Trajectory tracking in aircraft landing operations management using the adaptive neural fuzzy inference system

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ABSTRACT

The adaptive neural fuzzy inference system is used to simulate trajectory tracking in aircraft landing operations management. The advantage of the approach is that by using the linguistic representation ability of fuzzy sets and the learning ability of neural networks, the approximate linguistic representations can be improved or updated as more data become available. This approach is illustrated by the use of both zero and first order Takagi–Sugeno inference systems [T. Takagi, M. Sugeno, Fuzzy identification of systems and its application to modeling and control, IEEE Transactions on Systems, Man, and Cybernetics 15 (1) (1985) 116–132] with auto-landing flight path data.

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1. Introduction

A major challenge in modern aircraft design is the controllability of the flight vehicle. When an airplane is in the air, not all atmospheric factors acting on it can be controlled by human efforts. The trajectory tracking of a landing plane is a useful approach but is an unpredictable and sophisticated process. It is difficult to devise an approach that allows modern control theory to deal with this nonlinear control problem in a systematic way.


In this paper, the adaptive neural fuzzy inference system (ANFIS) is proposed for trajectory tracking in the nonlinear control of aircraft landing. Specifically, only longitudinal stability and control analysis are considered; and the open-loop pitch angle or the pitch angle of the elevator (PAE) is considered as the output of the system.

The fuzzy neural inference system will be summarized in Section 2 and the application of this ANFIS system to trajectory tracking with some numerical results will be presented in Section 3. The numerical auto-landing flight path data used are obtained from Shen et al. [13,14]. Finally, Section 4 presents some discussion.

2. Fuzzy inference system

To illustrate the fuzzy adaptive network, let us consider the following simple four fuzzy IF-THEN rules:

R1: If (x1 is small AND x2 is low), then (Y1 = Y1 = p01 + p11x1 + p21x2)
R2: If (x1 is small AND x2 is high), then (Y2 = Y2 = p02 + p11x1 + p22x2)
R3: If (x1 is large AND x2 is low), then (Y3 = Y3 = p03 + p12x1 + p22x2)
R4: If (x1 is large AND x2 is high), then (Y4 = Y4 = p04 + p11x1 + p22x2)

where x1 and x2 are input linguistic variables, and “small” and “large” are fuzzy sets. The above rules are known as the first order Takagi–Sugeno fuzzy inference system [1]. For a zero order Takagi–Sugeno inference system, the x’s after “then” are set equal to zero.

The fuzzy adaptive network, or the adaptive neural fuzzy inference system (ANFIS) [15–17] for these fuzzy rules is illustrated in Fig. 1, which is essentially a neural network except for the fact that some of the nodes are adaptive nodes where fuzzy membership functions are stored. To distinguish these adaptive nodes, rectangles are used to represent them. For example, the nodes in layers 1 and 4 are adaptive nodes, while the nodes in layers 2 and 3 are fixed nodes.

In this paper, the above Takagi–Sugeno fuzzy system, similar to that represented in Fig. 1, is used to simulate trajectory tracking of aircraft landing operations. Let node n in layer m be denoted by o_{m,n}; the node functions on each layer are summarized as follows [15]:

Layer 1: The input of this node is denoted by x_i and a_{i,h} is the hth fuzzy set, which is a linguistic term. The output of node n is defined by

\[ o_{1,n} = \mu_{a_{i,h}}(x_i), \quad \text{for } h_i = 1, 2, \ldots, p_i, \quad \text{and } i = 1, 2, \ldots, q \]  

(1)

where \( \mu_{a_{i,h}} \) is a membership function of \( a_{i,h} \), and \( p_i \) is the number of fuzzy sets associated with \( x_i \). The membership function is defined as the Gaussian function with the parameter set \{v_i, \sigma_{i,h}\} and is given as:

\[ \mu_{a_{i,h}}(x_i) = e^{-\left(\frac{1}{\sigma_{i,h}^2}(x_i - v_{i,h})^2\right)} \]  

(2)

Layer 2: The nodes in this layer are fixed. The output of these nodes is given by

\[ o_{2,h} = w' = \sum_{i=1}^{q} \mu_{a_{i,h}}(x_i), \quad \text{for all } h_i \]  

(3)

where \( h_i \) is the hth fuzzy set associated with \( x_i \), and \( h_i = 1, 2, \ldots, n_i \).

Layer 3: Each fixed node in this layer normalizes the output in layer 2, given by

\[ o_{3,h} = \bar{w}' = \frac{w'}{\sum_{r=1}^{m} w'} \]  

(4)
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