A Study on Application of Fuzzy Logic Concept in Autonomous Landing of UAVs

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***Abstract*— *Landing of an UAV is a most complicated and important operation for autonomous flight operations. Most of the UAVs are operate with external pilots. Nowadays it is essential to design the advance automatic landing control systems to reduce the work load of external pilots in the landing process of UAVs. In this paper various auto rectification landing systems using fuzzy logic has studied and discussed. They are mostly used for integration with classical landing controllers to obtain accurate and safe landing of UAVs.*

Keywords—controller; fuzzy; landing; UAV

1. INTRODUCTION

Fuzzy logic is a mathematical system, which analyses the analog values in terms of logical values like zero and one or true / false respectively. This system is an alternative design method for linear and nonlinear systems for control operations. It is widely used in control of machinery operations. The controllers using fuzzy logic consist of input, processing and output stages in operation. The input data can collect from machinery components like switches and sensors. In the processing stages, the presetting rules will generate the results for each operation. The output results can obtain from the processing data in specific control output value. All the input values are mapped by sets of membership functions known as fuzzy sets.

The basic fuzzy control system design consists of the following processes.

- Documentation of systems inputs, outputs and operational specifications
- Fuzzy sets documentation for inputs
- Rule set documentation
- Finding out suitable defuzzification methods
- Testing and adjusting of suitability with valid system
- Completion of documentation and production release

In 1964, Lotfi A.Zadeh has created the idea of fuzzy set [1]. A fuzzy reasoning system can design with the help of fuzzy set operations. This system can act as a fuzzy controller. The computational mechanism of Mamdani type controller can proceed in following steps.

- Fuzzification
- Degree of fulfillment
- Implication
- Aggregation
- Defuzzification

In Mamdani inference, centroid, bisector, middle of maximum (MOM), smallest of maximum (SOM), largest of maximum (LOM) or custom can choose for the traditional operations. In Sugeno- inference between weighted average or weighted sum can choose.

Fuzzy logic is based on ordinary verbal communications and the major advantages of fuzzy logic are

- More flexibility
- Easy to understand
- High tolerance with imprecise data

2. FUZZY LOGIC CONCEPT IN LANDING APPLICATION

The basic idea of fuzzy logic integration for landing application has shown in fig. 1. P. Riseborough [2] has reviewed the design of control system for autonomous UAVs. The fuzzy controller can obtain the input parameters from the classical landing controllers. These parameters are corrected for the smooth landing process for UAVs. But these systems also can used in so many others ways. Olivares-Méndez.M.A, Mondragón.I.F, Campoy.P and Martínez.C [3] present an application of Fuzzy Controllers for UAV landing using the 3D-position estimation. Here the visual tracking technique of piecewise objects has used. The visual information has analyzed by fuzzy controller to generate the commands to develop the landing task. Omer Cetin, Sefer Kurnaz and Okyay Kaynak [4] has proposed an autonomous flight and landing controller system based on fuzzy logic. The performance of that controller has evaluated by MATLAB and Aerosim block set. Timothy J. Ross [5] has proposed a simple logical method for find out the profile of landing approach for HTOL (horizontal take-off and landing) aircraft or UAV as shown in fig.2. The profile can obtain with the parameters of downward velocity with height from the classical controllers for analyze using fuzzy logic concept.

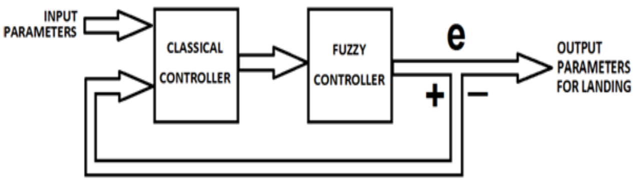

Fig.1. Basic idea of fuzzy logic integration for landing application

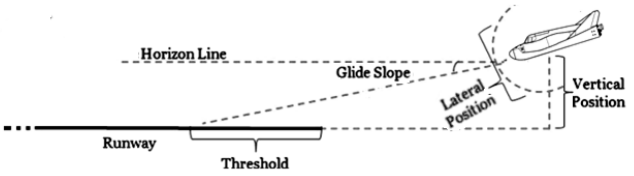

Fig. 2. Desired final approach path

During landing, if altitude decreases, the downward velocity also decreases. In certain limit, the downward velocity becomes vanishingly with altitude. In this way, the UAV can descend gently by avoiding damages. Here the state variables used are altitude (h) and downward velocity (v). The applied force to control the altitude and velocity is the control output. The general differential equations has desired from the below concept.

$$a = dv/dt \qquad (1)$$

Where a is acceleration
v is velocity

We know that from Newton's law, 'f = ma', So

$$dv = (f/m)\ dt \qquad (2)$$

Where f is force
m is mass

In the fig. 3, the moving mass (m) in velocity (v) has the momentum (p = mv). The mass will move in the same direction if no external forces are applied. To change the velocity of dv in a time interval dt, a force (f) can applied. So,

$$dv = F = (fxdt)/m \qquad (3)$$

or

$$v_{i+1} - v_i = F_i$$

We can say

$$v_{i+1} = v_i + F_i \qquad (4)$$

Where v_{i+1} is new velocity
v_i is old velocity

In one second of time interval, the change of velocity of mass of one lb-sec^2/ft is 'f' lb. So we can say, the velocity change is directly proportional to applied force (f). We know that,

$$Velocity\ (V) = ds/dt \qquad (5)$$

Where s is distance

TABLE I. SUMMARY OF FOUR-CYCLE SIMULATION RESULTS (SOURCE: TIMOTHY J.ROSS [5])

	Cycle 0	Cycle 1	Cycle 2	Cycle 3	Cycle 4
Height (ft)	1000.0	980.0	965.8	951.1	936.0
Velocity (ft/s)	-20.0	-14.2	-14.7	-15.1	-14.8
Control force	5.8	0.5	-0.4	0.3	-

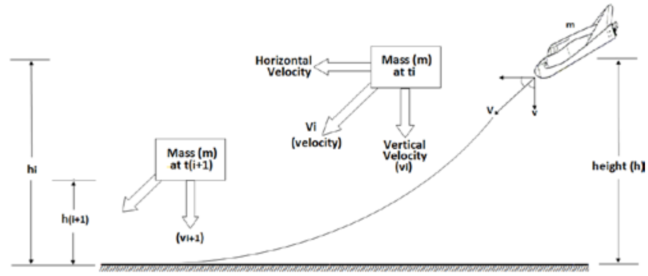

Fig. 3. Determination of landing path

In case of vertical velocity, height changes with respect to time. So that the formulae for vertical velocity (v) as given below.

$$v = dh / dt \qquad (6)$$

If time interval (dt) is one second, then

v = dh. Or in other form,

$$v_i = h_{i+1} - h_i$$

We can say

$$h_{i+1} = h_i + v_i \qquad (7)$$

Where h_{i+1} is new height
h_i is the old height

The control equations (4) and (7) define the new variables of v and h with respect to the control inputs and the previous variables. In the fig. 4 surface graph has obtained by putting the values for i = 0,1,2,….

The table 1 shows the summary of four-cycle simulation results. This concept used for obtain the 2D profile using less parameters. But fuzzy systems also used for obtaining profiles for studying the stability of UAVs in other maneuverings like rolling and yawing also. Jon C.Ervin and Sema E.Alptekin [6] have analyzed the effective use of fuzzy logic system in aircraft stability augmentation. The fuzzy systems can used for designing longitudinal, lateral and vertical controllers separately and also with integration methods.

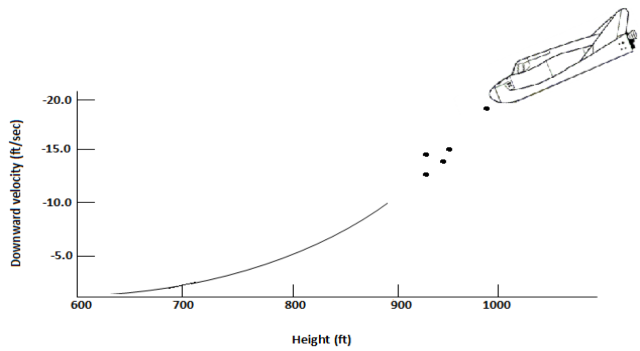

Fig. 4. Obtained landing profile using fuzzy logic. (Source: Timothy J. Ross [5])

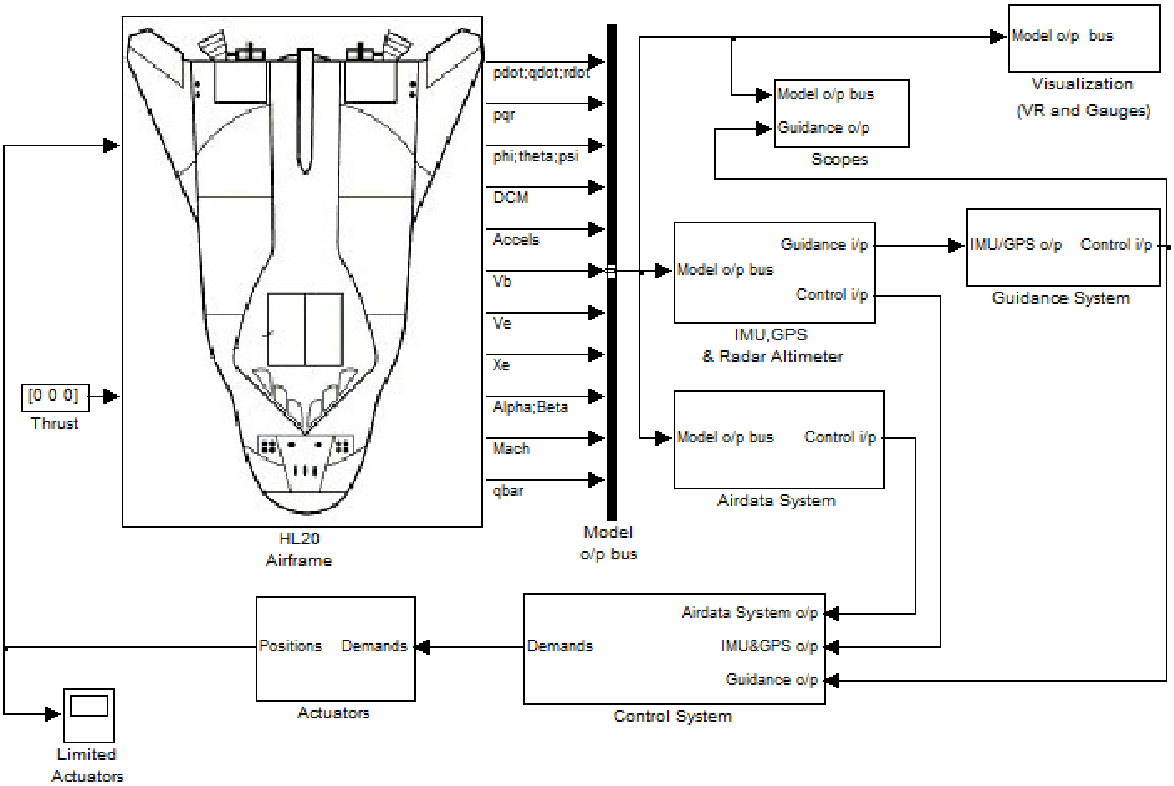

Fig. 5. Landing controller design of NASA's HL 20.
(source: mathworks [10])

Tan [7] has explained the integration of longitudinal and lateral controllers using NEM (Nonlinear Energy Method) for a specific aircraft. Fariborz Saghafi, Soha Pouya and S.M.Khansari Zadeh [8] has developed a fuzzy controller for auto landing of a fixed wing UAV with vision systems.

This study has focused the fuzzy logic concept only for auto landing. But the application of fuzzy logic has most extended for other flight phases like takeoff, climbing, cruising and descending also. Dániel Stojcsics [9] has examined the successful application of fuzzy controller for takeoff, cruise and landing for an UAVs. The simulation done by his work has indicates the results as same as in the original flight environments.

The major application of fuzzy logic in Aerospace landing application is NASA's (National Aeronautics and Space Administration) jet trainer for space shuttle operation. Fig. 5 shows the classical landing controller design of NASA's HL20 space launching system. Kimberly Bickraj, Thierry Pamphile, Aylin Yenilmez and Ming Li Ibrahim N. Tansel [11] have reviewed the available fuzzy logic control systems for UAV applications and they discussed a simple method known as Integration of health monitoring and FCS (flight control system). The important example of fuzzy logic application reviewed by them is Sugeno's control system for an unmanned helicopter.

To achieve the intelligent control, an onboard fuzzy controller has installed in that helicopter and it can control from ground by giving verbal commands.

3. Conclusion

A perfect landing controller for UAVs has not yet designed successfully. The major reasons for this drawback are cross wind effects, balance of center of gravity, facing the reaction forces in land during landing especially in touch down points in the landing areas. The vision based approach, fuzzy logic and neural network has using more effectively for design the landing controllers to solve these problems. Fuzzy logic reasoning systems are the mathematical approaches used with classical controllers and having more advantages with fault tolerant designing like less weight and reliability. The continuous effect has carried all over the world by design a successful landing controller for various types of UAVs. This study is very useful for gathering more ideas for advance landing controller designing purpose.

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