FUZZY IDENTIFICATION AND PARALLEL DISTRIBUTED COMPENSATION FOR CRUISE FLIGHT PHASE OF A BLIMP

IDENTIFICACION DIFUSA Y COMPENSACION PARALLELA DISTRIBUIDA PARA FASE DE VUELO CRUCERO DE UN DIRIGIBLE

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Abstract: The goal of this paper is to present some results of the study of fuzzy techniques for identification and control of non linear systems, applied on a blimp during the phase of cruise flight. This work intends to contribute to the UrAn project developed by the GIAP group of the University of Los Andes, whose objective is the autonomous flight of this aerial platform. To find a good representation of the system, we use Takagi-Sugeno (TS) fuzzy identification where the dynamics of the blimp are represented in groups of if-then rules, each rule having a linear model corresponding to a local dynamic. Using this fuzzy model structure, it was design a controller based on the Parallel Distributed Compensation (PDC) technique.

Resumen: El objetivo de este trabajo es presentar resultados del estudio de las técnicas difusas para la identificación y control de sistemas no lineales, aplicados en un dirigible durante la fase de vuelo crucero. Este trabajo se propone contribuir al proyecto UrAn desarrollado por el grupo GIAP de la Universidad de Los Andes, cuyo objetivo es el vuelo autónomo de esta plataforma aérea. Para encontrar una buena representación del sistema, se utiliza la identificación difusa Takagi-Sugeno (TS) donde la dinámica de los dirigibles están representados en los grupos de reglas si-entonces, cada regla tiene un modelo lineal que corresponde a una dinámica local. Usando este modelo de estructura difusa, se diseña un regulador basado en la técnica de compensación paralela distribuida.

Keyword: Blimp, fuzzy identification, Parallel distributed compensation, TS fuzzy model

1. INTRODUCTION

Blimps are aerial platforms with multiple applications in areas like: cartography, security and environmental protection. Some works had been developed to model and design controls for this type of platforms. Among them, we find the doctoral thesis [1], developed at LAAS (Laboratoire d’Analyse et d’Architecture de Systemes) in France.

In this thesis, the author proposes a model, product of a mechanical and aerodynamic analysis of blimp known as KARMA, and a control using backstepping technique. At the University of Los Andes, several undergraduate projects have been done based on KARMA results [2,3]. In 2002 the GIAP control group began the UrAn project which objective is to achieve the autonomous flight of this type of airship.

In this paper we present another approach to model and control a blimp, using fuzzy techniques. In the first part of this article we describe the identification method used to model the airship's dynamic. Then, we present the results of control design, using PDC technique, applied on a Simulink® model of KARMA.

2. IDENTIFICATION PROCESS

Because of the complexity of the system [1-6], different works represent the blimp's dynamic trough linear models. Following this approach, Takagi-Sugeno (TS) fuzzy identification represents a good alternative to handle nonlinear systems [7]. The idea of this type of identification is to model a system by if-then rules and linear models (consequents of rules) representing local dynamics.

The general form of TS fuzzy model is:

$$R_i\text{: } \textbf{if } x_1 \text{ is } A_{i1} \textbf{ and } x_2 \text{ is } A_{i2} \textbf{ and……and } x_p \text{ is } A_{ip}$$
$$\textbf{then } y_i = f_i(\mathbf{x}),\ i = 1,……,K.$$

Fuzzy models are constructed thanks to fuzzy clustering, which is basically a classification of objects according to similarities among them [7,8].

1.1. Phases of flight

Taking into account the complexity and non linear behavior of the system, a method to treat the problem was proposed by [1-3]. Under some specific conditions of operation, we can reduce the problem into less complex models, by identifying three phases of flight:

? Takeoff: The airship rises up reaching the desired altitude.
? Cruise: The airship reaches an aerodynamic speed and moves in a horizontal plane.
? Landing: The airship descends to a secure altitude where it starts to slow down.

1.2. Identification method for cruise flight

In a cruise flight, there are three input variables that we must control: thrust generated by motors (T), angle for rotations (d_g) and elevation angle (d_e). The vectored thruster remains constant at zero. To simplify identification of blimp during cruise flight, we decide to work with a decoupled model with three SISO (single input single output) systems, following the procedure in [1, 10]:

- Propulsion system (Input - torque, Output - airspeed)
- Horizontal flight: Motion in horizontal plane with constant airspeed (Input - angle for rotations, Output - yaw angle)
- Vertical flight: Motion in vertical plane with constant airspeed (Input – elevation angle, Output – altitude)

For each of these systems, a fuzzy model is obtained using the TS fuzzy identification. We use a simulink model of blimp's dynamic with KARMA's physical parameters (dimensions, weight) to acquire input-output data. The toolbox FMID (Fuzzy modeling and identification) developed by Robert Babuska [6], contains the Gustaffson-Kessel algorithm for fuzzy clustering and computes the parameters of TS fuzzy models.

Before running FMID toolbox, we must fix some parameters: number of clusters (c), fuzziness of clusters (m), sample time (Tm), number of delays in output (ny), number of delays in input (nu) and number of transport delays (nd). Fuzzy model is validated with a function in toolbox that computes the percentile variance accounted (VAF) between two signals. Figures 1, 2 and 3 show the membership functions of different fuzzy models.

In vertical and horizontal flights we decide to identify dynamics indirectly defining new output signals.

For vertical flight, a new output signal is calculated using the following variable:

$$\Delta Z(k) = Z(k) - Z(k-1) \tag{1}$$

For horizontal flight, a new output signal is calculated using the following variable:

$$\Delta y\ (k) = y\ (k) - y\ (k-1) \tag{2}$$

The input signal chosen to guarantee proper excitation of the system, in three cases, is a step wise signal with random amplitude and random width.

1.3. Propulsion system

Parameters of identification are:

c = 2, m = 2.5, ny = 2, nu = 1, nd = 1, Tm = 0.5s.
Validation result: VAF = 99.7290

TS fuzzy model is:

1. If $V_a(k-1)$ is A_{11} and $V_a(k-2)$ is A_{12} and $T(k-1)$ is A_{13} then
   $V_a(k)=1.01V_a(k-1)-0.06V_a(k-2)+0.02T(k-1)+0.07$
2. If $V_a(k-1)$ is A_{21} and $V_a(k-2)$ is A_{22} and $T(k-1)$ is A_{23} then
   $V_a(k)=0.91V_a(k-1)-0.01V_a(k-2)+0.02T(k-1)+0.05$

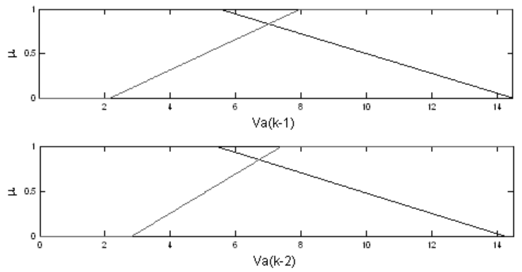

Fig. 1: Membership functions of fuzzy propulsion model

1.4. Vertical flight

Parameters of identification are:

c = 2, m = 2, ny = 1, nu = 1, nd = 1, Tm = 0.5s.
Validation result: VAF = 98.1780

TS fuzzy model is:

1. If $\Delta Z(k-1)$ is A_{11} and $d_e(k-1)$ is A_{12} then
   $\Delta Z(k)=9.61\cdot10^{-1}\Delta Z(k-1)+1.02\cdot10^{-3}d_e(k-1)+2.32\cdot10^{-2}$
2. If $\Delta Z(k-1)$ is A_{21} and $d_e(k-2)$ is A_{22} then
   $\Delta Z(k)=9.70\cdot10^{-1}\Delta Z(k-1)+6.18\cdot10^{-4}d_e(k-1)+1.14\cdot10^{-2}$

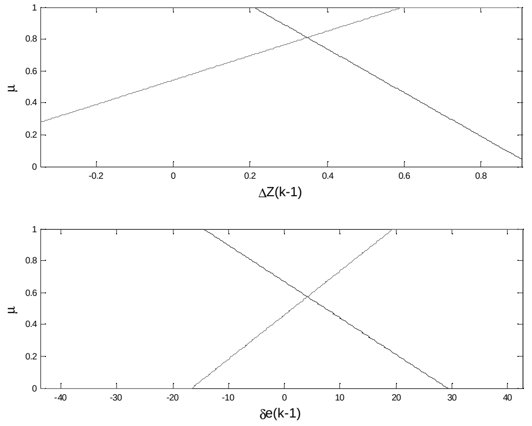

Fig. 2: Membership functions of fuzzy vertical flight model

General form of linear models is:

$$\Delta Z(k)=a\Delta Z(k-1)+bu(k-1)+c \tag{3}$$

Using expression $\Delta Z(k)=Z(k)-Z(k-1)$, we find a new difference equation with Z(k) for each rule.

$$Z(k)=(1+a)Z(k-1)-aZ(k-2)+bu(k-1)+c \tag{4}$$

1.5. Horizontal flight

Parameters of identification are:
c = 2, m = 2, ny = 2, nu = 1, nd = 1, Tm = 0.5s.
VAF = 97.32

TS fuzzy model is:

1. If $\Delta y\ (k-1)$ is A_{11} and $\Delta y\ (k-2)$ is A_{12} and $d_g(k-1)$ is A_{13} then
   $\Delta y\ (k)=1.57\Delta y\ (k-1)-0.59\Delta y\ (k-2)-0.02d_g(k-1)+0.08$
2. If $\Delta y\ (k-1)$ is A_{21} and $\Delta y\ (k-2)$ is A_{22} and $d_g(k-1)$ is A_{23} then
   $\Delta y\ (k)=1.65\Delta y\ (k-1)-0.67\Delta y\ (k-2)-0.01d_g(k-1)-0.03$

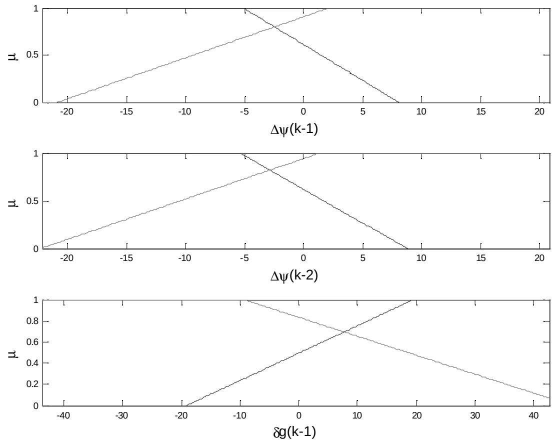

Fig. 3: Membership functions of fuzzy horizontal flight model

$$\Delta y\ (k)=a\Delta y\ (k-1)+b\Delta y\ (k-2)+cu(k-1)+d \tag{5}$$

Using expression $\Delta y\ (k)=y\ (k)-y\ (k-1)$, we find a new difference equation with $y\ (k)$ for each rule.

$$y(k)=(1+a)y(k-1)+(b-a)y(k-2)-by(k-3)+cu(k-1)+d \tag{6}$$

3. CONTROL DESIGN

From TS fuzzy identification, we get a fuzzy model. It describes the behavior of the system, through a group of if-then rules, whose consequents are linear models corresponding to local dynamics.

Based on this structure, Parallel Distributed Compensation technique [9] suggests designing a new TS fuzzy model with the same rules (fuzzy sets, variables of antecedents). Consequents of this new fuzzy model are regulators. For each linear model a regulator is designed.

After the identification process we have a group of fuzzy models representing blimp's dynamic during cruise flight.

The next step is to design a group of controllers able to provide stability and guarantee linear tracking. In each case we propose a PDC controller, using the rule base of corresponding fuzzy model and designing a controller for each linear model.

In this work we tried three approaches in compensator's design: pole placement, algebraic compensator and fuzzy optimal control design.

In pole placement and algebraic compensator we design controllers based on linear model without affine term. These approaches are valid if we consider affine terms small comparing to the output values. The last approach looks to minimize the following criterion:

$$J=\frac{1}{2}\sum_{k=0}^{\infty}\left(x_k^T Q x_k + u_k^T R u_k\right) \qquad (7)$$

Where x_k is a state vector and u_k is an input vector. Fuzzy optimal controller includes affine terms in design process [11].

After many essays, pole placement design provided us the best control behavior. Thus, rule's consequents, which are difference equations, must be transformed into state space representation. Since states are measurable delayed output variables, there is no need for an observer. Consequents of rules in new fuzzy models are implemented using a structure which includes state feedback and integrator.

We look for general stable behavior, designing controllers which allow slow closed-loop dynamic. For each controller, poles of the closed loop-system are placed near to the unit circle of stability region in the z-plane.

The blimp must reach a minimum constant airspeed to flight, then must maintain a constant altitude and finally it moves in a horizontal plane. Following these steps, we validated controllers in the simulation without wind using a Simulink® model of KARMA (see figures 4, 5, 6).

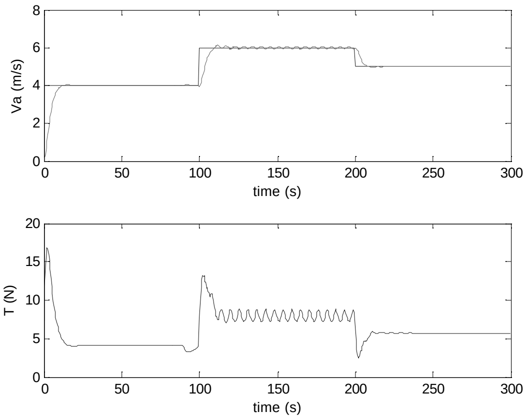

Fig. 4: Airspeed

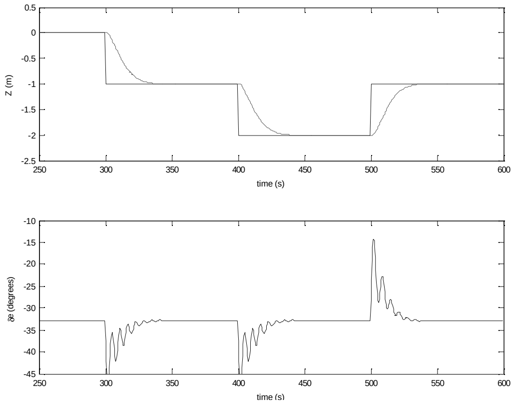

Fig. 5. Altitude

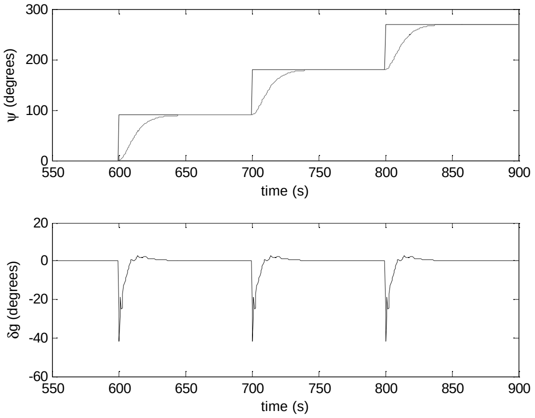

Fig. 6: Horizontal motion

Performance of controllers must assure conditions of cruise flight despite changes in system's dynamic because of disturbances caused by wind and additional mass.

A second simulation validated compensators with a constant wind blowing from the south at 2 m/s and an additional mass of 0.1kg (see figures 7, 8, 9).

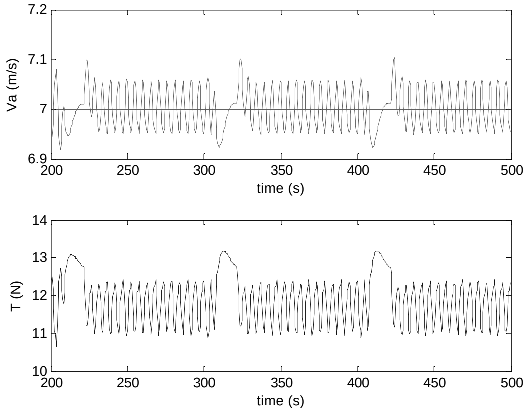

Fig. 7: Airspeed

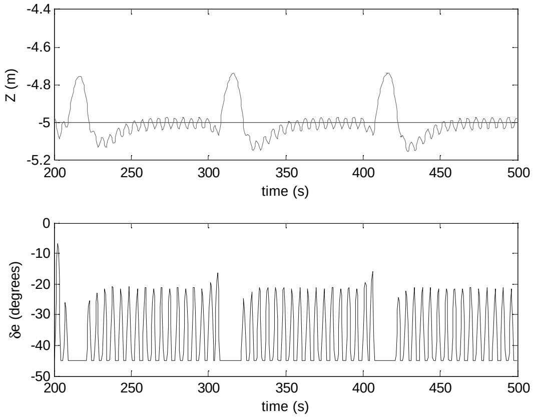

Fig. 8: Altitude

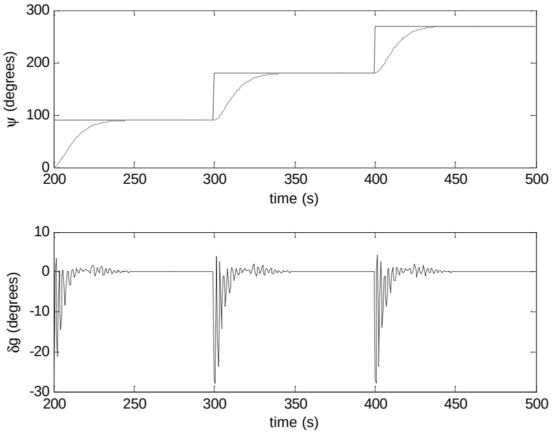

Fig. 9: Horizontal motion

6. CONCLUSIONS

Following the procedure proposed in [1], we simplify the identification problem looking for three less complex models which represent blimp's dynamic during cruise flight. From input-output data and using FMID toolbox we obtain three fuzzy models with excellent validation results. PDC technique allows us to use fuzzy model structure to create fuzzy controllers.

Thanks to pole placement design, we obtain consequents of rules for each fuzzy controller. Simulation with ideal conditions (no wind, no additional mass), shows us a good performance of control. A second simulation tests the behaviour of the controllers under disturbances (wind and additional mass). Control signals are stronger than those in ideal conditions, but controllers are still able to provide stability and eliminate steady-state error. Therefore, these fuzzy controllers are robust. TS fuzzy identification and division of blimp's dynamic during cruise flight in three subsystems, demonstrate to be a good method of modelling the airship. From these models and using PDC theory, a strategy of control has been developed and tested in simulation with good results.

The next step in this project is to model and control a real aerial platform (UrAn) using these fuzzy techniques and data from test flights.

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