Chinese Journal of Aeronautics, (2017), **xxx**(xx): xxx–xxx

Chinese Society of Aeronautics and Astronautics
& Beihang University

Chinese Journal of Aeronautics

cja@buaa.edu.cn
www.sciencedirect.com

Automatic landing system using neural networks and radio-technical subsystems

Romulus Lungu, Mihai Lungu *

University of Craiova, Faculty of Electrical Engineering, 107 Decebal Blvd., Craiova, Romania

Received 16 February 2016; revised 29 April 2016; accepted 27 May 2016

KEYWORDS

Adaptive control;
Automatic landing;
Neural network;
PID;
Reference model

Abstract The paper focuses on the design of a new automatic landing system (ALS) in longitudinal plane; the new ALS controls the aircraft trajectory and longitudinal velocity. Aircraft control is achieved by means of a proportional-integral (PI) controller and the instrumental landing system – the first phase of landing (the glide slope) and a proportional-integral-derivative (PID) controller together with a radio-altimeter – the second phase of landing (the flare); both controllers modify the reference model associated with aircraft pitch angle. The control of the pitch angle and longitudinal velocity is performed by a neural network adaptive control system, based on the dynamic inversion concept, having the following as components: a linear dynamic compensator, a linear observer, reference models, and a Pseudo control hedging (PCH) block. The theoretical results are software implemented and validated by complex numerical simulations; compared with other ALSs having the same radio-technical subsystems but with conventional or fuzzy controllers for the control of aircraft pitch angle and longitudinal velocity, the architecture designed in this paper is characterized by much smaller overshoots and stationary errors.

1. Introduction

Most aircraft have automatic landing systems (ALSs) based on the instrumental landing system[1,2] and different conventional controllers (proportional-derivative – PD, proportional-integral – PI, proportional-integral-derivative – PID),[1–4] for aircraft trajectory's control during landing, and the use of optimal control laws ($H_2, H_\infty, H_2/H_\infty$), together with full- or reduced-order observers, provides good results.[3,5] Because the atmospheric conditions and the dynamics of aircraft are drastically changing during flight and, of course, during landing, it is difficult to land safely by using conventional controllers. To design perfect conventional controllers, one has to know the precise mathematical model of the system to be controlled. Furthermore, the aircraft dynamics may vary with respect to the altitude and the flight conditions. Therefore, the adaptive controllers are better choices.

The presence of unknown or partially known nonlinearities in aircraft dynamics leads to the necessity of using evolved adaptive control architectures in various stages of the flight

* Corresponding author.
E-mail address: Lma1312@yahoo.com (M. Lungu).

Peer review under responsibility of Editorial Committee of CJA.

ELSEVIER **Production and hosting by Elsevier**

http://dx.doi.org/10.1016/j.cja.2016.12.019
1000-9361 © 2017 Production and hosting by Elsevier Ltd. on behalf of Chinese Society of Aeronautics and Astronautics.

and especially during landing. Also, the actuators have strongly nonlinear behavior because of the saturation of their displacements and/or mobile elements' velocities. In these cases, in the context of using the inversion of the nonlinearities' dynamics, the adaptive control based on dynamic inversion and neural networks theories is a very good choice.[6–9] The adapting and the train of the neural networks (NNs) are based on the signals provided by the observers which receive information relative to the error of the automatic control system. The adaptive component of the automatic control law (provided by the NNs) must compensate the inversion (approximation) error of the aircraft dynamics' nonlinear subsystem. For a safety landing, the required information in longitudinal plane is obtained by means of gyro transducers (for aircraft pitch angle – θ and pitch rate – $q = \dot{\theta}$), accelerometers (providing the acceleration signal and, by integration, the aircraft longitudinal velocity), or aerodynamic transducers (for aircraft attack angle[10]) whether or not the landing control architecture includes an observer.

One of the most commonly employed nonlinear control method is the feedback linearization; in the automatic landing systems' design it is used in some papers,[11] but the paper presents limited insight into the performance of simulations of this controller and no tests are performed outside of these simulations; the main disadvantage of the feedback linearization method is that all parametric plant uncertainties must appear in the same equation of the state-space representation as the control.

Feed-forward neural networks based on the back propagation learning algorithm have also been used[12]; the main disadvantage is that the neural networks require a priori training on normal and faulty operating data. Other approaches involves the usage of the time delay neural networks; a controller based on this type of neural networks has been designed,[13] but its main drawback is related to the flight path track accuracy and the fact that it is enable only under limited conditions. Several neural network control approaches have been proposed based on Lyapunov stability theory.[13,14] The main advantage of these control schemes is that the adaptive laws were obtained from the Lyapunov synthesis and, therefore, guarantee the system's stability; the disadvantage is that some conditions should be assumed; these requirements are not easy to be satisfied in practical control application.[15] Juang designed a new learning technique using a time delay network or networks with back-propagation through time algorithms to control the landing[16]; the main drawbacks are: (1) the number of hidden units was determined by trial; (2) the convergence time is high. Seven different neural network structures (including critic or Radial Basis Function Neural Networks) have been used for obtaining intelligent auto-landing controllers by means of linearized inverse dynamic model[17,18]; also, the fuzzy logic technique was used to design controllers that track a pre-determined flight path trajectory for safe landing.[19] In the research area of optimal synthesis, Ref. 20 have developed a mixed technique for the H_2/H_∞ control of landing, while Ref. 21 have used the H_∞ control technique to design an approach for aircraft automatic and landing. In these papers, the authors did not analyze the robustness of the designed controllers in the presence of sensor errors and external disturbances.[22]

The auto-landing systems designed in the above mentioned works are characterized by insufficient generality or accuracy; the neural network and dynamic inversion based control approaches could bring improvements. Thus, the paper presents a new adaptive landing architecture for aircraft control in longitudinal plane. According to the authors of this paper, little progress has been reported for the landing flight control systems in longitudinal plane by using neural networks, dynamic inversion concept, linear dynamic compensator, state observer, and PCH block; this motivates the present study. Also, it is interesting to see if the aircraft's trajectory during landing in longitudinal plane can be tracked with high accuracy by a neural network based controller which uses both the dynamic inversion technique and PCH blocks. The main advantages of the dynamic inversion are: (1) the plant nonlinearities are canceled; (2) the closed loop plant behaves like stable linear system; (3) simplicity in the control structure, ease of implementation, global exponential stability of the tracking error, etc.[11] On the other hand, the strong point of the neural networks is their approximation ability, these being capable to approximate an unknown system dynamics through learning. A PCH block eliminates the NNs' adapting difficulties. Having in mind the advantages of the NNs, dynamic inversion approach, PCH blocks and the combining of these elements with linear dynamic compensators and state observers, the present paper brings absolute novelty in the search area of ALSs' design.

The paper is organized as follows: the structure of the ALS is given in the second section; the design of the adaptive system for the control of the pitch angle and the longitudinal component of the flight velocity is presented in the third section; in the next section, complex simulations to validate the new designed ALS have been performed and the obtained results are analyzed; finally, some conclusions are shared in the fifth section of the paper.

2. Structure of the new automatic landing system

The automatic control of aircraft during landing (longitudinal plane) is achieved by means of two systems: an automatic system for the trajectory's control and an automatic system for the control of flight velocity. The automatic system for the control of the flight trajectory in longitudinal plane has two subsystems: (1) the first one is for the aircraft control during the *glide slope* phase (control of the angular deviation $\Gamma = \gamma - \gamma_c$; γ and γ_c are the real and the calculated slope angles of the aircraft trajectory, respectively), by using an ILS system for the determination of the angle Γ at altitudes $H \geqslant H_0$; (2) the second one is for the aircraft control during the *flare* phase by means of a radio-altimeter (control of the altitude $H, H < H_0, H_0$ – the altitude at which the glide slope phase ends and the second landing phase begins). There are many papers in the literature which threat the control of aircraft in lateral-directional plane in the presence of crosswind. These systems cancel the angular deviation of aircraft with respect to the runway direction, the deviation of the flight direction relative to the runway, and aircraft lateral velocity. Concluding, the control of aircraft in the lateral-directional plane (one landing phase: initial approach) can be achieved by means of other automatic control systems, while the control in

Please cite this article in press as: Lungu R, Lungu M Automatic landing system using neural networks and radio-technical subsystems, *Chin J Aeronaut* (2017), http://dx.doi.org/10.1016/j.cja.2016.12.019