Design and Implementation of Fuzzy Controller for Estimating the Attitude of Unmanned Aerial Vehicles

S. Roopashree[1], K.M. Deepika[2], and Shubha Bhat[1]

[1] Department of Computer Science and Engineering, Dayananda Sagar College of Engineering, Affiliated to VTU, Bangalore-560078, India
{roopashree.patil,shubha22}@gmail.com
[2] Department of Information Science and Engineering, NitteMeenakshi Institute of Technology, Affiliated to VTU, Bangalore-560064, India
km.deepika4@gmail.com

Abstract. This paper describes the design of Compact, accurate and inexpensive Fuzzy Logic Controllers and Fuzzy Inference Systems which estimates the attitude of Unmanned Aerial Vehicles(UAV).Attitude refers to parameters of Unmanned Aerial Vehicle such as latitude, longitude and altitude and angles of rotation known as pitch and roll. A Soft Computing technique called Fuzzy Logic is used to design the Fuzzy Logic Controllers and Fuzzy Inference Systems. Visual simulation tool and Aerosim (Aeronautical Simulation Set) Flight gear interface are used for Simulation purpose.

Keywords: Unmanned Aerial Vehicle (UAV), Soft Computing Techniques, Fuzzy Logic (FL), Fuzzy Inference System (FIS).

1 Introduction

An Unmanned Aerial Vehicle (UAV) is an aircraft that flies without human crew. One of the critical Capabilities for making UAV autonomous and practical is the precise estimation of its position and orienatation.The position and orientation of UAV is termed as attitude (Latitude-Longitude,Altitude,Heading,roll and pitch. Usually UAV relies on GPS (Global Positioning System) and INS (Inertial Navigation System) to determine its position and orientation, but if the GPS signal for reasons like adverse weather conditions and hostile jamming becomes unavailable or corrupted, the state estimation solution provided by the INS alone drifts in time and will be unusable after sometime. GPS signal can also be unreliable when operating close to obstacles due to multipath reactions. Therefore when GPS and INS cannot predict and correct the position of UAV, Fuzzy Logic Controllers helps to predict the precise position and orientation of UAV autonomously and in turn helps in navigation of UAV.The objective of this paper is to demonstrate the design and implementation of an Fuzzy Inference System (FIS) which in turn are fed as input to three modular Fuzzy Logic Controllers named as Latitude-Longitude FLC, Altitude FLC and Heading FLC to predict the position of UAV and helping in autonomous navigation of UAV .To design Fuzzy Inference System a Soft Computing technique called the Fuzzy Logic is explored. Literature review has revealed the fact that Fuzzy Logic

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Controllers are designed to control the attitude of UAVs but have failed to give accurate results due to burden of many rules in the controller. Techniques such as Kalman filtering and steady state Genetic algorithms are used to design FIS, but they require a prior mathematical model to estimate the flight parameters, where as Fuzzy logic does not require any reference or pre-existing model to estimate the flight parameters.In section 2 the general structure of Fuzzy Logic Controller is explained. The Design of FIS which is used by FLC is explained in section 3. The results are discussed in section 4 Conclusion and future enhancements are discussed in Section 5.

2 Fuzzy Logic Controller

When a UAV navigates from one waypoint to another the attitude (Flight Dynamic Parameters) of the UAV varies. Therefore Fuzzy Inference Systems are designed which in turn used by modular FLCs to estimate the attitude of UAVs. The general structure of FLC is shown below.

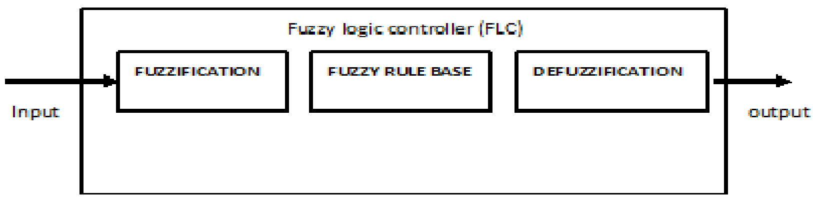

Fig. 1. General structure of Fuzzy Logic Controller

The block diagram of the generalized Fuzzy Logic controller consists of three elements

1) Fuzzification block: transforming input physical values into linguistic variables
2) Fuzzy Rule Base: containing rules to estimate and control UAV parameters.
3) Defuzzification block: transforming output linguistic variables into physical values to control the Flight Parameters.

The three modular Fuzzy Logic Controllers consists of three modules. First module is Latitude-Longitude FLC.Second module is altitude FLC and third module is heading FLC. Latitude-Longitude FLC determines the position of UAV along UAV.Altitude Module estimates the current altitude (height) of UAV .Altitude module has its inputs as altitude error, change of altitude error and airspeed. These inputs are used in design of FIS which controls the Fuzzy Logic Controller output parameters such as elevator, throttle and scaling and in turn helps in controlling Altitude of UAV. The third module is the heading module which has inputs as the change of heading error and airspeed, these inputs are used in design of FIS which controls the Fuzzy Logic Controller output parameters such as Heading and Roll angle and in turn helps in controlling the angles of rotation of UAV. The proposed Fuzzy Logic Controller which comprises of three modules is shown in Fig.2. The three modular FLC is responsible for the estimation and control of Altitude, Latitude-Longitude and Heading of UAV.

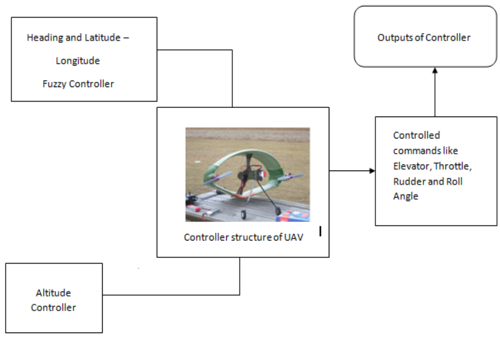

Fig. 2. Fuzzy Logic Controller comprising three modules

3 Simulation Environment

A Simulated environment in MATLAB and Aerosonde Model from Flight gear interface has been used for Simulation. The derived Aerial Controller model is shown in Fig.3. It consists of following Subsystems.

1) Fuzzy Logic Controller: It is composed of combination of Altitude, Latitude-Longitude and Heading Fuzzy Logic Controllers.
2) Scaling Embedded Matlab Function: it contains aircraft states as the input and calculates the scaling factor.
3) Altitude Embedded Matlab Function: it takes scaling as the input and calculates the change in altitude.
4) ErrorCalc Embedded Matlab Function: It Contains two inputs called Altitude and Airspeed. This block contains conditions to Control the Elevator and throttle of Aircraft.

The Functional model Altitude fuzzy logic controller is shown below:

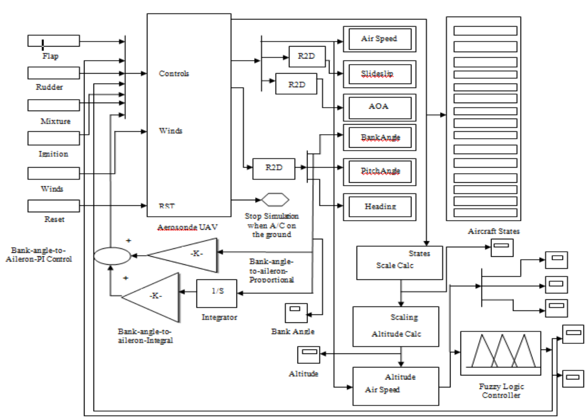

Fig. 3. Demonstrating the Aerosonde Simulation Model for Estimation of altitude of Unmanned Aerial Vehicles

4 Results

Considering the model shown above the Fuzzy Inference system for all the three modules of Fuzzy Logic Controllers is designed. The Fuzzy Inference System (FIS) for Altitude Fuzzy Logic Controller is designed and displayed in the Graphical User Interface (GUI) of Fuzzy Logic Toolkit using Matlab.The below section also explains about the command outputs of FLC which are obtained when simulation model is run for a specified time. The inputs to the Altitude controller are:

- Altitude: The altitude at which the aircraft will be trimmed.
- Airspeed: The airspeed at which the aircraft will be trimmed.
- Altitude Error: It is the difference between the desired altitude and the current altitude of the airplane.
- Change of Altitude: The error indicates whether the, aerial vehicle is approaching the desired altitude or if it is going away from it.

The graphs of inputs are shown below:

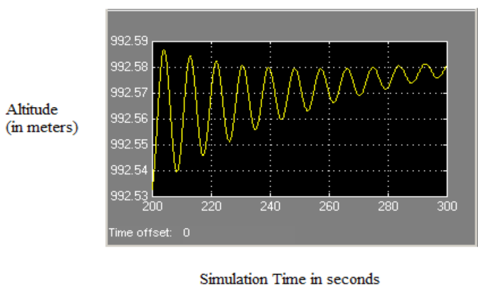

Fig. 4. Altitude of UAV

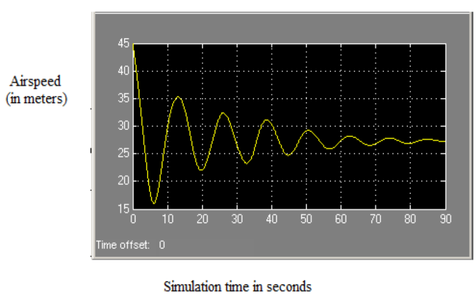

Fig. 5. Airspeed of UAV

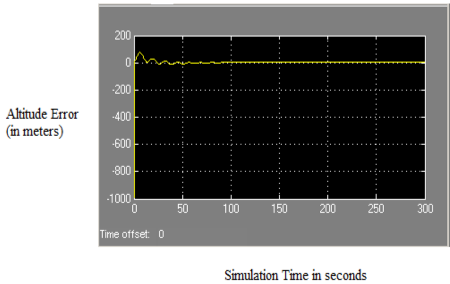

Fig. 6. Altitude error

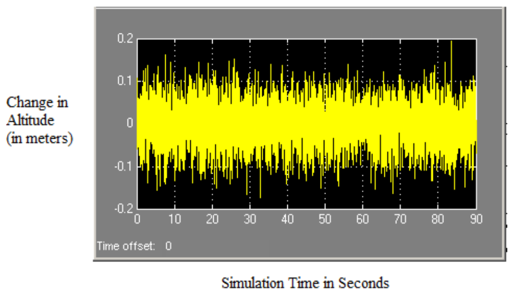

Fig. 7. Change of Altitude Error

The command outputs to the Altitude controller are:

- Elevator: The initial guess for the elevator position at trim condition.
- Throttle: The initial guess for the throttle position at trim condition.
- Scaling: This is the factor that indicates uniform change in altitude from one waypoint to another. Constant scaling in maintained when flight is navigating from one waypoint to another.

The graphs of command outputs are shown below:

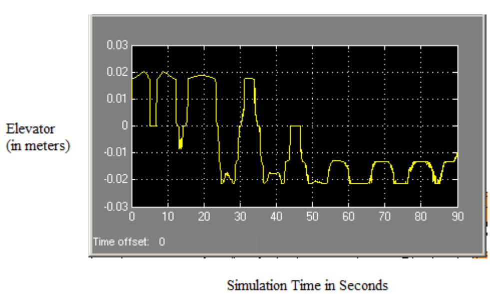

Fig. 8. Elevator of UAV

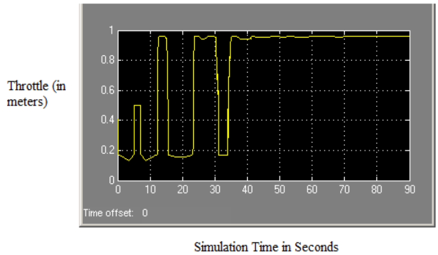

Fig. 9. Throttle of UAV

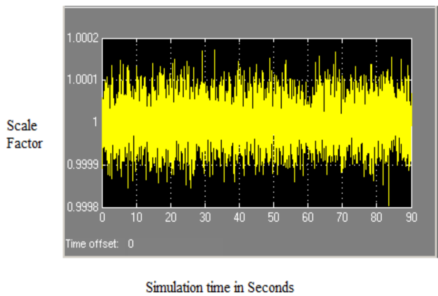

Fig. 10. Scaling of UAV

5 Conclusion and Future Enhancements

The purpose of this paper is to demonstrate the Fuzzy Logic Controller which is used for Waypoint Navigation and Control of Small Aerial Vehicles. Fuzzy Logic is the best and promising technique to control Aerial Vehicles when precise mathematical models are not available. Fuzzy logic controllers have the following advantages over the conventional Controllers. Experiments show comparable results with conventional systems like Kalman filter and particle filter. They are cheaper to develop, they cover a wider range of operating conditions, and they are more readily customizable in natural language terms. A self-organizing fuzzy controller can automatically refine an initial approximate set of fuzzy rules. Simulation Studies have shown adequate overall performance but sometimes controllers may be overloaded with many inputs and outputs which in turn increase the rules that are generated to control the attitude of UAVs and thus degrade the tuning of parameters of UAVs. To overcome the rule expansion a method called Combs method is employed to select minimum number of inputs and outputs. This in turn reduces the membership functions and thus the Controllers are not overloaded. The attitude of UAV may oscillate because the controller design is based on human pilot experience. In order to achieve better results the Controller can be designed on flight performance observations.

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