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NEURAL-NETWORK BASED AIRCRAFT CONTROL SYSTEM OPTIMISATION

Introduction

The problem of automatic control systems development for complex dynamic objects (in particular, aircrafts under influence of environmental disturbances) is characterized by transition from a paradigm of adaptive control to a paradigm of intellectual control [1, 2]. The reasons for this are: objects to be controlled and conditions of their performance continuously becoming more complicated, new classes of means for calculation being discovered (in particular, the distributed computing systems), requirements to accuracy and speed of control systems performance under conditions of uncertainty or the incomplete input information being increased.

Application of neural networks allows to remove mathematical problems of analytical synthesis and analysis of designed system properties [3].

Problem formulation

The objective of this paper is to research the designed control system robustness to change of control object's parameters (engine thrust, aircraft mass, shift centre of gravity, change of the wing area) as well as to define the optimal genetic algorithm's parameters which will minimize altitude control error and time of transient process when the aircraft changes to another flight echelon.

Algorithm of system performance

The general scheme of system structure and operation is shown in Figure 1.The multilayered neural network has been chosen for construction of neural controllers NN1 and NN2 [4]. The architecture of a neural network: network of direct signal transmission, which consists of input, output and two hidden layers. The network structure is identical for each channel – 2 inputs, 15 neurons in the first hidden layer, 15 neurons in the second hidden layer and 2 outputs neurons. The neural network training was conducted by genetic algorithm.

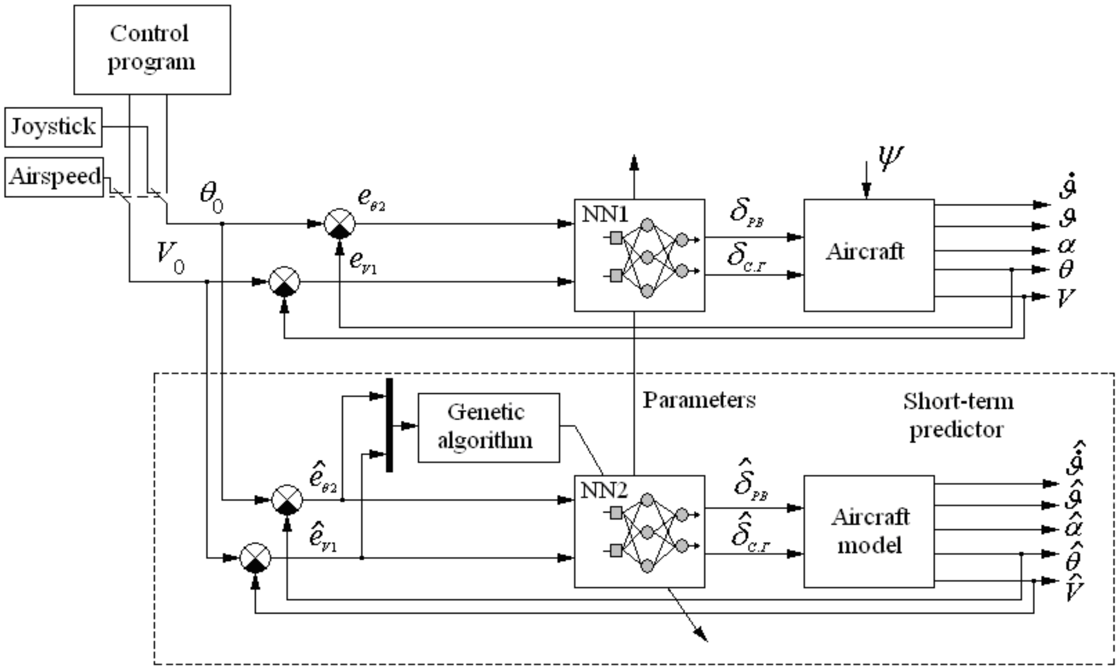


Fig. 1. General structure of a neural-network based aircraft control system

The system performance has been simulated using NN_GA software, which is developed using Delphi computer language. The software consists of: the block of longitudinal nonlinear motion of aircraft, the block of atmosphere simulated model, the block of wind indignations simulated model, the blocks which are realized by the neural controller and the neural emulator, the block of genetic algorithm.

The following concept of adaptive control system performance is proposed. The system consists of two channels: the channel of a direct control and the virtual channel. In the direct channel neural controller NN1 stabilises aircraft at desired input flight trajectory angle and airspeed. In the virtual channel aircraft behaviour is predicted for the certain time range (prediction horizon). Prediction horizon is assumed at 5 sec.

Desired aircraft airspeed and trajectory slope angle are provided from the tactical level of control either by the pilot or control program algorithm. Control at the execution level is aimed at stabilization of the airspeed and flight trajectory angle. Value of trajectory slope angle is calculated based upon the desired altitude as follows:

$$\theta_0 = (H_0 - H) \cdot K_\theta \tag{1}$$

At the first stage of algorithm operation population of chromosomes, in which all the neural-network parameters are encoded, is randomly initialised. Each of network's parameters (weights values and bias) are encoded by 32 bits.

After initial conditions initialization, errors on airspeed and flight trajectory angle are calculated. The received signals move on an input of neural emulator NN2. On outputs of a neural network are formed two standards signals – elevator angle (from –1 up to 1) and throttle value (from 0 up to 1).

Following step – simulated aircraft dynamics on the certain time range.

The control quality criterion as fitness function in genetic algorithm is calculated according to the following expression:

$$J = \int_0^T [\hat{e}_{\theta 2}^2(t) + \hat{e}_{V2}^2(t)]dt, \quad (2)$$

where $\hat{e}_{\theta 2}^2 = \theta_0 - \hat{\theta}, \hat{e}_{V2}^2 = V_0 - \hat{V}$.

Calculations of fitness function for each chromosome in the population is performed. In this case, evolution termination criteria are not checked – genetic operators are applied and the new generation is produced.

At a following stage optimization parameters are copied to the neural controller NN1. Controller NN1 produces throttle and elevator control to provide the desired flight trajectory angle and airspeed. Control algorithm operation is demonstrated by the flow-chart diagram in figure 2.

Control system optimization

Optimization of control system consists of studying influence of genetic algorithm's parameters on control error and transient time of flight trajectory angle. System behaviour is evaluated as a reaction to the several pulses applied as an input (shown in figure 3).

Research is executed for genetic algorithm with the following ranges of parameters probabilities: cross-over: 0,5 – 0,95; mutation: 0,05 – 0,4; inversion: 0,01 – 0,45. Dependency charts of flight trajectory angle error and transient time are shown in figures 4, 5.

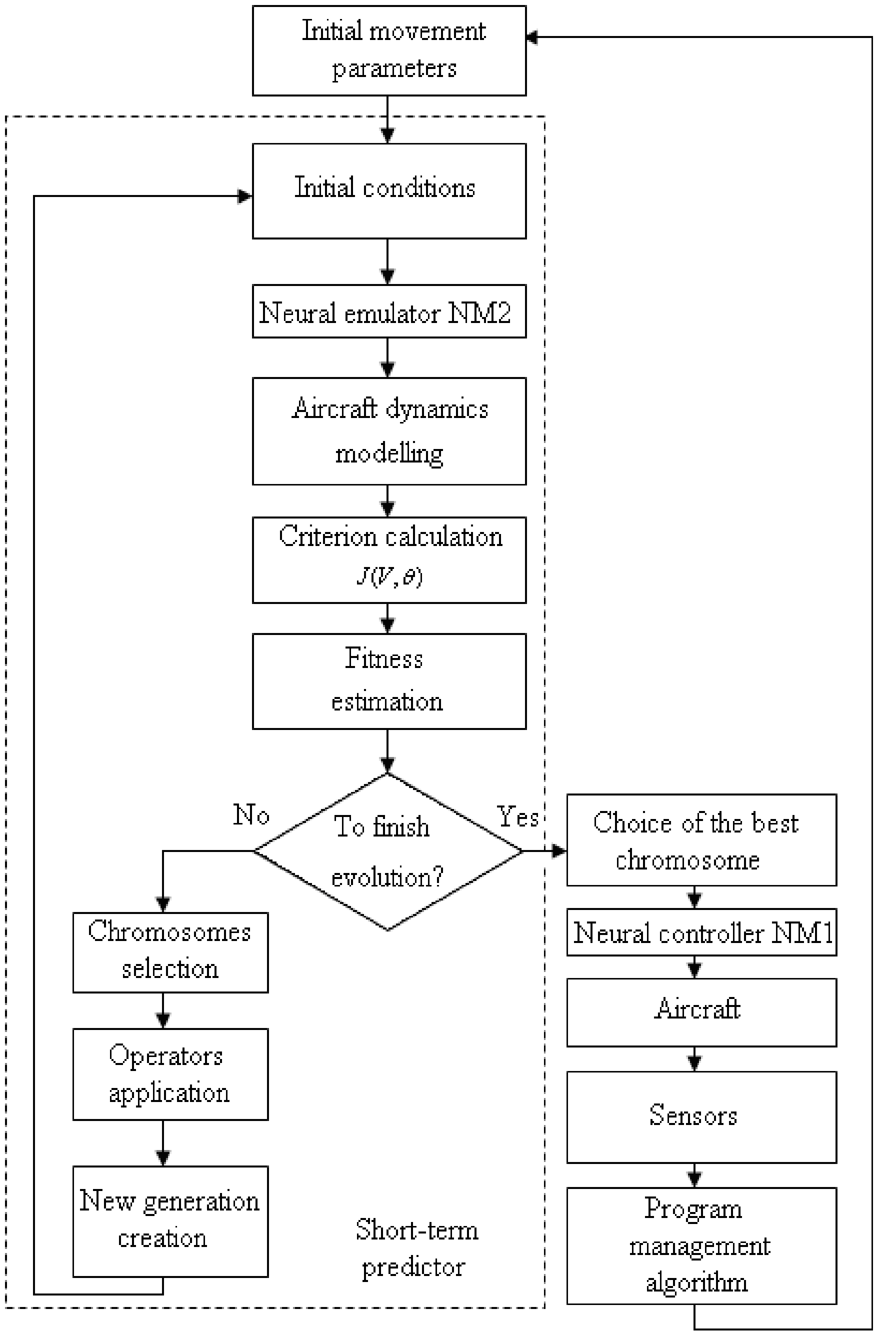


Fig. 2. Algorithm operation flow-chart

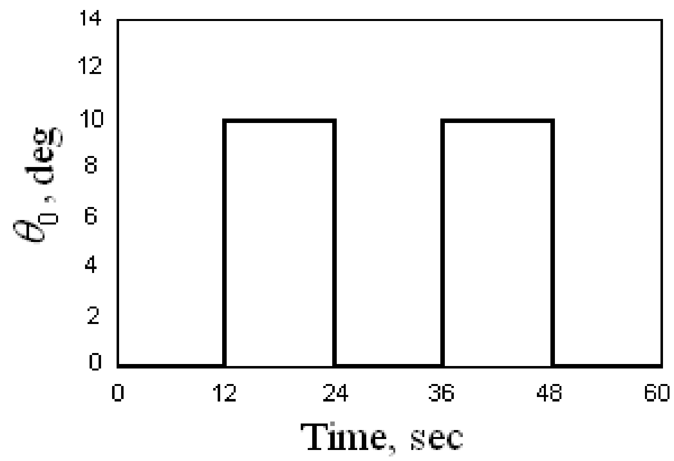


Fig. 3. Test pulses

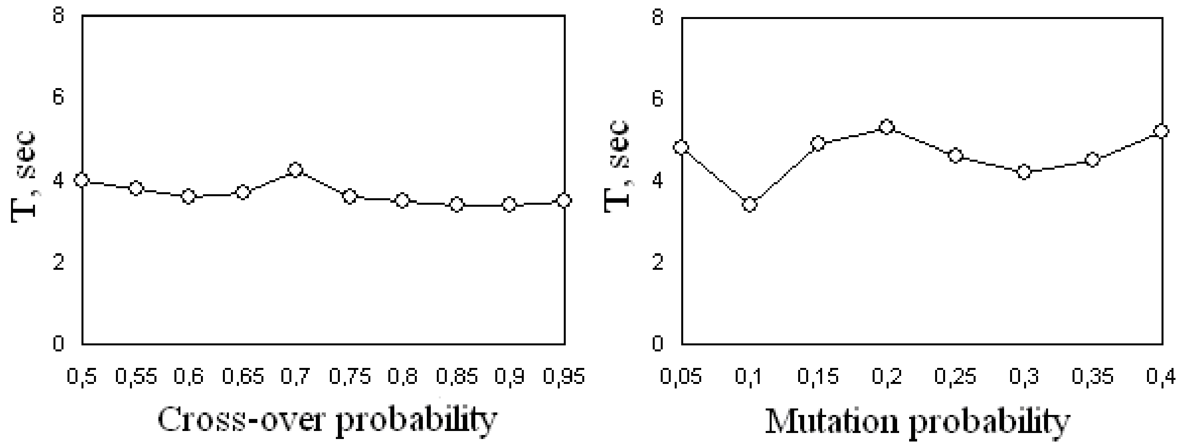


Fig. 4. Change of transient time of flight trajectory angle depending on genetic algorithm's parameters

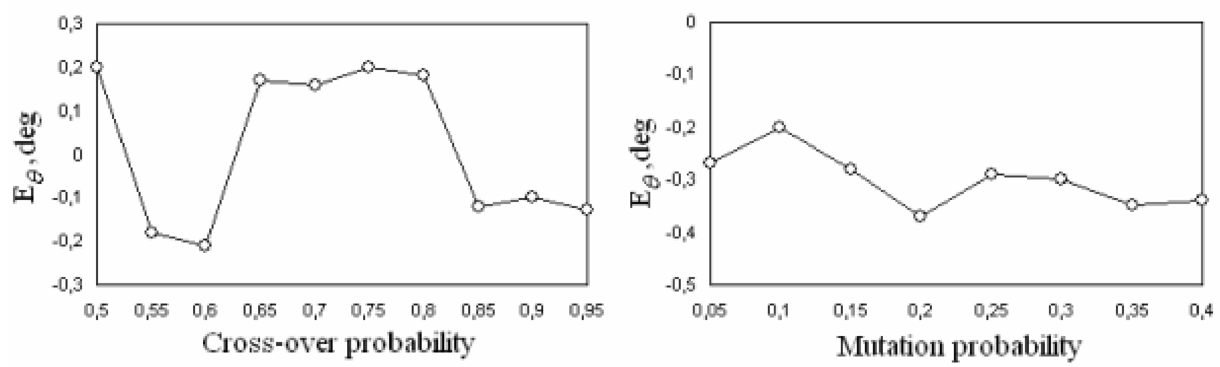


Fig. 5. Dependence of flight trajectory angle error from genetic algorithm's parameters

The analysis of results has shown, that optimal values of genetic algorithm parameters are: cross-over – 0,9; mutation – 0,1; inversion – 0,05. The specified parameters minimize error of flight path angle and transient time.

System response on test pulse for genetic algorithm's optimal parameters is shown in figure 6.

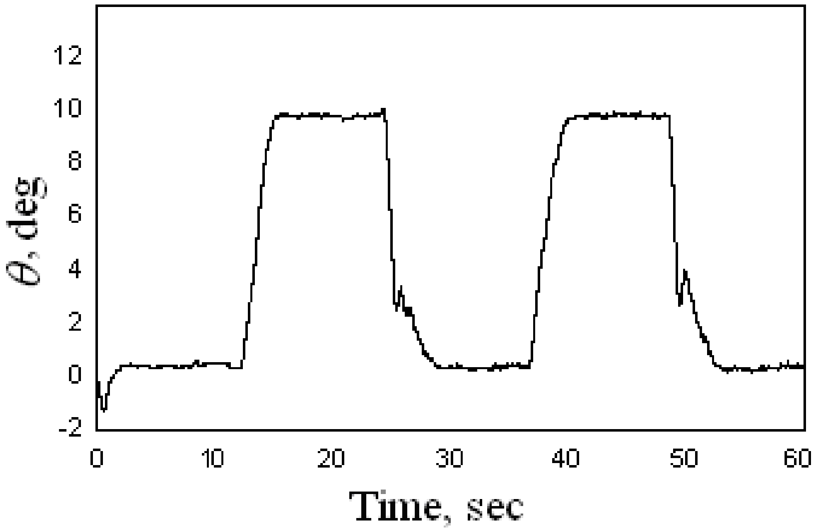


Fig. 6. Flight path angle change

Influence of aircraft parameters variation on system performance

Numerical modelling of system operation has been made for the altitude – 1000 m and airspeed – 120 m/s. Characteristics of jet fighter F–15(eagle) were used as parameters of aircraft model [5]. Simulation results for maintaining constant altitude are shown in figure 7.

Sudden change of altitude during flight (vertical climb on 300 m on 18 sec and descent to 300 m on 38 second) is shown in figure 8. Dryden's model was used as wind model.

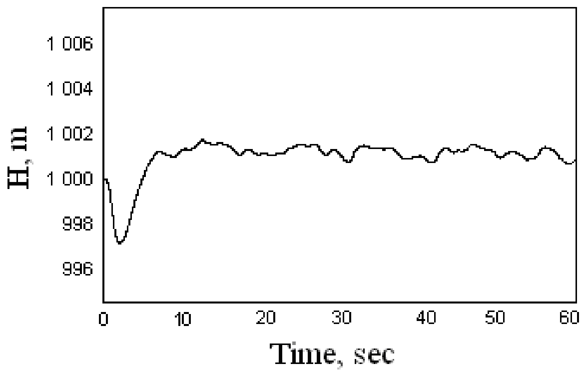


Fig. 7. Constant maintain altitude

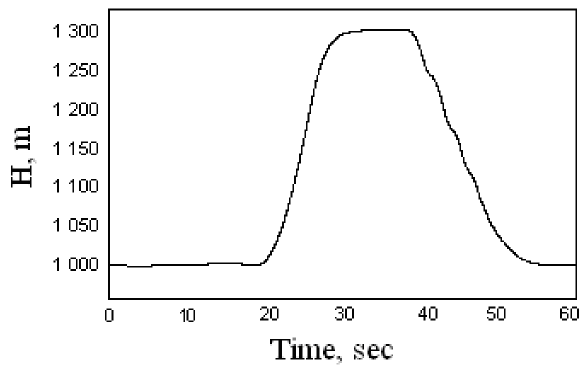
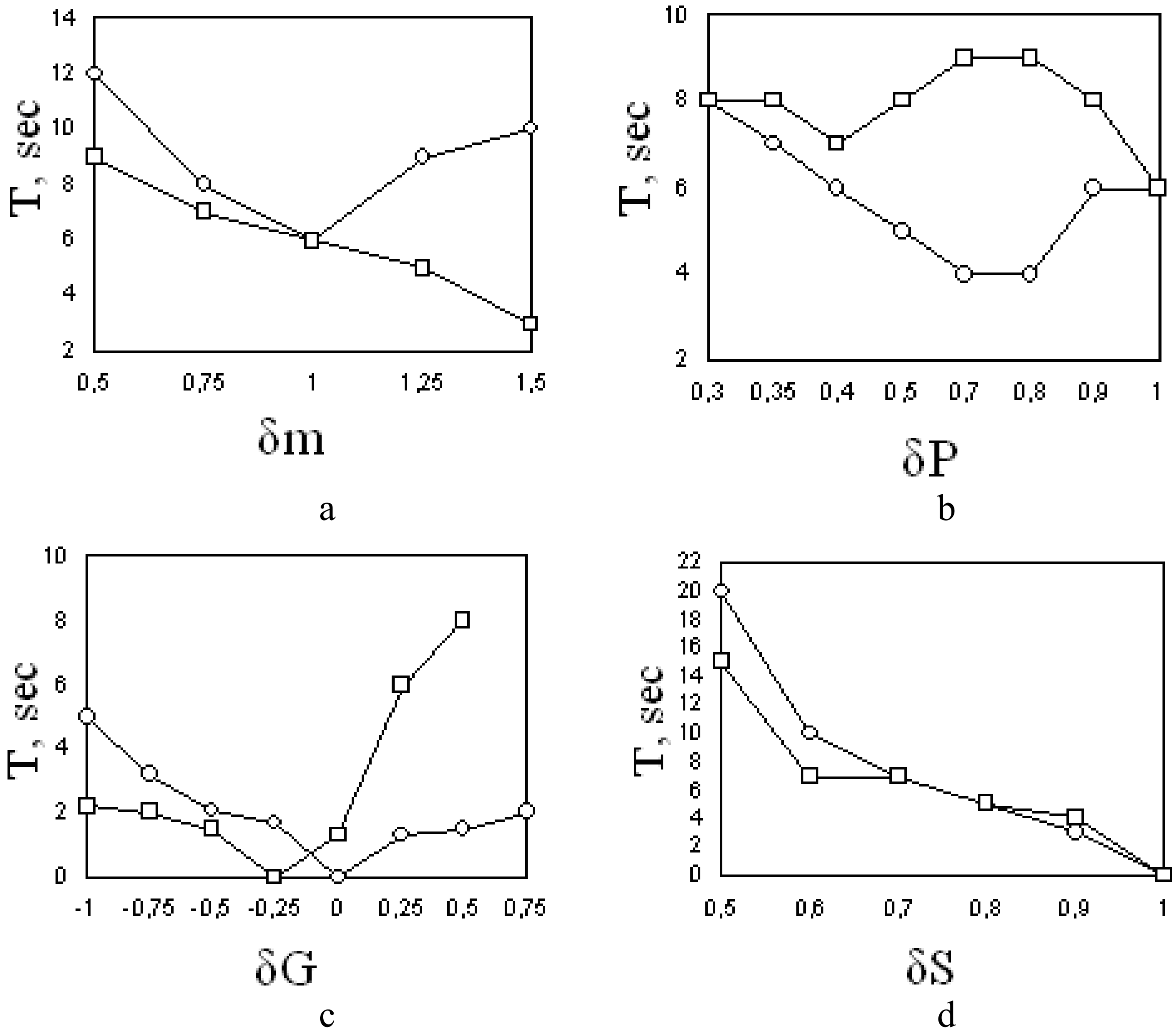


Fig. 8. Altitude change

System performance research has been conducted for two cases: under the conditions of wind disturbances being absent and under presence of wind disturbances. Variable parameters are aircraft mass characteristics, the maximal engine thrust, change of the wing area, shift centre of aircraft gravity along the longitudinal axis.

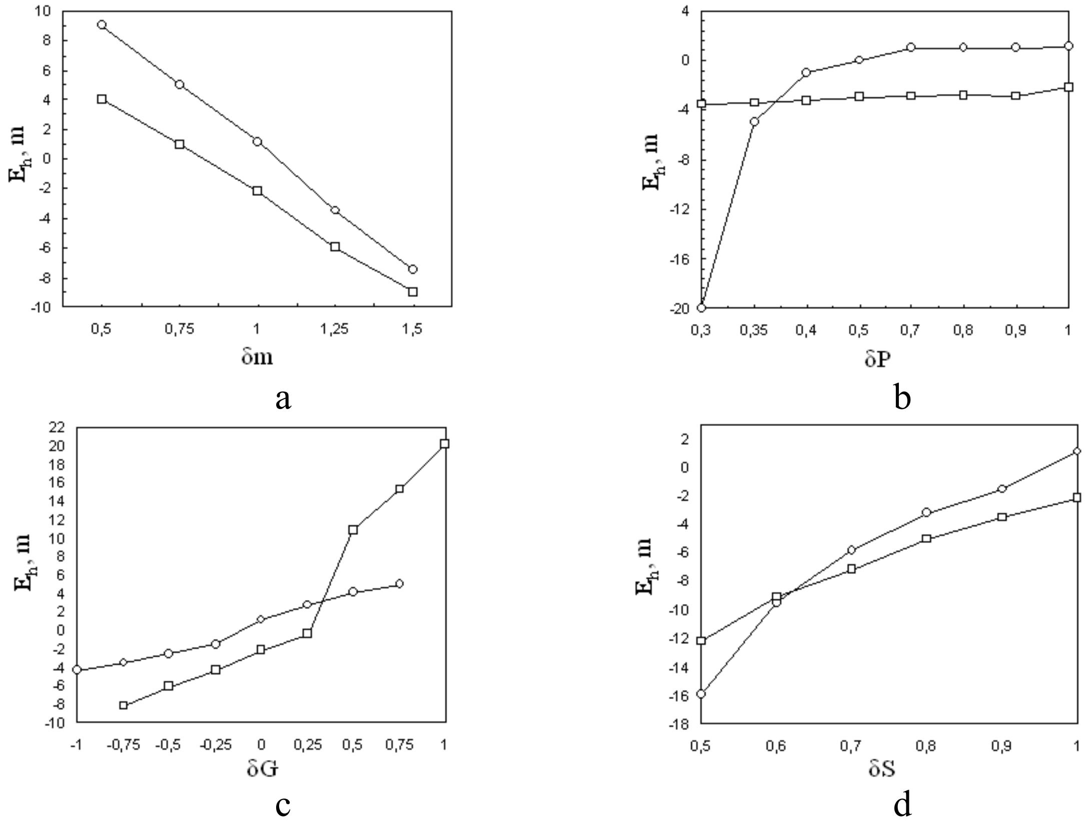
Transient time of flight path angle, when specified above parameters are being changed, is shown in figure 9. Thus, when the maximal thrust goes down to 70 percent, the maximal time of transient makes 9 seconds. When the aircraft weight both reduces twice and increase one and a half times – maximal transient time is 12 seconds.



–o–o– – modeling without a wind;
–□–□– – modeling with a wind.

Fig. 9. Change of transient time of flight path angle depending on:
a) change of weight; b) change of thrust; c) change of centre weights; d) change of the wing area

Altitude hold error as a function of variable aircraft parameters is shown on figure 10.



–o–o– – modeling without a wind;
–□–□– – modeling with a wind

Fig. 10. Dependence of altitude hold error from:
a) change of weight; b) change of thrust; c) change of centre weights; d) change of the wing area

For an example, system response on test pulse when the aircraft weight has decreased for 10 and 25 percent (on 36 second) shown in figure 11 and figure 12.

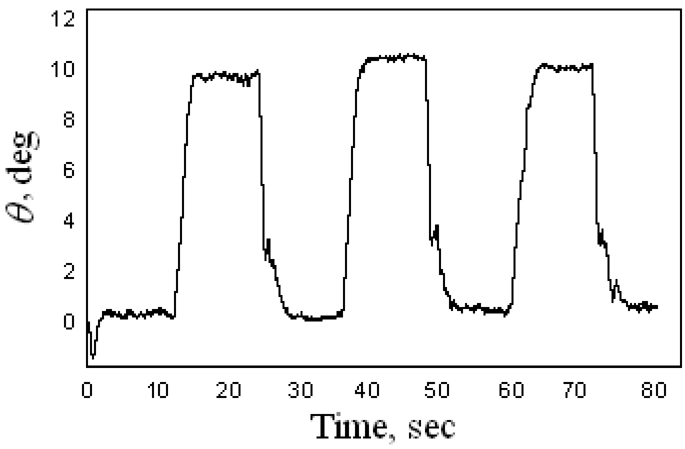


Fig. 11. Flight trajectory angle variations (0,9m)

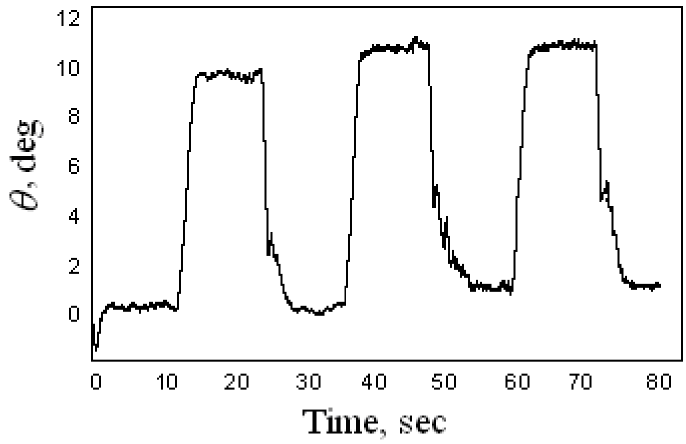


Fig. 12. Flight trajectory angle variations (0,75m)

Conclusions

Suggested neural-network based aircraft control system concept demonstrated high robustness and excellent performance in realising desired flight trajectory angle and airspeed.

Optimal parameters of the genetic algorithm were identified to be as follows: crossover –0,9; mutation – 0,1; inversion: – 0,05. The specified parameters minimize error of flight trajectory angle and transient time. Henceforth, at the trajectory control level both minimization of altitude hold error and time of aircraft transition for another flight level occur. The following control performances were achieved: altitude stabilisation error 1.1 m, transient time - 12 s.

Obtained absolute error of altitude stabilisation does not exceed 3 m. The neural controller has appeared practically insensitive to action of wind disturbances at constant parameters of the plane.

Research results demonstrate that at change of aircraft weight twice and at it increase in one and a half time – the maximal error of altitude stabilisation does not exceed 10 m. Reduction of thrust (up to 25 percent from initial) influences altitude stabilisation error within the limits of 4 m.

Research of centre of gravity shifts influences shows, that at shift of ± 1 m the system remains stable on all modes of flight with satisfactory parameters of accuracy and quality of transient. At change of wing area for 30 percent error of altitude hold does not exceed 10 m.

As a future research, it is planned to modify genetic algorithm and to study neural networks structural adaptation as well.

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