AIRCRAFT PARAMETER IDENTIFICATION USING GENTIC ALGORITHMS

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Abstract

An approach to identification of aircraft simulation model parameters alternative to deterministic methods is proposed. A new heuristic identification method named Two-Step Genetic Algorithm (TSGA) was developed and implemented. The computations are performed in two subsequent steps. At each step a similar structure of genetic algorithm is applied, but a population is defined in a different manner.

The algorithm performance was tested and evaluated using a nonlinear model of an aircraft, as an example of a mechanical system modelled by first order Ordinary Differential Equations.

1 Introduction

An analysis, investigation and testing of phenomena and systems in science and technology is based on modeling. Models are widely used in design and control of dynamic systems such as airplanes, rotorcraft, vessels submarines, mobile robots, as well as systems in aeronautics and space [2, 7, 8, 9, 20]. In aeronautics a reliable simulation model is needed both for aircraft flying qualities investigation and for application in flight simulator. There are also other situations (for instance accident investigation), when aircraft reliable model enables to avoid expensive and high risk flight tests and to investigate various failures of aircraft systems. To make the simulation results as close as possible to a reality, parameters of a model are usually estimated by identification process, using flight tests results, which number due to economic constrains should be limited.

The identification process may be done on-line [1, 13], in such cases, when a real time determination of aircraft parameters is important (for instance in model based control) or off-line, when a model parameters may be estimated in somehow distinctive to model application. In the later case the identification methods which may require more computational time are used and more data is processed during identification process. An off-line method was developed during the study reported in this paper.

2 Identification methods

There are many well established methods for off-line aircraft identification; the well known example are Maximum Likelihood type methods [16, 17, 19].

Recently widely investigated Genetic Algorithms (GA) are based on a heuristic approach having many advantages in comparison to deterministic methods. Inspired by nature and based on principles of genetics and natural selection, Genetic Algorithms mimic processes in nature to optimize natural phenomena [4, 11].

The main advantage of Genetic Algorithms (GA) over deterministic methods is ability to search an optimized solution in a more broad parameters space and its prospective convergence to a global extremum despite the initial search point. The method performs well with respect to systems with a large number of variables as well as systems with complex interactions. The GA based methods are recognized as more resilient to disturbances in identification data. The GA methods are well suited for parallel computations.

There are not many applications of GA based identification methods in aeronautics [5, 14], so this study was intended to partially fill this gap and obtaining insight and hands –on experience in GA application for aircraft flight dynamic model.

3 The aircraft model

An aircraft nonlinear model used in this study for parameters identification is based on [3, 10, 12, 15]. The aircraft model is formulated as the first order system of nonlinear differential equation resulting from force and moments equilibrium equations in an aircraft body-axes system of coordinates (including moments from control surfaces), and from kinematic relations. The Newton-Euler formalism is applied for derivation of equation describing an aircraft motion.

The model has a general form:

$$\dot{\mathbf{x}} = f\left(t, \mathbf{x}, \mathbf{u}, \mathbf{c}\right), \qquad (1)$$

where:

$\mathbf{x}$ - aircraft state vector,

$\mathbf{u}$ - control vector,

$\mathbf{c}$ - vector of aerodynamic coefficients, to be identified.

The aircraft state vector is defined as:

$$\mathbf{x} = [\,u \quad v \quad w \quad p \quad q \quad r \quad \phi \quad \theta \quad \psi\,] \qquad (2)$$

where:

u, v, w - translational velocities,

p, q, r -roll, pitch, yaw rate,

θ, ψ, ϕ -pitch, yaw, roll angle respectively.

The vector of aircraft control variables $\mathbf{u}$ is composed of the aircraft control surfaces deflection angles and thrust control of the left and the right aircraft engines:

$$\mathbf{u} = \left[T_r \quad T_l \quad \delta_{a_r} \quad \delta_{a_l} \quad \delta_e \quad \delta_r\right], \qquad (3)$$

where:

T_r -thrust form the right engine,

T_l -thrust form the left engine.

$\delta_a, \delta_e, \delta_r$ - angle of aileron, elevator and rudder control surface deflection respectively.

The aerodynamic loads coefficients $\mathbf{c}$ are described by functions of aircraft states $\mathbf{x}$ and controls $\mathbf{u}$:

$$\mathbf{c} = \mathbf{c}(\boldsymbol{\theta}, \mathbf{x}, \mathbf{u}), \qquad (4)$$

where:

$\boldsymbol{\theta}$ - identified parameters vector.

The coefficients of aerodynamic loads model are the parameters to be identified:

$$\boldsymbol{\theta} = [\,C_{D0}\; C_{D\alpha}\; C_{L0}\; C_{L\alpha}\; C_{Y0}\; C_{Y\beta} \ldots \qquad (5)$$
$$C_{P0}\; C_{P\beta}\; C_{Pp_n}\; C_{Pr_n}\; C_{P\delta_a}\; C_{Q0}\; C_{Q\alpha} \ldots$$
$$C_{Qq_n}\; C_{Q\delta_e}\; C_{R0}\; C_{R\beta}\; C_{Rp_n}\; C_{Rr_n}\; C_{R\delta_r}\,].$$

They are embedded in nonlinear equation of aircraft motion.

The systems output equations describes relation between aircraft states $\mathbf{x}$ and output of the model $\mathbf{y}$, which correspond to parameters measured during flight tests:

$$\mathbf{y} = \mathbf{g}\left(t, \mathbf{x}\right), \qquad (6)$$

The output quantities of aircraft model (assumed to be measured) are:

$$\mathbf{y} = [\,V \quad \alpha \quad \beta \quad p \quad q \quad r \quad \phi \quad \theta \quad \psi\,], \qquad (7)$$

where

V -airspeed

α, β -angle of attack and sideslip, respectively.

The numerical implementation of the model was prepared in Matlab computational environment. As the model is calculated for different parameter sets many times, the analytical transformation was done to prepare efficient form of model for identification purposes.

For identification purposes, data of test aircraft from [3] were used.

4 TSGA method

A new method TSGA (Two Step Genetic Algorithm) based on Genetic Algorithms approach is applied in this study [15]. TSGA, has two steps of computations, named due brevity S1 and S2. In both similar structure of algorithm but with different approach to the data (population).

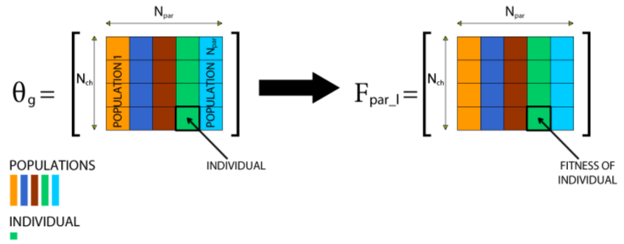

Fig. 1 Population and fitness in the S1 of TSGA algorithm.

In the first S1 step, each parameter of aircraft is treated as individual ones and the fitness of them is evaluated. Each of N_{param} set of identified parameters has its own population (Fig.1). Thus N_{param} populations of N_{ch} individuals make one generation. The modification of every population is performed using annihilation, crossover and mutation. In that manner after modification of N_{param} populations, a new generation is created. At the end of the first step of TSGA, all generations are gathered to exploit convergence of the method and the randomness potential.

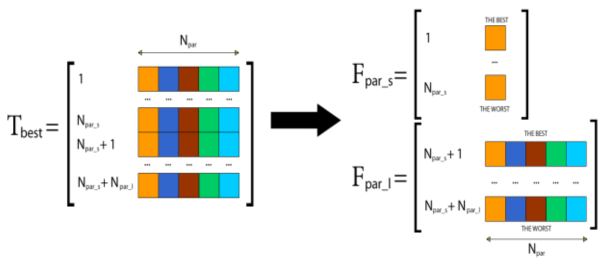

Fig. 2 Initial generation for S2 step of TSGA algorithm.

The N_{par_s} parameter sets with best fitness of the whole set are selected. To these N_{par_s} sets, another N_{par_l} sets are added. Those are created from N_{par_l} individuals of the best fitness from each of N_{param} population, combined in N_{par_l} sets, starting from the best ones. In that manner $N_{gener} = N_{par\_s} + N_{par\_l}$ sets of parameters are selected and are making initial generation in the second stage of the identification algorithm (Fig.2).

In the second step of TSGA, a set of N_{param} parameters is treated as an individual described by N_{param} chromosomes and fitness of the whole set is evaluated (Fig.3).

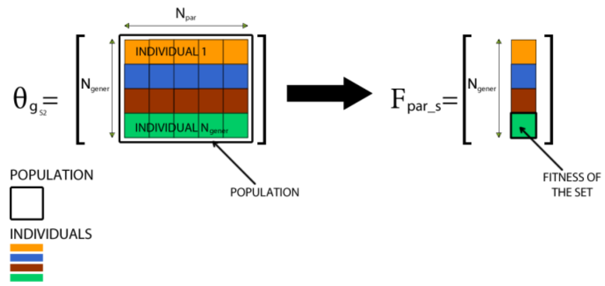

Fig. 3 Population and fitness in the S2 of TSGA algorithm.

One population is created from N_{gener} individuals (sets of parameters). Form each generation, only one population considered. As these N_{gener} sets are the best ones form first stage of the method, it is expected that they form a very good initial population of the second stage, which may lead to a global optimal solution as it is in deterministic methods but it may also present a whole class of them, which is important advantage taking into consideration further practical application.

5 Identification results

The airplane parameter values $\boldsymbol{\theta}$ were identified by TSG3A identification method on the basis of observations from the experiment. For this purpose data of test airplane gathered in [6] are used.

During the identification process using TSG3A method, the fitness of each parameter is evaluated (in S1 stage of the method) and finally fitness of parameters set (in the step S2 of the algorithm) is determined. During evaluation of fitness of parameter set, model output values are calculated using, and computed parameters are compared to the corresponding observations (data gathered during flight test in case of the airplane). Values of parameters set with the best fitness of the whole set are chosen as identified parameters.

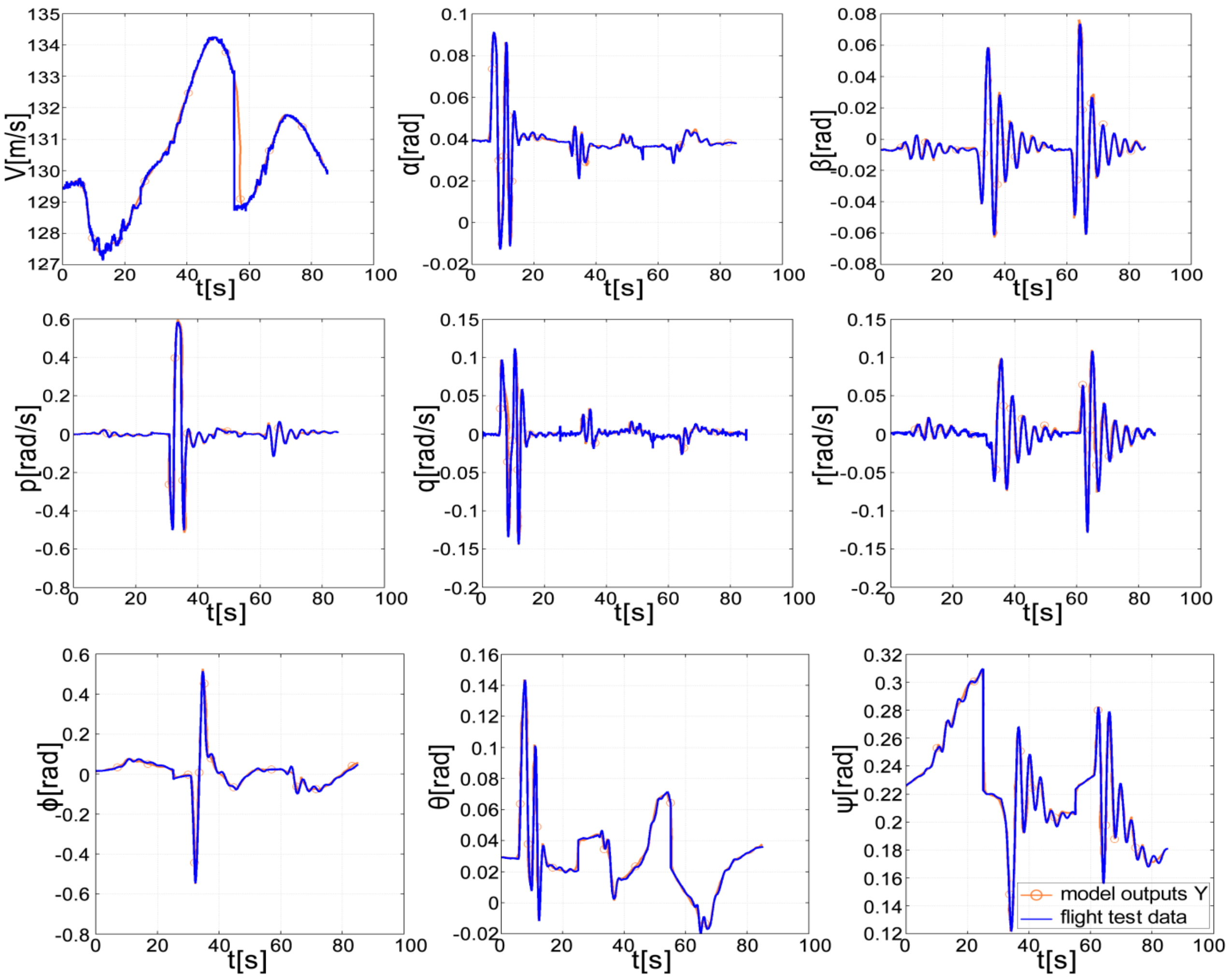

Fig. 4 Results of aircraft identification using TSGA algorithm.

The parameters identified using TSG3A method $\boldsymbol{\theta}$ are compared to the parameters values identified on the basis of the same flight test data and found in the literature[6]. Additionally the model output variables $\mathbf{y}$ calculated using parameters identified by TSG3A method ($\boldsymbol{\theta}$) are compared to the observations from flight test. As it may be seen in the Fig.4, all calculated outputs $\mathbf{y}$ of nonlinear airplane model are very close to the observation data gathered during the flight.

The differences between outputs of the model calculated using identified set of parameters and observations (presented in diagram form) are relatively low.

5 Conclusion

A new approach to aircraft parameter identification using Two-Step Genetic Algorithm (TSGA) is proposed.

The aircraft nonlinear model is used for the method tests. On the basis of fight test data [3], parameters of nonlinear aircraft model is identified applying a new TSGA algorithm.

Identified model parameters lead to aircraft model behaviour, which is reasonably similar to the data gathered during flight tests.

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