Auto landing using fuzzy logic

Pavle Boskoski1, Biljana Mileva[2], Stojche Deskoski[3]

1 Faculty of Electrical Engineering – Skopje, R. Macedonia
2Military Academy „General Mihajlo Apostolski“ – Skopje, R. Macedonia
3Faculty of Technical Sciences – Bitola, R. Macedonia
E-mail: pavleb@mobimak.com.mk

Abstract: Fuzzy logic controllers (FLCs) are increasing its popularity as replacement of the conventional control methods. The FLCs finds their usage in all kind of processes: industrial, medical, environmental etc. The FLCs are used in this publication for auto landing of an airplane.
Landing procedure for any aircraft consists of several parts. This paper puts stress on the actual descending and touch down phase of the landing. During the landing procedure the aircraft goes through three phases: the descending, the flare manuvar and the actual touch down. The descending trajectory is steady descend on strait line from a start altitude, down to a several meters from the ground level. In that point the aircraft should proceed with a flare manuvar. The flare manuvar is actually changing the attack angle of the aircraft from steep descend to a small elevation. This manuvar allows the aircraft to decrease its vertical down speed. This short manuvar is followed by the actual touching down of the aircraft.
The aircraft used in this paper is an Unmanned Aerial Vehicle (UAV) model given in the Aerosim adds in Matlab. The model of the airplane itself is unstable and before any simulation is made with it, there is a need to stabilize it. The stabilization of the Aerosim add model in MATLAB is performed by using conventional techniques of PI, PD and / or PID controllers. In order to remain consistent in the whole publication, the authors of this
publication managed to replace the PID controllers with suitable FLCs. In total, there are four FLCs that are used to auto land the Aerosim UAV.
As input signals to the FLC responsible for the landing of the airplane, only simple
triangle and trapezoid membership functions are used and only 12 rules create the output of the FLC which actually gives the attack angle of the airplane.
This application shows once again that the fuzzy logic control with its simple design and
its robust properties can totally replace the conventional techniques of control management.

Keywords: Fuzzy Logic Contollers, Autolanding, Aerosim

1. INTRODUCTION

1.1. Instrument landing

The landing procedure consists of two major phases. The glide path phase and the finishing flare maneuver.

With the advent of the instrument landing system (ILS), aircraft became able to operate safely in weather conditions with restricted visibility. The instrument landing system is composed of ground-based signal transmitters and onboard receiving equipment. The ground-based equipment includes radio transmitters for the local-izer, glide path, and marker beacons. The equipment on the airplane consists of receivers for detecting the signals and indicators to display the information.

Before addressing the auto landing system, we briefly review the basic ideas behind the ILS equipment. To guide the airplane down toward the runway, the guidance must be lateral and vertical. The localizer beam is used to position the aircraft on a trajectory so that it will intercept the centerline of the runway. The transmitter radiates at a frequency in a band of 108-112 MHz. The purpose of this beam is to locate the airplane relative to a centerline of the runway. This is accomplished by creating azimuth guidance signals that are detected by the onboard localizer receiver. The azimuth guidance signal is created by superimposing a 90-Hz signal directed toward the left and a 150-Hz signal directed to the right on the carrier signal. Figure 1 shows an instrument landing localizer signal. When the aircraft is flying directly along the projected extension of the runway centerline, both superimposed signals are detected with equal strength. However, when the aircraft deviates say to the right of centerline, the 150-Hz signal is stronger. The receiver in the cockpit detects the difference and directs the pilot to fly the aircraft to the left by way of a vertical bar on the ILS indicator that shows the airplane to the right of the runway. If the airplane deviates to the left, the indicator will deflect the bar to the left of the runway marker.

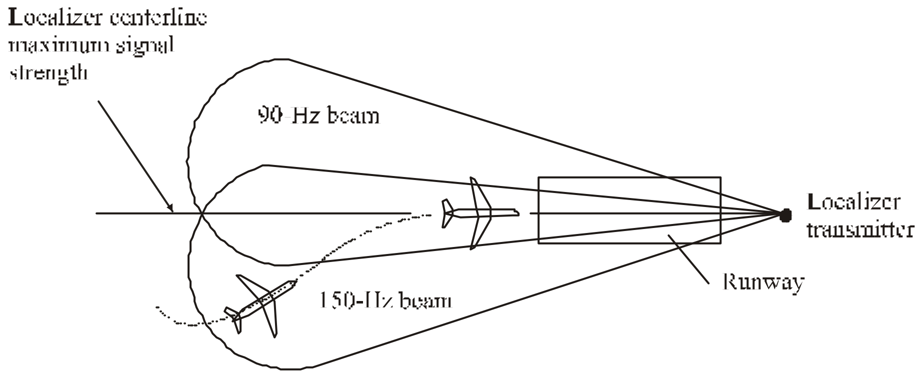


Figure 1

The glide path or glide slope beam is located near the runway threshold and radiates at a frequency in the range 329.3-335.0 MHz. Its purpose is to guide the aircraft down a predetermined descent path. The glide slope is typically an angle of 2.5-3° to the horizontal. Figure 8.31 shows a schematic of the glide path beam. Note that the glide path angle has been exaggerated in this sketch. As in the case of the localizer, two signals are superimposed on the carrier frequency to create an error signal if the aircraft is either high or low with respect to the glide path. This usually is indicated by a horizontal bar on the ILS indicator that moves up or down with respect to the glide path indicator. The marker beacons are used to locate the aircraft relative to the runway. Two markers are used. One, located 4 nautical miles from the runway, is called the outer marker. The second, or inner, marker is located 3500 ft from the runway threshold. The beams are directed vertically into the descent path at a frequency of 75 MHz. The signals are coded, and when the airplane flies overhead the signals are detected by an onboard receiver. The pilot is alerted to the passage over a marker beacon by both an audio signal and visual signal. The audio signal is heard over the aircraft's communication system and the visual signal is presented by way of a colored indicator light on the instrument panel.

In flying the airplane in poor visibility, the pilot uses the ILS equipment in the following manner. The pilot descends from cruise altitude under direction of ground control to an altitude of approximately 1200 ft above the ground. The pilot then is vectored so that the aircraft intercepts the localizer at a distance of at least 6 nautical miles from the runway. The pilot positions the airplane using the localizer display so that it is on a heading toward the runway centerline. When the aircraft approaches the outer marker, the glide path signal is intercepted. The aircraft is placed in its final approach configuration and the pilot flies down the glide path slope. The pilot follows the beams by maneuvering the airplane so that the vertical and horizontal bars on the ILS indicator show no deviation from the desired flight path. The ILS system does not guide the aircraft all the way to touchdown. At some point during the approach the pilot must look away from the instruments and outside the window to establish a visual reference for the final portion of the landing. The pilot may take 5 or 6 seconds to establish an outside visual refer. Obviously the pilot must do this at sufficient altitude and distance from the i 0 so that if the runway is not visible the pilot can abort the landing. This gi\ to a "decision height," which is a predetermined height above the runway t\ pilot cannot go beyond without visually sighting the runway.

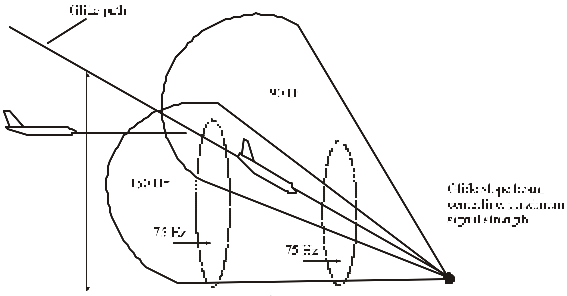


Figure 2

The ILS as outlined in the previous paragraphs is an integral part of an automatic landing system. To be able to land an airplane with no visual refer to the runway requires an automatic landing system that can intercept the localizer and glide path signals, then guide the airplane down the glide path to some j selected altitude at which the aircraft's descent rate is reduced and the air executes a flare maneuver so that it touches down with an acceptable sink rate, auto land system comprises a number of automatic control systems, which inc a localizer and glide path coupler, attitude and airspeed control, and an automatic flare control system.

1.2. Gliding path controller

The system uses the output signal from the airborne glide path receiver as a guidance command to the attitude control system of the aircraft. The loop is closed via the aircraft kinematics which transforms the pitch attitude of the aircraft into a displacement form that preferred the gliding path. The situation is represented on the figure 2 The glide path angle is denoted by g_G and its nominal value is -2.5^0. If an aircraft is flying into an airport, but it is displaced below the gliding by a distance *d*, that distance is negative. The geometry is shown on figure 2b. If the value of the aircraft's own flight path is -2.5^0, the displacement is 0. Any angular deviation from the centre-line of the glide path transmission is measured by the airborne glide path receiver: that deviation depends upon both the displacement, *d*, and the slant range from the transmitter. Since the value of g_G is so small it is customary to regard the slant and the horizontal ranges, *R* and *x*, as identical. The correct relationship is:

$$x = R\cos(-2.5^0) \tag{1}$$

In this section *x* and *R* are taken as identical. Therefore the angular deviation ? is defined as:

$$\Gamma = d / R \tag{2}$$

where ? is in radians. The component of the airspeed which is perpendicular to the glide path is $U_0 \sin\Gamma$. This quantity represents the rate of change of the displacement, i.e:

$$\dot{d} = U_0 \sin \Gamma = (U_0 / 57.3)\Gamma \tag{3}$$

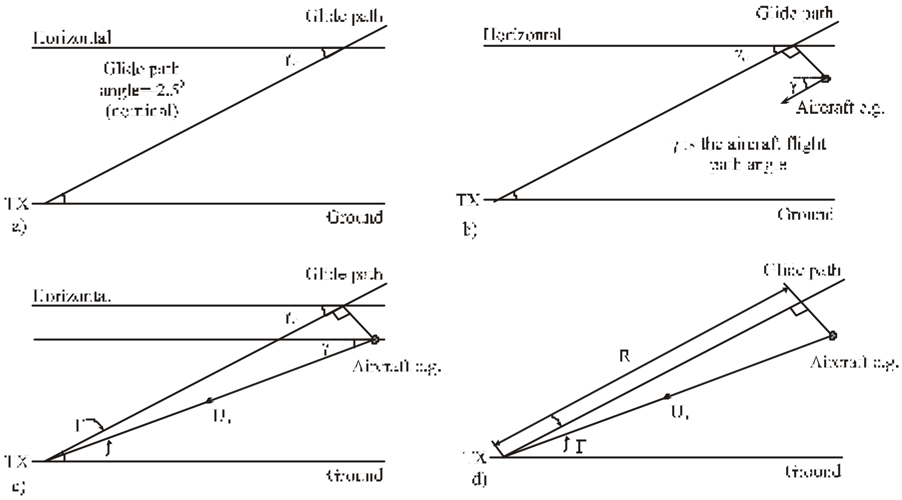


Figure 3

However, for the situation shown on figure 2 the aircraft's flight path angle is less then 2.5^0, therefore ? is positive (note that ? = $\gamma + 2.5^{0)}$ and d is positive. As the initial displacement was negative, and its rate of change is positive, the situation shown on figure 2c represents the case when the aircraft is approaching the glide path from below:

$$d = (U_0 / 57.3)\int (g + 2.5^0)dt = (U_0 / 57.3)\int \Gamma dt \tag{4}$$

The block diagram representing the equation is shown on the figure 3.

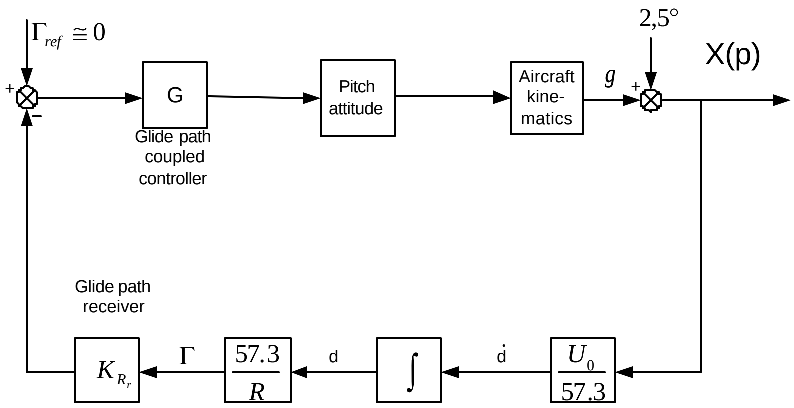


Figure 4

2. FLARE MANEUVER CONTROLLER

Although the contribution to development of airplane automatic landing systems has been international, the basis of most of the operational systems in service is the system developed in the UK by the Blind Landing Experimental Unit (now disbanded) of the Royal Aerospace Establishment.

The automatic flare control system is arranged to provide a flare trajectory corresponding to that shown in Figure 4. The trajectory represents the path of the aircraft's wheels as the landing is carried out. During this flare maneuver, the flight path angle of the aircraft has to be changed from - 2.5° to the positive value which is recommended for touchdown; in other words, during the flare maneuver the control system must control the height the aircraft's e.g. and its rate of change such that the resulting trajectory corresponds as nearly as possible to the idealized exponential path shown in Figure 4, while at the same time causing the aircraft to rotate in a fashion similar to the representation of Figure 4 The equation which governs idealized, exponential flare trajectory shown in Figure 4 is

$$h = h_0 e^{-t/t} \tag{5}$$

The distance from h_0, to the point of touchdown depends on the value of h_0, the flare entry height, and the approach speed of the aircraft, U_0. Usually the point of touchdown, which is aimed for, is 300 m from the runway threshold which is the nominal location of the glide path transmitter. Assuming that the airspeed does not change significantly throughout the flare trajectory (a not unreasonable assumption), then:

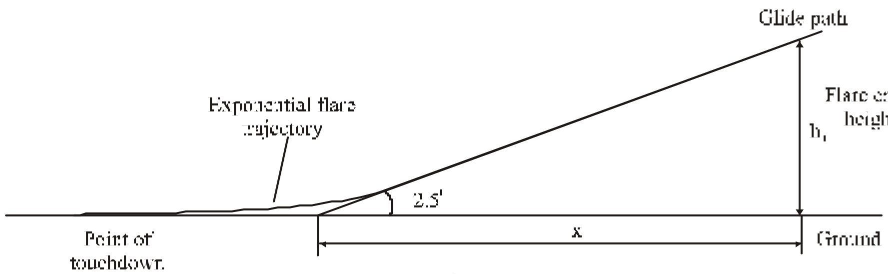


Figure 5

$$\dot{h}_0 = U_0 \sin g = U_0 \sin(-2.5^O)$$
$$\cong \frac{-2.5}{57.3} \times 57.3 = -2.5 ms^{-1} \tag{6}$$

(assuming landing speed for CHARLIE-l of 57.3 m s^{-1}). From eq. (6) it can easily be shown that:

$$\dot{h} = \frac{-h_0}{t} e^{-t/t} = \frac{-h}{t} \tag{7}$$

From eq. (7):

$$h_0 = -h_0 / t \tag{8}$$

hence:

$$-2.5 = -h_0 / t \tag{9}$$

From Figure 5, $h_0 = x \tan 2.5^0 = 0.0435x$, therefore:

$$t = (0.0435 / 2.5)x \tag{10}$$

Hence, substituting eq. (9) in eq. (10) yields:

$$
\begin{aligned}
& x + 300 = (286.5 \times 0.0435 / 2.5)x \\
& \therefore x = 75.3m \\
& \therefore h_0 = 3.25m \\
& t = 1.3s
\end{aligned}
\tag{11}
$$

Hence, the ideal flare maneuver is assumed to take 6.5s to completion. The law which governs the flare trajectory is given by:

$$h = -0.77h \tag{12}$$

A block diagram of an automatic flare control system is shown in Figure 4

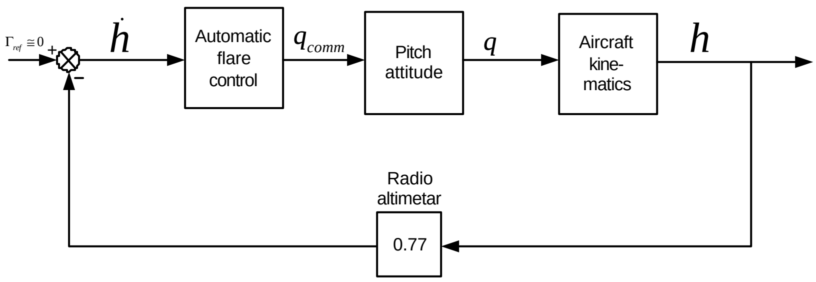


Figure 6

Note that the pitch attitude control system is used: changing G results in a change in flight path angle, and consequently, a change in height. Because the heights involved are very low, an accurate measurement of height is necessary for this control system: a low range altimeter is used. The control law used can be simply:

$$q_{comm} = -K_C \dot{h} \tag{13}$$

but, to ensure accuracy, it is usual to add an integral to the proportional term so that:

$$q_{comm} = -K_c \dot{h} - K_{c_2} h \tag{14}$$

The addition of the integral term, and the need to remove, by filtering, any noise from the height signal obtained from the radio altimeter tends to destabilize the closed loop system. Consequently, it is customary to include a phase advance network with the feedback terms to improve the stability, i.e.:

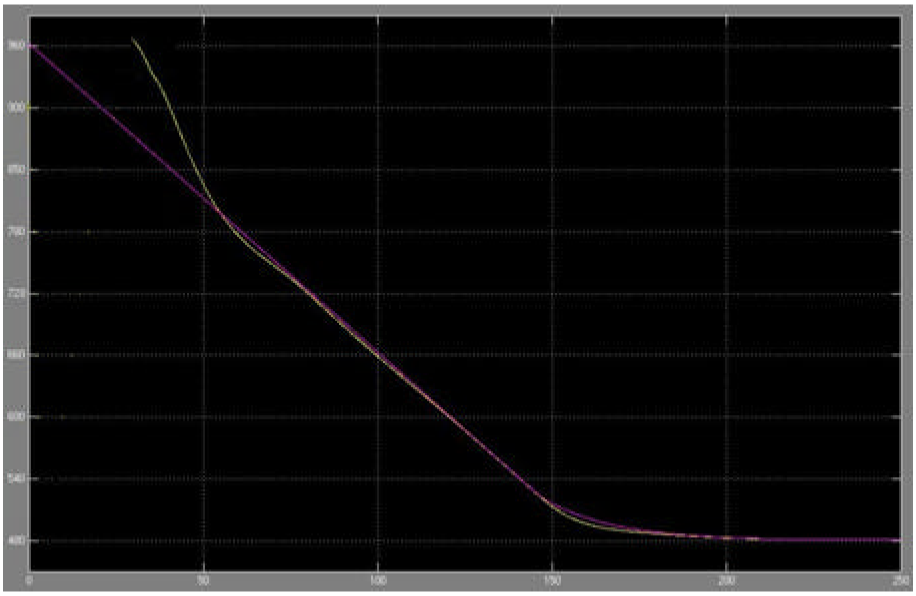
$$q_{comm} = -K_{c_1} \left(1 + \frac{K_{c_2}}{K_{c_1}} \cdot \frac{1}{p} \right) \left(\frac{1 + pT_1}{1 + pT_2} \right) h \tag{15}$$

where p = d/dt and $T_1 >> T_2$.

Because the model flare trajectory is exponential it takes infinite time to reach zero height the reference height is set to be -1.5m, thereby ensuring that the wheels will touch the runway at a time much nearer 5τs.

3. SIMULATION RESULTS

For the simulation purposes the UAV 6DOF is used. The model is defined in Aerosim plug-in of Matlab. The controllers used for the glide path an flare maneuver are fuzzy logic controllers.



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