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# A Framework for Fuzzy Logic Based UAV Navigation and Control

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***Abstract*— A two module fuzzy logic controller that also includes a separate error calculating box is derived for autonomous navigation and control of small manned – unmanned aerial vehicles demonstrating ability to fly through specified waypoints in a 3-D environment repeatedly, perform trajectory tracking, and, duplicate / follow another vehicle's trajectory. A *MATLAB* standard configuration environment and the *Aerosim Aeronautical Simulation Block Set* are utilized for simulation studies, presented through a visualization interface; results illustrate controller performance and potential.**

***Keywords: UAV, autonomous navigation, fuzzy-logic control.***

## I. INTRODUCTION

The paper objective is to demonstrate fuzzy-logic based autonomous navigation and control of small manned – unmanned aerial vehicles as shown in Fig. 1. Given an aerial vehicle dynamic model, a two-module fuzzy logic controller is derived that allows any such vehicle: i) to fly through specified waypoints in a 3-D environment repeatedly, ii) to perform trajectory tracking, and, iii) to duplicate / follow another aerial vehicle's trajectory.

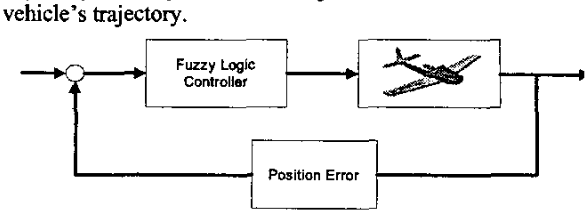


Figure 1. Overall system configuration

The implementation framework utilizes *MATLAB*'s standard configuration and the *Aerosim Aeronautical Simulation Block Set* that provides a complete set of tools for rapid development of detailed 6 degrees-of-freedom nonlinear generic manned / unmanned aerial vehicle models (which may be customized through parameter files), including, among others, the *Aerosonde UAV* and the *Navion* general-aviation airplane) [11].

The two-module fuzzy logic controller is composed of the *altitude* module, and the *latitude-longitude* module; an additional *error-calculating box* is also designed for fuzzy controller parameter tuning and flight adjustment purposes.

The proposed approach is modular and general; it is applicable to all types of aerial vehicles with minor control module adjustments, provided that the respective dynamic model is known or it may be derived. Further, the derived framework is also suitable for VTOL navigation and control. However, as a first step, only the class of small manned aerial vehicles is considered in this paper.

The rest of this section presents related research, while Section II discusses details of the proposed fuzzy logic controller. Section III presents the simulation environment and describes the modules developed in *MATLAB*, essential for simulation studies. Section IV includes results, while Section V concludes the paper.

### *A. Related Research*

There exist several approaches related to navigation and control of UAVs; representative research includes neural networks [1], non-linear adaptive control [2], fuzzy logic [3], [6], neuro-fuzzy control, fuzzy logic and evolutionary or genetic algorithms [4], [10], feed-forward plus PD feedback control [5] and controllers implementing feedback linearization and adaptive neural networks [9]. In addition, there exist intelligent control systems like the CIRCA-II [7] that utilizes real-time artificial intelligence and control theory to design an integrated UAV control system, and WITAS [8], a long-term basic research project its purpose being the development of technologies and functionalities leading to a fully autonomous UAV.

## II. FUZZY LOGIC CONTROL SYSTEM

The proposed fuzzy logic controller configuration is shown in Fig. 2. The aerial vehicle controller is of Mamdani-type, designed and tested on the North American Navion model; the same design may be applied to any UAV model.

The two fuzzy logic controller modules are responsible for altitude control and latitude-longitude control; when combined, they may adequately navigate the aerial vehicle. All input and output linguistic variables have a finite number of linguistic values with membership functions empirically defined after exhaustive simulation studies.

The altitude fuzzy logic controller has three inputs: a) altitude error, b) change of altitude error, and, c) airspeed. The altitude error is the difference between the desired altitude and the current altitude of the airplane. The change of altitude error indicates whether the aerial vehicle is approaching the desired altitude or if it is going away from it. The airspeed is the current speed of the vehicle. Outputs are the elevators command and the throttle command, responsible for the decent and accent of the aerial vehicle.

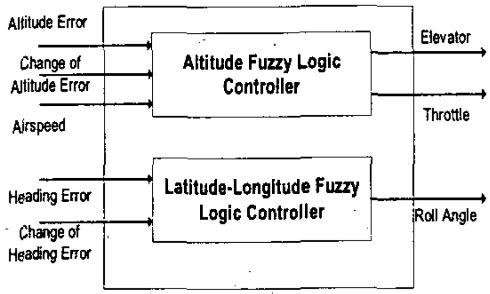


Figure 2. Fuzzy Logic Controller

Linguistic values representing the linguistic variable altitude error are: *{Altitude_Error_Negative (AEN), Altitude_Error_Stable (AES), Altitude_Error_Positive (AEP)}*. Linguistic values corresponding to the linguistic variable change of altitude error are: *{Negative_Change (NC), stable (S), positive_change (PC)}*. Linguistic values that represent the linguistic variable airspeed are: *{Small_Airspeed (SA), Medium_Airspeed (MA), Big_Airspeed (BA)}*. Their corresponding membership functions are shown in Fig. 3 to 5, respectively.

Linguistic values that describe the output linguistic variable elevator are: *{Negative_Elevator (NE), Stable_Elevator (SE), Positive_Elevator (PE)}* with membership functions shown in Fig. 6.

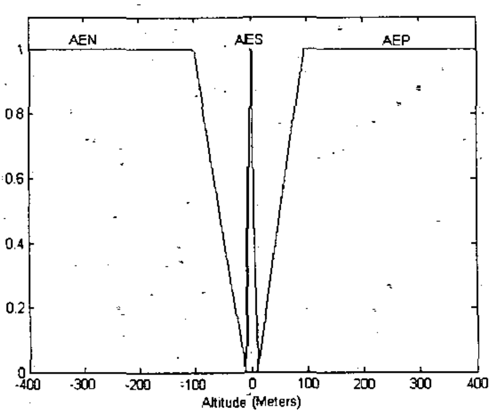


Figure 3. Alitude Error

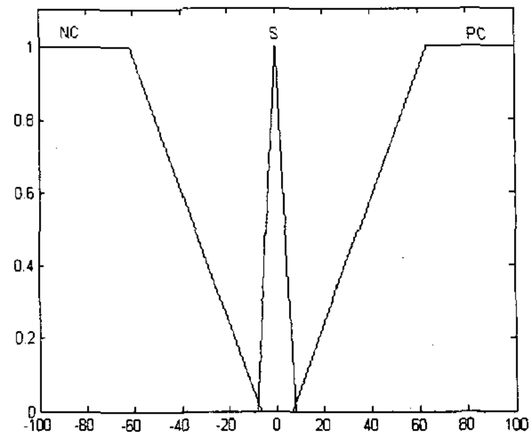


Figure 4. Change of Altitude Error

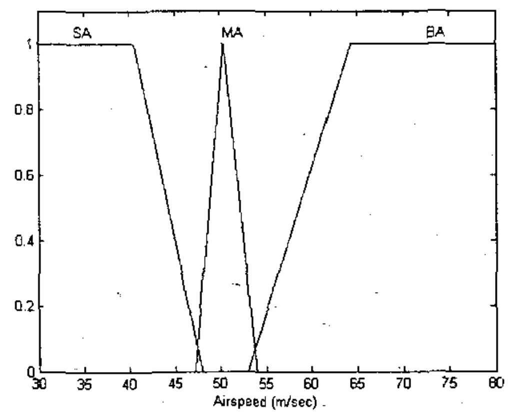


Figure 5. Airspeed

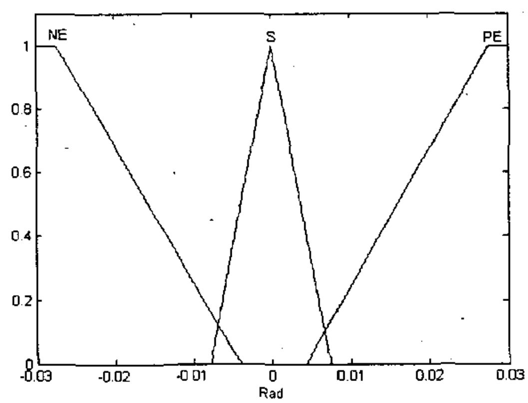


Figure 6. Elevator

Linguistic values representing the linguistic variable throttle command are: *{Low_Throttle (LT), Medium_Throttle (MT), High_Throttle (HT)}*, as shown in Fig. 7.

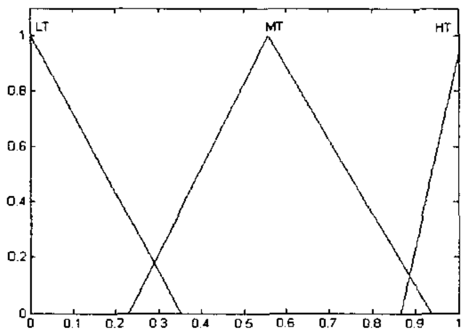


Figure 7. Throttle

The latitude-longitude controller has as inputs the heading error and the change of heading error. The heading error is the difference between the desired and the actual heading of the airplane. The output is the roll angle of the airplane.

The linguistic values that describe the input linguistic variable heading error are: *{Center_1(C1), Too_Right (TR), Right (R), Center (C), Left (L), Too_Left (TL), Center_2 (C2)}*. The heading error membership function is shown in Fig. 8.

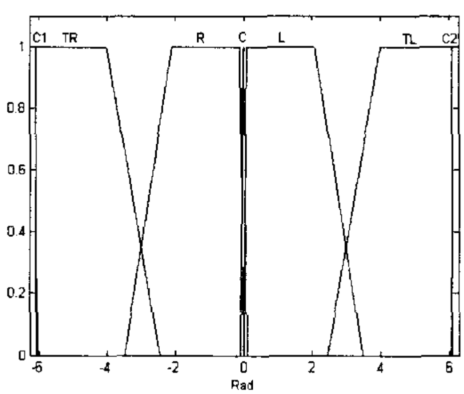


Figure 8. Heading

The change of heading error linguistic values are: *{Negative (N), Stable (S), Positive (P)}* as shown in Fig. 9.The output variable linguistics values are: *{Too_Left (TL), Left (L), Ahead (A), Right (R), Too_Right (TR* with membership function shown in Fig. 10.

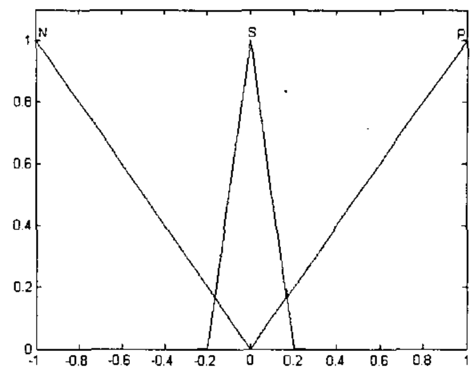


Figure 9. Change of Heading Error

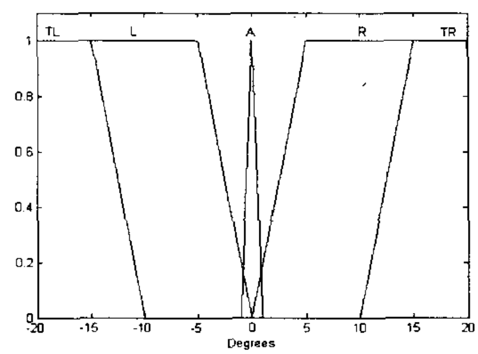


Figure 10. Roll Angle

## III. MATLAB IMPLEMENTATION ENVIRONMENT

A simulated environment in *MATLAB* has been implemented. The *Aerosim Block Set* has been extensively used.

The derived flight controller model is shown in Figure 11. It consists of six sub-systems represented as *Simulink* blocks, also shown in Fig. 11.

- *Aircraft model*: It is provided by the *Aerosim Block Set*; in this case, the American Navion is used.

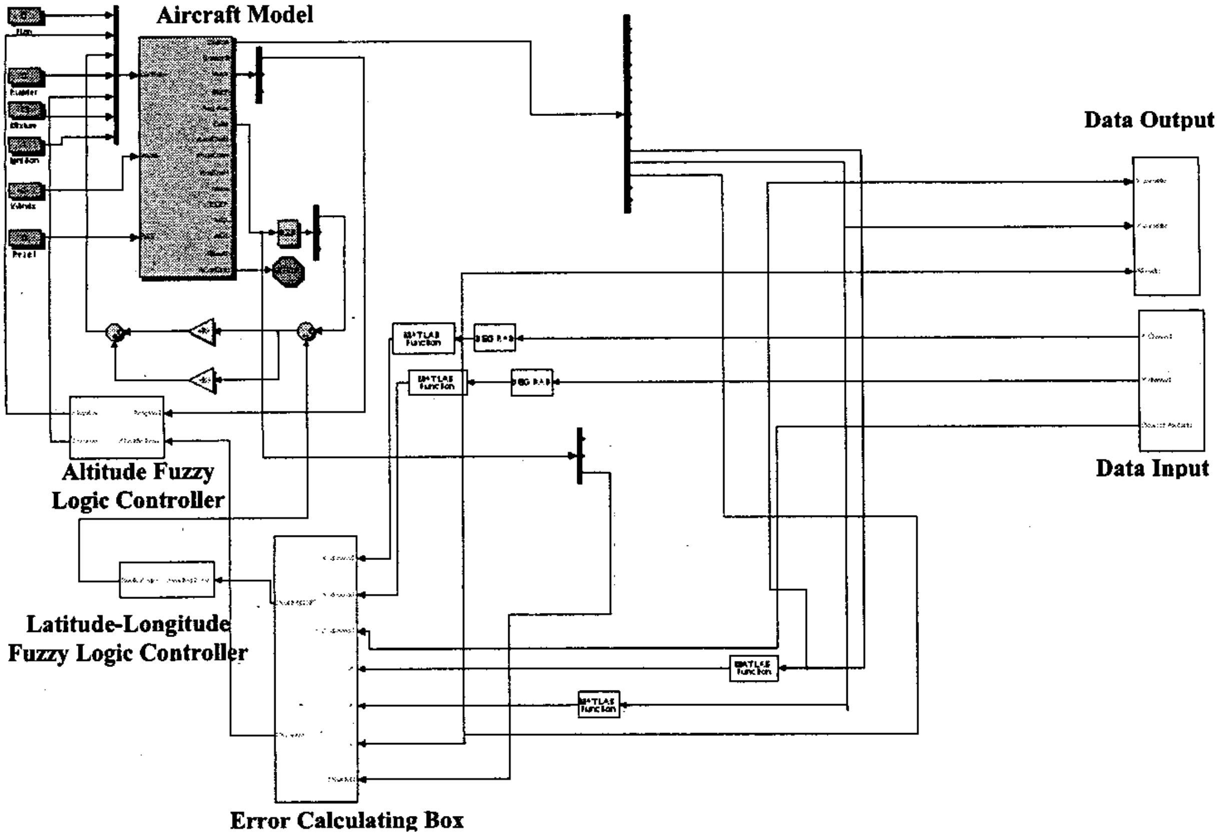


Figure 11. Simulink model

- *Altitude Fuzzy Logic Controller:* This is the derived altitude fuzzy logic controller module, described in the previous section.
- *Latitude-Longitude Fuzzy Logic Controller:* This is the derived in Section II latitude-longitude fuzzy logic controller.
- *Error Calculating Box:* This is the block in which the altitude error and the heading error are calculated.
- *Data input:* This is the block where joystick commands, pre-defined trajectories, data from another plane, or a target point in the 3-D space that needs be reached are inputs to the plane. Data inputs may be modified depending on the type of performed experiments.
- *Data output:* This is the block in which data from the airplane are recorded.

## IV. Experimental results

Considering the control model of Fig. 11, several scenarios have been performed: In the first one, the aerial vehicle starts in latitude 35.5, longitude 24.15. The target point is in latitude 35.3, longitude 24.6. The actual trajectory followed is presented in Fig. 12. The altitude corresponding to time is presented in Fig. 13.

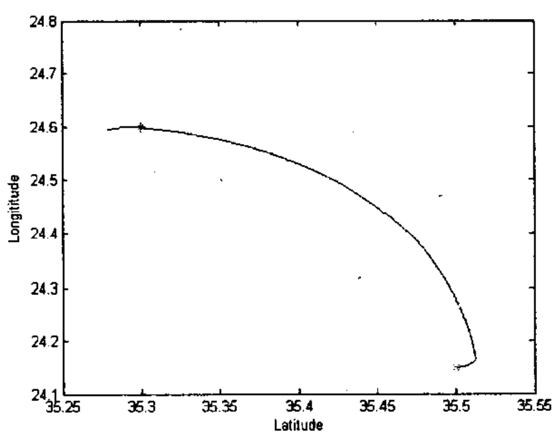


Figure 12. Plane passing through a target point

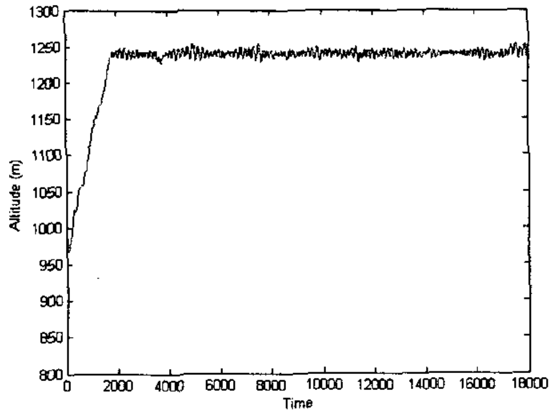


Figure 13. Change of altitude

Fig. 14 demonstrates the same scenario but the vehicle is commanded to pass through the same point (red dot) several times.

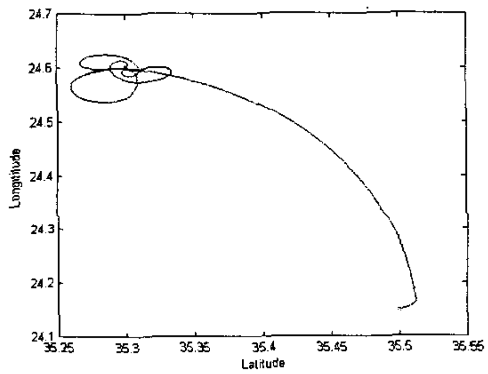


Figure 14. Plane passing through the same point several times

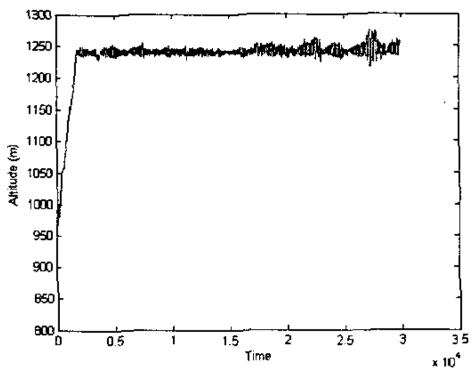


Figure 15. Change of altitide whhile passing from the same point

Another scenario considers 3 aerial vehicles flying in the same region. The corresponding trajectories and their initial coordinates are shown in Table I. The objective is that the "red" and "black" vehicle follow the "blue" one, as shown in Fig. 16.

TABLE I. INITIAL COORDINATES

| *Plane* | *Coordinates* | |
|---|---|---|
| | *Latitude* | *Longititude* |
| Blue | 35.1 | 24.15 |
| Red | 35.15 | 24.2 |
| Black | 35.07 | 24.15 |

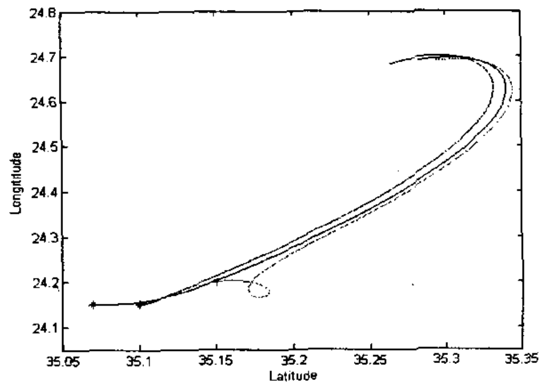


Figure 16. Scenario with 3 vehicles

The "red" vehicle starts ahead of the "blue" one, while the "black" starts behind it.

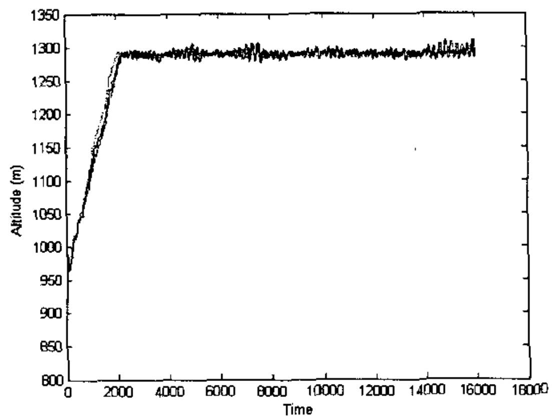


Figure 17. Change of altitude of the 3 vehicles

## V. Discussion and Conclusions

The purpose of the paper has been to demonstrate fuzzy logic based navigation and control of small aerial vehicles. Simulation studies have shown adequate overall performance of the controller. However, as shown through the results, there exist oscillations in the z-axis (altitude), once the aerial vehicle reaches the desired / commanded altitude. This is because the controller design is currently based on human pilot experience and not on flight performance observations. In order to achieve better results, tuning is essential. We are developing algorithms for membership functions tuning based on evolutionary genetic methods.

Another module under development is that of virtual radar. Currently, the system is capable of importing actual maps in *MATLAB* as shown in Fig. 18 and 19. The actual map of Fig. 18 is in the Greek grid system format. Its equivalent as presented in *MATLAB* is shown in Fig. 19. Therefore, given feedback from the environment, will allow the controller to perform not only navigation but also collision avoidance.

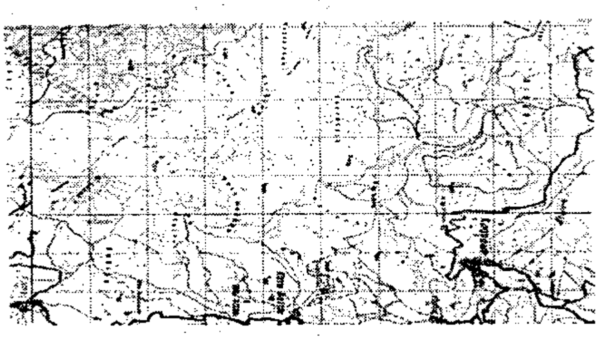

Figure 18. Actual map in Greek grid system

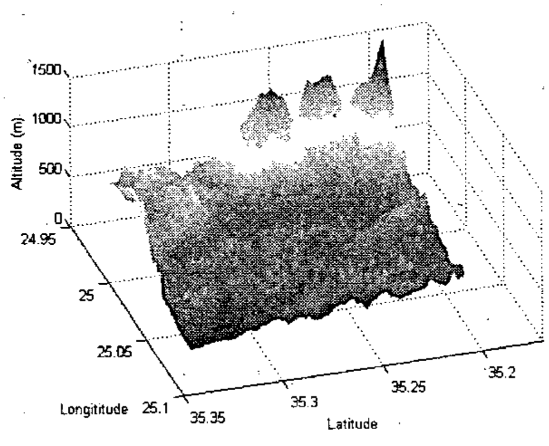


Figure 19. Actual map visualized in MATLAB

Further, we are also designing *MATLAB* based models for navigation of small unmanned VTOLs (like the *RAPTOR* and the *BERGEN*), following work reported in [12].

## VI. Acknowledgment

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