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A generalized type-2 fuzzy granular approach with applications to aerospace

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ABSTRACT

In this paper a granular approach for intelligent control using generalized type-2 fuzzy logic is presented. Granularity is used to divide the design of the global controller into several individual simpler controllers. The theory of alpha planes is used to implement the generalized type-2 fuzzy systems. The proposed method for control is applied to a non-linear control problem to test the advantages of the proposed approach. Also an optimization method is used to efficiently design the generalized type-2 fuzzy system to improve the control performance.

1. Introduction

This paper deals with fuzzy logic, granular computing and control concepts to propose a new method for controlling complex non-linear plants. The first part in this paper explains the proposed method. This method is based on granular computing to provide a framework for dividing a complex control problem into simpler problems. Then the particular non-linear control problem is explained, which in this case is the total flight control of an airplane and this is considered to test the architecture and the proposed method. Once the proposed method and the control problem are explained, then fuzzy logic is applied to achieve the control of the plant. In this paper generalized type-2 fuzzy logic [1,4,5] is applied to control the flight of the airplane, which has not been considered in previous methods that have been applied to this problem. Also a genetic algorithm [7,10,13] is used to optimize the parameters in the generalized type-2 fuzzy system [12,16,21] to achieve the best possible control performance.

In this paper the main contribution is an approach consisting in dividing a complex control problem into many individual sub-problems of control. The main idea is that individual control problems can be solved utilizing reduced and simpler controllers. The proposed approach is relevant for solving complex control problems requiring more than one individual controller. When a control problem requires 2 or more controllers the objective of control is that these controllers can work together and not individually. For example in this case of flight control, three controllers are necessary to achieve total global flight control of an airplane. For this reason an approach is presented, where individual controllers work together with the aggregator to achieve global flight control, and the main contribution is the proposed method that allow us to

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work by joining the individual controllers as a global single control using fuzzy systems. In addition a generalized type 2 fuzzy aggregator is applied to the proposed method to combine and improve the results of the individual controllers. Also, using generalized type-2 fuzzy logic allows achieving a better solution in complex problems with higher levels of noise. It is important to mention that one of the main advantages of using generalized type-2 fuzzy logic is because it can support noise in higher levels and in complex control problems (with a high noise level) generalized type-2 can better solve these control problems. The architecture of the proposed method has two levels in the topology, first the individual controllers that are used to make a local control of the individual subsystems and then an aggregator mechanism is applied to combine and improve the outputs of the individual controllers.

In the control area some authors have proposed techniques to achieve control that can be considered to have some similarity with the approach presented here, such as: in the work of Sanchez et al. [28], different flight controllers for an X-Cell mini-helicopter are proposed. They divided their total control in 2 parts. The first scheme consists of a conventional PID controller for the z-position and roll, pitch and yaw angles. In the second scheme, two of the previous PID controllers are used for roll and pitch, and a linear regulator is added to control the altitude and the yaw angle. In the work of Rachman et al. [25], a non-linear simulation for automatic flight control system to the complete control design process is used. They used a linear approach in the design and simulation of the controller (control laws) and then simulated the controller on the non-linear real aircraft model [3,6,8,9,11]. In the work of Martinez-Soto et al. [17], a type-2 fuzzy system is applied as a controller for the dynamic model of a unicycle mobile robot by integrating a kinematic and a torque controller based on type-2 fuzzy logic theory and genetic algorithms, but they use individual controllers for the wheels of the robot. However, these works and other ones with similarity to the previous ones, do not use generalized type-2 fuzzy logic integrators for the outputs of the individual controllers, as it is proposed in this paper. In the previous review all of these mentioned works each controller is considered separately, but in the proposed method we use the individual controllers and also design an aggregator to join the results of the individual controllers as one system to contribute to the total control, which contributes to the realization of generalized systems for an improved flight control technique. The advantage for example in this case study is that when an airplane needs to move in a different direction is necessary to use the 3 controllers at the same time, not only one individually and is for this reason that the aggregator joins the individual controllers as one and this enables to use these controllers in any movement of the airplane.

The rest of the paper is organized as follows: In Section 2 we present some basic concepts needed to understand this work, in Section 3 we define the proposed method and the problem description, Section 4 presents the optimization process and simulation results and finally the conclusions are presented in Section 5.

2. Basic concepts

This section presents some basic concepts needed to understand the contents of this paper.

2.1. Generalized type-2 fuzzy logic

First, in a type-2 fuzzy system the uniform shading for the FOU represents the entire interval type-2 fuzzy set and it can be described in terms of an upper membership function $\bar{\mu}_{\tilde{A}}\ (x)$ and a lower membership function $\underline{\mu}_{\tilde{A}}(x)$. A fuzzy logic system (FLS) described using at least one type-2 fuzzy set is called a type-2 FLS. Type-1 FLSs are unable to directly handle rule uncertainties, because they use type-1 fuzzy sets that are certain (viz, fully described by single numeric values) [27,28]. On the other hand, type-2 FLSs, are useful in circumstances where it is difficult to determine an exact numeric membership function, and there are measurement uncertainties [25,26]. A type-2 FLS is characterized by IF–THEN rules, where their antecedent or consequent sets are now of type-2. Type-2 FLSs, can be used when the circumstances are too uncertain to determine exact membership grades, such as when the training data is affected by noise [16,18]. A type-2 fuzzy set $\widetilde{A}$ (T2 FS) is characterized by a membership function of the form:

$$\tilde{A} = \left\{\left((x,u),\mu_{\tilde{A}}(x,u)\right)\middle|\forall_x \in x,\ \forall_u \ \in j_x \ \subseteq [0,1]\right|\right\} \tag{1}$$

in which $0 \le \mu_{\tilde{A}}(x,u) \le 1$. In fact $j_x \ \subseteq [0,1]$ represents the primary membership of x, and $\mu_{\tilde{A}}(x,u)$ is a type-1 fuzzy set (T1 FS) known as the secondary set. Hence, a type-2 membership grade can be any subset in [0, 1], the primary membership, and corresponding to each primary membership, there is a secondary membership (which can also be in [0,1]) that defines the possibilities for the primary membership. Uncertainty is represented by a region, which is called the footprint of uncertainty (FOU). When $\mu_{\tilde{A}}(x,u) = 1$, $\forall_u \ \in j_x \ \subseteq [0,1]$ we have an interval type-2 membership function. The uniform shading for the FOU represents the entire interval type-2 fuzzy set and it can be described in terms of and upper membership function $\bar{\mu}_{\tilde{A}}(x)$ and a lower membership function $\underline{\mu}_{\tilde{A}}(x)$ [5,14].

2.2. α-planes theory

A horizontal slice is analogous to the α-cut of a T1 FS, and it is called an α-plane representation for a T2 FS. An α-plane in the case of a generalized T2 FS $\widetilde{A}$, is represented by $\tilde{A}_\alpha$, and is the union of all primary membership functions of $\tilde{A}$, where the secondary membership degrees are higher or equal than α $(0 \le \alpha \le 1)$ [15,22,25–27]. The alpha planes are represented