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Type-2 fuzzy logic aggregation of multiple fuzzy controllers for airplane flight control

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ABSTRACT

This paper presents a proposed new approach for complex control combining several simpler individual fuzzy controllers. This method is particularly useful when the case of study is a multivariable control system. The proposed method has a hierarchical architecture with 2 levels (individual fuzzy systems and a superior control to adjust the global result). The behavior of the proposed method is illustrated with a problem of flight control that requires several individual controllers. In addition a statistical comparison is performed using the t student test, where the proposed control strategy is compared against a simple fuzzy control approach. Finally, an optimization method is also applied to achieve an optimal design of the fuzzy systems.

1. Introduction

At the moment, many complex control problems exist where traditional approaches are applied, but these methods usually provide limited results [15]. In most cases when control problems are treated with soft computing, techniques such as neural networks, ANFIS, fuzzy logic and so on [37] are applied. In this paper the main contribution is a proposed approach consisting in dividing a complex control problem [42] into many individual simple sub-problems of control [30]. The main idea is that individual control problems are solved utilizing reduced and simpler controllers [13]. The proposed approach is relevant to solving complex control problems requiring more than one individual controller [27]. In addition a type-2 fuzzy aggregator is applied in the proposed method to combine and improve the results of the individual controllers. Also, the use of type-2 fuzzy logic [5] allows achieving a better solution in complex problems with noise. The architecture of the proposed method has two levels in the topology, first the individual controllers [8] 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 [4].

In the control area [1] some authors have used techniques to achieve the control [6] that can be considered to have some similarity with the proposed approach, such as the following: In the work of Sanchez, Becerra and Velez [35], different flight controllers for an X-Cell mini-helicopter are proposed. They divided their work in 2 parts. The first scheme consists of a conventional SISO 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, Jaam and Hasnah [33], a non-linear simulation for automatic flight control system for the complete control design process is used. In addition, they used the linear approach in the design and simulation of the controller (control laws) and they simulated the controller on the non-linear real aircraft model [9]. As mentioned above, there are also several works on aviation

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[28] for their importance regarding the control, flight control range from small, trajectories, using methods such as fuzzy logic [14] and neural networks [24].

The rest of the paper is structured as follows. In Section 2, we present some essential concepts of flight control. In Section 3 the proposed method is explained and a description of the problem is presented in Section 4. Simulation results and statistical tests are presented in Section 5. Finally, Section 6 presents conclusions.

2. Basic concepts

In this section some concepts are presented to understand this paper.

2.1. Fuzzy sets

The difference between crisp (i.e., classical) and fuzzy sets is established by introducing a membership function [42]. Consider a finite set X = {x1, x2, … , xn} which can be considered the universal set in what follows [17]. The subset A of X consisting of the single element x1 can be described by the n-dimensional membership vector Z(A) = (1, 0, 0, … , 0), where the convention has been adopted that a 1 at the *i*-th position indicates that xi belongs to A [18]. The set B composed of the x1 and xn elements is described by the vector Z(B) = (1, 0, 0, … , 1). Any other crisp subset of X can be represented in the same way by an n-dimensional binary vector [45]. But what happens if we eliminate the restriction of binary vectors? In that case we can define the fuzzy set C with the following vector description: $Z(C) = (0.5, 0, 0, \dots, 0)$ [34].

The basic structure of a type-1 fuzzy inference system consists of three conceptual components: a “rule base”, which contains a selection of fuzzy rules; a “data base” (or “dictionary”), which defines the membership functions used in the fuzzy rules; and a “reasoning mechanism”, which performs the inference procedure upon the rules and given facts to derive a reasonable output or conclusion [46]. Type-1 fuzzy logic was first introduced by Zadeh [47,48]. Fuzzy logic systems are based on the concept of a type-1 fuzzy set (T1FS) and have demonstrated their ability in many applications, especially for the control of complex nonlinear systems that are difficult to model analytically [10]. Type-1 fuzzy sets handle uncertainties by using precise membership functions that the user believes capture the uncertainties. Type-1 fuzzy sets are characterized by two-dimensional membership functions in which each element of the type-1 fuzzy set has a membership grade that is a crisp number in [0,1] [11]. Basically, a type-2 fuzzy set is a set in which we also have uncertainty about the membership function. Since we are dealing with uncertainty for the conventional fuzzy sets (which are called type-1 fuzzy sets here) we can achieve a higher degree of approximation in modeling real world problems. Of course, type-2 fuzzy systems consist of fuzzy if-then rules, which contain type-2 fuzzy sets. We can say that type-2 fuzzy logic is a generalization of conventional fuzzy logic (type-1) in the sense that uncertainty is not only limited to the linguistic variables but also is present in the definition of the membership functions [7]. Type-2 fuzzy sets are characterized by fuzzy membership functions that are three dimensional. The membership grade for each element of a type-2 fuzzy set is a fuzzy set in [0, 1]. The additional third dimension provides additional degrees of freedom to capture more information about the represented terms [23]. Type-2 fuzzy sets are useful in circumstances where it is difficult to determine the exact membership function for a fuzzy set, which is useful for incorporating the existing uncertainty [2].

2.2. Aircraft control

The most basic flight control system designs are mechanical and date back to the early aircrafts. They operate with a collection of mechanical parts such as rods, cables, pulleys, and sometimes chains to transmit the forces of the flight deck controls to the control surfaces [36]. The aerodynamic forces acting upon the control surfaces increased exponentially. To make the control force required by pilots manageable, aircraft engineers designed more complex systems [41]. At first, hydro mechanical designs, consisting of a mechanical circuit and a hydraulic circuit, were used to reduce the complexity, weight, and limitations of mechanical flight controls systems. As aircrafts became more sophisticated, the control surfaces were actuated by electric motors, digital computers, or fiber optic cables. Called “fly-by-wire,” this flight control system replaces the physical connection between pilot controls and the flight control surfaces with an electrical interface [43]. In addition, in some large and fast aircrafts, controls are boosted by hydraulically or electrically actuated systems. In the fly-by-wire and boosted controls, the feel of the control reaction is fed back to the pilot by simulated means [47]. The main goal in this work is to develop a proposed method using the flight control system based on fuzzy logic. When applied directly to the flight control system feedback errors, this method would provide adjustments to improve aircraft performance in normal flight as well as with system failures. With this method, a pilot is able to maintain control and safely land an aircraft that has suffered a failure to a control surface or damage to the airframe. It also improves mission capability, increases the reliability and safety of flight, and eases the pilot workload. The ailerons, elevator, and rudder constitute the primary control system and are required to control an aircraft safely during flight [19]. An aircraft typically has three aerodynamic controls, each capable of producing moments about one of the three basic axes (roll, pitch and yaw). To control the motion in these axes it is necessary to use the elevator, aileron and rudder. To control the pitch the elevator is applied, to control the roll the ailerons are required and to control de yaw the rudder is applied [22]. The elevators are attached to the horizontal stabilizer and it controls the climb or descent (pitch) of the aircraft and this action is named lateral control. Elevator deflection is characterized by the deflection angle δe. The variables ∂L, ∂M, ∂N represent the components of aerodynamic deflection moments about the x, y, and z axes, respectively. Elevator deflection is defined as positive