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The Model Identification for Small Unmanned Aerial Rotorcraft Based on Adaptive Ant Colony Algorithm

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Abstract

This paper proposes a model identification method to get high performance dynamic model of a small unmanned aerial rotorcraft. With the analysis of flight characteristics, a linear dynamic model is constructed by the small perturbation theory. Using the micro guidance navigation and control module, the system can record the control signals of servos, the state information of attitude and velocity information in sequence. After the data preprocessing, an adaptive ant colony algorithm is proposed to get optimal parameters of the dynamic model. With the adaptive adjustment of the pheromone in the selection process, the proposed model identification method can escape from local minima traps and get the optimal solution quickly. Performance analysis and experiments are conducted to validate the effectiveness of the identified dynamic model. Compared with real flight data, the identified model generated by the proposed method has a better performance than the model generated by the adaptive genetic algorithm. Based on the identified dynamic model, the small unmanned aerial rotorcraft can generate suitable control parameters to realize stable hovering, turning, and straight flight.

Keywords: small unmanned aerial rotorcraft, model identification, adaptive ant colony

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1 Introduction

With the ability of taking off and landing vertically, as well as hovering, Small Unmanned Aerial Rotorcraft (SUAR) plays an irreplaceable role in civil applications, including road traffic monitoring, city building surveillance, *etc.*[1–5].

As a complex Multi-Input Multi-Output (MIMO) system, a SUAR has the characteristics of nonlinear, multivariable and complex coupled[6–8]. Therefore, a precise dynamic model is the basis for high performance attitude and position control[9]. Since parameter identification method is relatively simple, it has become a common way for the model construction of a SUAR system[10]. With the experimental input-output data, parameter identification method can produce a mathematical representation of the system dynamics quickly. Many researchers have used time-domain system identification and frequency-domain identification methods to get optimal parameters of the dynamic model[11].

Based on straight steady flight data, Nino *et al.*[12] used frequency-domain identification method to construct lateral and longitudinal Single Input Single Output (SISO) models for micro air vehicle. With different frequencies data, Wu *et al.*[13] constructed two autoregressive models to represent the attitude characteristics of a homemade 1-m sized aircraft[13]. Frequency-domain identification method needs a lot of flight data regarding different frequencies[14]. However, pilots could not accurately finish the whole frequency range control due to the constraint of visual delay. Although the autopilot can replace human pilot to generate different frequency control commands, there exist certain flight dangers for SUAR system in data collection process.

Time-domain system identification method is often used in the dynamic model identification process. Park *et al.*[15] used the Least-Squares Estimation (LSE) to develop a new autoregressive model for helicopters[15]. With the adaptive genetic algorithm, Lei *et al.*[16] proposed a linear dynamic model for a small unmanned aerial vehicle to realize stable hovering motion. Salman *et al.*[17] used a nonlinear mapping method to get a

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non-linear state space model for a MUAV system.

Since there are so many variables in the dynamic model of SUAR system, the selection of optimal parameters of the dynamic model is computationally expensive. With the positive feedback strategy, Ant Colony (AC) has already shown high searching performance in large ranges. Hence, AC was used to get optimal parameters for the dynamic model of SUAR system.

For the above purposes, the objective of this paper is to propose a model identification method for SUAR system. With the Adaptive Ant Colony (AAC) algorithm, the dynamic model of SUAR system can be identified with flight data.

The remainder of the paper is organized as follows: in Section **2**, the dynamic model of SUAR is analyzed. In Section **3**, an AAC method is developed to realize precise parameter identification for the proposed dynamic model based on the test data. A series of flight tests for hovering and straight flight validate the effectiveness of the dynamic model in section **4**, followed by the conclusion in section **5**.

2 System dynamic model

The flight characteristics of SUAR can be classified into the hovering, low speed flight and the high speed flight. Compared with other flight vehicles, the low speed flight and hovering are the special characteristics of SUAR. According to the need of project application, the cases of hovering and low speed flight are considered in this paper.

The dynamic model of SUAR can be derived from the Newton-Euler equations for a rigid body with six degrees of freedom. The external forces, including aerodynamic and gravitational forces, are represented in a stability derivative form. For simplicity, the control forces produced by the main and tail rotors are expressed by the multiplication of a control derivative and associated control input. Thus, the dynamic model of a SUAR is defined as

$$m\vec{V} + m(\vec{\boldsymbol{\omega}} \times \vec{V}) = \vec{F}, \tag{1}$$

$$I\vec{\boldsymbol{\omega}} + (\vec{\boldsymbol{\omega}} \times I\vec{\boldsymbol{\omega}}) = \vec{M}, \tag{2}$$

where $\vec{V} = [u\ v\ w]'$ is velocity vector; $\vec{\boldsymbol{\omega}} = [p\ q\ r]'$ is angular speed vector; $\vec{F} = [x\ y\ z]'$ and $\vec{M} = [L\ M\ N]'$ are vectors of external forces and external moments acting on the SUAR, respectively; m is mass, and I is inertial tensor.

Using the Newton-Euler equations, the translational and angular fuselage motions of SUAR can be derived as

$$\begin{cases} \dot{u} = vr - wq - g\sin\theta + (Y_{\text{mr}} + Y_{\text{fus}} + Y_{\text{tr}} + Y_{\text{vf}}) / m \\ \dot{v} = wp - ur + g\sin\phi\cos\theta + (X_{\text{mr}} + X_{\text{fus}}) / m \\ \dot{w} = uq - vp + g\cos\phi\cos\theta + (Z_{\text{mr}} + Z_{\text{fus}} + Z_{\text{ht}}) / m \\ \dot{p} = qr(I_{yy} - I_{zz}) / I_{xx} + (L_{\text{mr}} + L_{\text{vf}} + L_{\text{tr}}) / I_{xx} \\ \dot{q} = pr(I_{zz} - I_{xx}) / I_{yy} + (M_{\text{mr}} + M_{\text{ht}}) / I_{yy} \\ \dot{r} = pq(I_{xx} - I_{yy}) / I_{zz} + (N_{\text{vf}} + N_{\text{tr}} - Q_{\text{e}}) / I_{zz} \end{cases}. \tag{3}$$

The subscripts indicate the respective forces or moments generated by the components, e.g. "mr", "fus", "tr", "vf" and "ht" are for mail rotor, fuselage aerodynamics effects, tail rotor, vertical fin and horizontal tail respectively. Q_{e} is the torque produced by the engine to counteract with the aerodynamic torque on the main rotor blades.

Since gravity acts along the earth axis, it is necessary to introduce the Euler angles to express orientation with respect to the earth axes. Therefore, Euler angles can be obtained by the following kinematic relations

$$\begin{cases} \dot{\phi} = p + \tan\theta(q\sin\phi + r\cos\phi) \\ \dot{\theta} = q\cos\phi - r\sin\phi \\ \dot{\psi} = (q\sin\phi + r\cos\phi) / \cos\theta \end{cases}. \tag{4}$$

Based on the small perturbation theory, the linear dynamic model of SUAR can be constructed by Taylor series expansion to reduce the computation complexity. According to the system identification theory, the suitable system model is the compromise between the modeling complexity and accuracy. Therefore, the coupled system for SUAR can be defined as

$$\dot{\boldsymbol{x}}(t) = \boldsymbol{A}\boldsymbol{x}(t) + \boldsymbol{B}\boldsymbol{u}(t), \tag{5}$$

where $\boldsymbol{x} = [\varphi, \theta, \psi, u, v, w, p, q, r, a_{1p}, b_{1p}]^{\text{T}} \in \boldsymbol{R}^n$ is state variable vector, representing corresponding angles, velocities, angle speeds, blade angle information. φ, θ, ψ are roll, pitch and yaw angles respectively; u, v, w are velocities along the body frame in x, y, z axes respectively; p, q, r are angle speeds around x, y, z axes respectively. a_{1p}, and b_{1p} are longitudinal blade angle and lateral blade angle respectively. $\boldsymbol{u} \in [A_{1s}, B_{1s}, A_M, A_T]^{\text{T}} \in \boldsymbol{R}^m$ is control input, representing longitudinal cyclic input, lateral cyclic input, collective and heading respectively. $\boldsymbol{A} \in \boldsymbol{R}^{n\times n}$ and $\boldsymbol{B} \in \boldsymbol{R}^{n\times m}$ are weighting matrixes.