Available online at www.sciencedirect.com
ScienceDirect
Journal of Bionic Engineering 13 (2016) 504–514

System Identification Method for Small Unmanned Helicopter Based on Improved Particle Swarm Optimization

Qi Bian, Kairui Zhao, Xinmin Wang, Rong Xie

School of Automation, *Northwestern Polytechnical University*, *Xi'an* 710129, *China*

Abstract

This paper proposes a novel method for Small Unmanned Helicopter (SUH) system identification based on Improved Particle Swarm Optimization (IPSO). In the proposed IPSO, every particle will do a local search as a "self-check" before updating the global velocity and position. Then, the global best particle is created by a certain number of elitist particles in order to get a rapid rate of convergence during calculation. Thus both the diversity and convergence speed can be taken into consideration during a search. Formulated by the first principles derivation, a state-space model is built for the analysis of dynamic modes of an experimental SUH. The helicopter is equipped with an Attitude Heading Reference System (AHRS) and the corresponding data storage modules, which are used for flight test data measurement and recording. After data collection and reconstruction, the input and output data are utilized to determine the corresponding aerodynamic parameters of the state-space model. The predictive accuracy and fidelity of the identified model are verified by making a time-domain comparison between the responses from the simulation model and the responses from actual flight experiments. The results show that the characteristics of the experimental SUH can be determined accurately using the identified model and the new method can be used for SUH system identification with high efficiency and reliability.

Keywords: small unmanned helicopter, state-space model, system identification, improved particle swarm optimization

doi: 10.1016/S1672-6529(16)60323-2

1 Introduction

Small Unmanned Helicopters (SUHs) have the advantage of agile movement and without risking the lives of pilots. Hence, they have drawn a wide range of applications in considerable situations. In the recent years, a wide variety of SUHs have been employed in many civil and military fields[1–5], such as ground mapping, border patrol, animal protection, aerial photograph, and forest fire surveillance. With the ability to move sideways, hover, or even move backward, SUHs that feature an increased inertia torque-to-moment ratio and a high power-to-mass ratio can produce a wide range of flight maneuvers[6]. These characteristics often require close analysis and modeling with the aim of flight mechanics characterization, handling-quality applications, and control system design. Therefore, it is necessary to study the dynamic system model of SUHs in order to explore inherent features and carry out further research.

System identification is a very useful method for efficiently and rapidly extracting the dynamic model from a target system. Relying on the input-to-output data relationship, the system identification method can accurately characterize the overall input-to-output response dynamics and provide important insight into a suitable model structure[7]. For this reason, helicopter theory and system identification methods are used in this paper in order to develop a dynamic model for an experimental SUH. The dynamic model identification of aerial vehicles from flight experiment data is largely associated with test input, test record length, signal-to-noise ratio, and the flight data measurement system. In order to improve the fidelity of the identified models, numerous studies have been conducted on various aspects. In order to avoid measuring physical parameters directly from the helicopter, Chen *et al*.[8] designed a variable weighted least-squares estimator to get the yaw dynamic model. On the basis of a number of system identification experiments, Hamel *et al*.[9] proposed the most popular 4M (Maneuver, Measurement,

Corresponding author: Qi Bian
E-mail: bianqi@mail.nwpu.edu.cn

Method, Model) method to accomplish system identification. By using CIFER®, Cai *et al*.[10] obtained the linear model parameters to perfect the fidelity of identified nonlinear model. Schafroth *et al*.[11] developed a covariance matrix adaptation evolution strategy for identifying the model of a micro coaxial unmanned helicopter. With the extension of rotor degrees of freedom, Song *et al*.[12] built a nonlinear model with ten states using an extended Kalman parameters estimator. Conventional system identification methods for aerial vehicles mostly focus on parameter-dependent problems which are based on local optimization. However, being limited to initial conditions and working points, the aforementioned methods can hardly work well for large-scale parameter estimation. Furthermore, the performances of these conventional techniques are greatly influenced by the occurrences of discontinuities in measured data[13]. Without being constrained by initial values and under relatively relaxed assumptions, artificial intelligence algorithms based on global optimization techniques are superior options when tackling multidimensional problems[14].

Currently, the heuristic optimization technique is regarded as a powerful means in many mathematical modeling applications. By extracting the dynamic model parameters from aerial vehicles rapidly and efficiently, artificial intelligence algorithms such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) have shown many important advantages. Tang *et al*.[15] proposed an adaptive GA to identify parameters that cannot be directly measured from SUHs. Lei *et al*.[16,17] identified a small unmanned aerial rotorcraft system based on a new adaptive GA and adaptive Ant Colony Algorithm (ACA) methods. Jiang *et al*.[18] used the modified PSO with Selective Regeneration PSO (SRPSO) to estimate the longitudinal parameters of a small unmanned aerial vehicle. By utilizing multi-objective differential evolution techniques, Tijani *et al*.[19] optimized the nonlinear auto regressive model with eXogenous inputs network (NARX-network) in order to identify a small-scale unmanned air vehicle. Based on the modes partition distributed GA, Wang *et al*.[20] built the dynamic yaw model of an unmanned helicopter. It can be seen that artificial intelligence algorithms have been applied in many optimization fields, but they still have shown some shortages in the following two aspects. Firstly, in terms of "global exploration", as a result of a large number of numerical computations in global optimization, the slow convergence rate of artificial intelligence algorithms is quite time consuming and has always been criticized. Secondly, in terms of "local exploitation", being susceptible to the parameters of complex problems, artificial intelligence algorithms often result in premature convergence[21,22].

In order to overcome the above-mentioned shortcomings, this paper presents an IPSO method that combines modified virtual particle and adaptive local search mechanisms to rationally balance global exploration and local exploitation. In the proposed method, every particle conducts a local search as a "self-check" before the iteration to prevent premature convergence. Meanwhile, the global best position is obtained from the virtual particle, which is generated from a certain number of elitist particles in order to achieve rapid convergence during calculation. In many applications of system identification, the often required end-products are state-space models, which are expressed in terms of the aerodynamic parameters of physical system. To characterize the Multi-Input and Multi-Output (MIMO) behavior of an SUH system, a linear state-space model is constructed with the help of small perturbation theory, and an experimental SUH is used as a test bed to testify the effectiveness and practicality of the proposed IPSO method. Some characteristics of the proposed IPSO method are discussed later, and this method is employed to estimate the aerodynamic parameters of the experimental SUH.

The rest of this paper is structured as follows. In section **2**, the MIMO behavior of the SUH system is analyzed, and a linear state-space model is presented. Section **3** introduces the IPSO method used to identify the optimal parameters of a state-space model. Section **4** includes simulations and real flight tests in order to validate the identified model. Finally, the conclusion is given in section **5**.

2 System dynamic model of an SUH

With the aim of achieving hovering, forward-flight, autonomous landing, *etc*., a precise mathematical model is the basis for designing an advanced flight control system. Thus, a linear state-space model is introduced according to differential equations of motion to analyze the general model of an SUH system. The complexity of the state-space model used to describe the system is