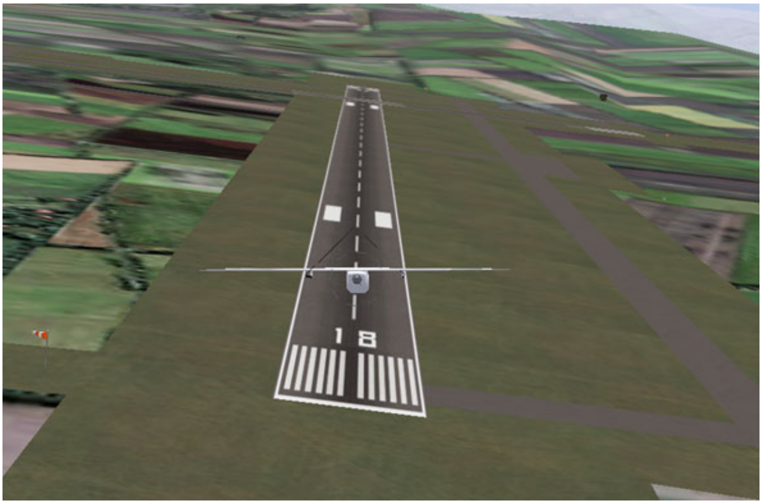


Fig. 9 Visualization of landing by the use of FlightGear

In Fig. 10, the top and the side views of the test flight pattern is shown. There are some important points which must be defined as GPS coordinates, like the initial approach point (IAP), the last turn point (LTP), the last approach point (LAP), the minimum altitude point (MIN) and the downwind turn point (DWTP). The UAV must reach the minimum altitude before the MIN point after takeoff. Then the UAV continues to the MIN point and starts to turn to reach DWTP. The particular set of these points that is used in the simulation studies is shown in Table 1.

In Table 1, the test pattern of the UAV autonomous landing system can be seen with the GPS coordinates and the altitude values of Istanbul Ataturk Airport 18–36 L runway. Each point of the pattern is represented by three values, the latitude and the longitude as the GPS position and the altitude as the vertical position.

To land, the aircraft must reach to the first point, which is the IAP and then it aims to reach the LTP and the LAP in order. After reaching the LAP, if airfield is not suitable for landing, it goes into a holding pattern. When the airfield becomes ready to land, the UAV completes the turn until the LAP is reached and goes into the final approach stage.

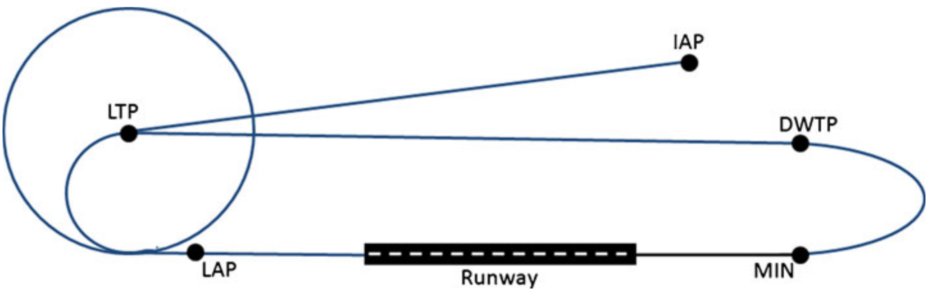


Fig. 10 The test pattern of the UAV autonomous landing system

Table 1 Definitions of test pattern waypoints

Point name	Coordinate (GPS)	Altitude (feet)
Runway starting point (RSP)	N40 59 24 E28 48 32	158
Minimum altitude point (MIN)	N41 03 13 E28 48 32	1,500
Down wind turn point (DWTP)	N41 03 13 E28 44 32	1,500
Initial approach point (IAP)	N40 55 57 E28 28 31	1,700
Last turn point (LTP)	N40 47 13 E28 44 32	1,500
Last approach point (LAP)	N40 49 12 E28 48 32	1,200
Runway end point (REP)	N40 58 11 E28 48 32	158

The autonomous landing system test pattern can successfully be achieved by using the fuzzy logic based navigation computer system which is developed earlier by the authors [7] except the last, final approach period of this pattern. In this work, the final approach period of landing pattern is handled. It begins with the LAP and finishes at the touchdown point of the runway. The coordinates of these points and the elevations are given in Fig. 11.

The final approach period of autonomous landing test pattern is applied in this work. The result of this test can be seen in Fig. 12. As shown in Fig. 12 all the points which are defined in Fig. 11 are reached in an order.

5 Discussions on the Simulation Results

The UAV must reach exact altitude values during the flying pattern as shown in Fig. 13. There are some levels which depend on the distance from the runway. The dashed line shows the altitude command and the other one shows the current altitude at that simulation time. As we can see in Fig. 13, fuzzy logic based autonomous landing system gets the desired altitude values in desired time. Also it manages not to sway too much from the 3° glide path angle throughout the pattern.

The last approach air speed of Aerosonde UAV is 60 knot. The fuzzy logic based autonomous landing system therefore tries to hold 60 knots during approach as

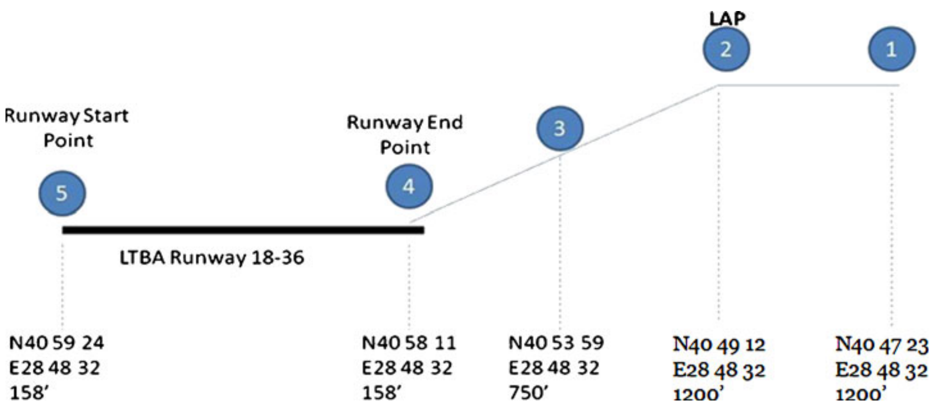


Fig. 11 Final approach period of autonomous landing test pattern

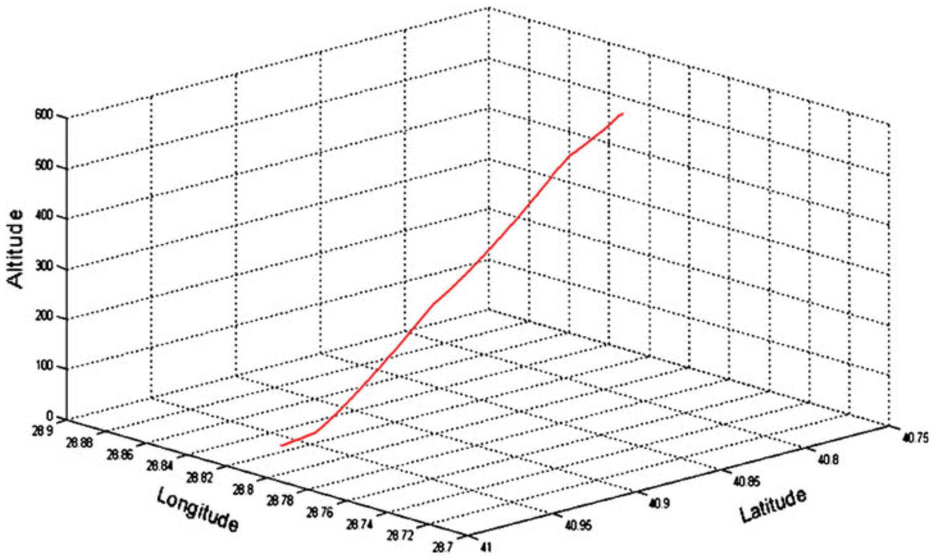


Fig. 12 The position of the UAV in final approach stage of pattern (GPS coordinate system)

shown in Fig. 14, The dashed line shows the desired air speed value and the continues one indicates the current air speed of UAV in that simulation time.

The vertical control and the air speed UAV are parameters that are related to each other. When the UAV pitches up, its speed decreases in parallel. The opposite of this is true also, when the UAV pitches down its speed increase. However, in this work there is no control relation between the air speed and the vertical control. The control of the air speed is provided by just using the throttle. The Aerosonde UAV is a kind of small fixed wing UAV. So this technique works to get airspeed of UAV under control. But major UAVs air speed must be controlled by using pitch angle and throttle together. So the architecture of control must be definitely different one.

In Fig. 12, we can see instant position of UAV in three dimension space during final approach of test pattern. Two dimensions of space are GPS coordinate frames to show the UAV's exact position. The other dimension is altitude of UAV in meter

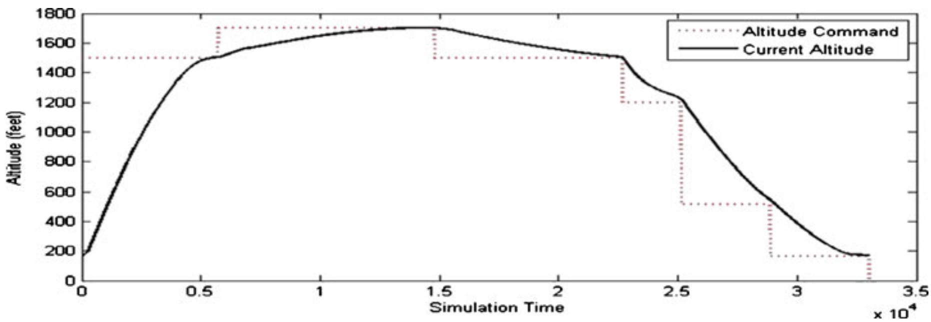


Fig. 13 Current and command altitude—simulation time diagram

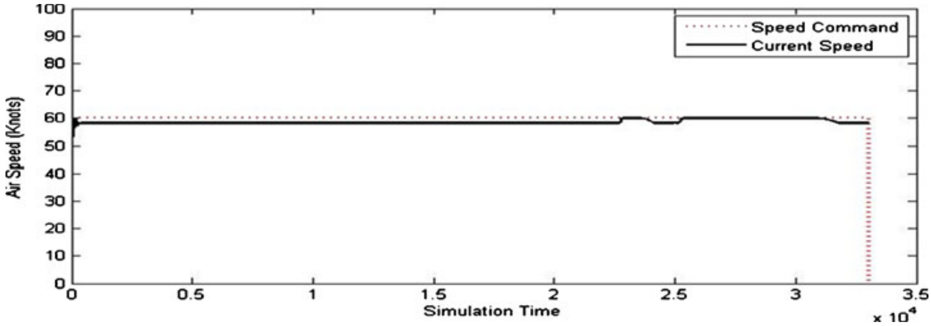


Fig. 14 Current and command air speed—simulation time diagram

scale. When we look at the diagram, we can say that fuzzy logic based autonomous landing system manage to hold UAV in correct position.

As shown in Fig. 15, UAV reached the waypoints which have been defined in test pattern waypoints table (Table 1). After manual take off, fuzzy logic based navigation computer system (FLBNCS) takes the control of UAV until UAV reaches the IAP. After reached IAP, UAV starts to be controlled by fuzzy logic based autonomous landing system (FLBALS). Both of the fuzzy logic based system successfully manage the UAV in test pattern, it can be seen in Fig. 16.

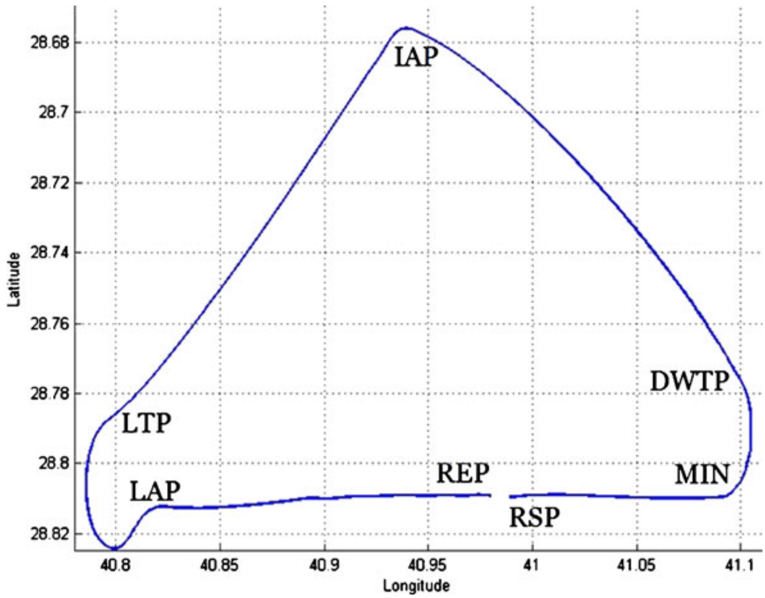


Fig. 15 UAV position in 2D GPS diagram

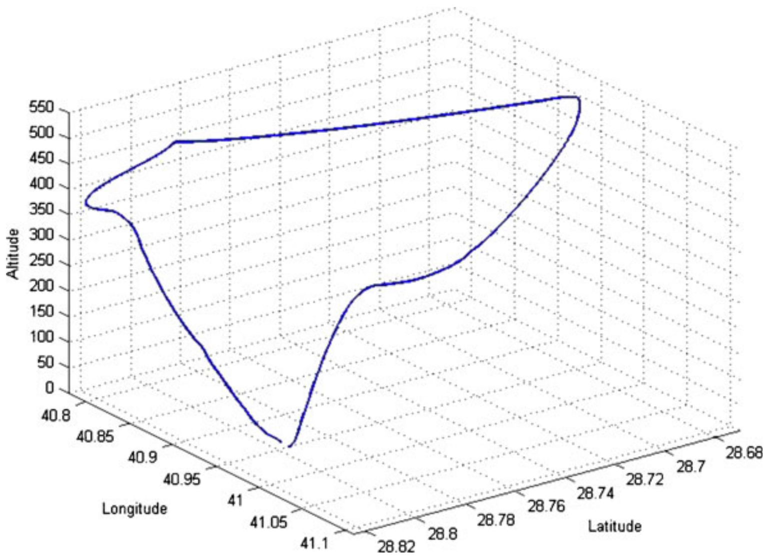


Fig. 16 Current position of UAV in test pattern diagram

6 Conclusions

The purpose of the paper has been to demonstrate fuzzy logic based autonomous landing of small aerial vehicles. The simulation studies have shown adequate overall performance of the controllers. The main objective of this work is to keep the UAV in a frame which is critical to hold the correct position during the final approach. This frame will be smaller when the UAV gets closer to the runway. The controllers must therefore show high performance against disruptive effects like wind. In our future work we will demonstrate the performance of fuzzy logic based autonomous landing system under disruptive effects.

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