AN EVOLUTIONARY ALGORITHM FOR IDENTIFICATION OF NON-STATIONARY LINEAR PLANTS WITH TIME DELAY

Janusz P. Papliński
Technical University of Szczecin, Institute of Control Engineering, 26 Kwietnia 10, 71-126 Szczecin, Poland,

Keywords: evolutionary algorithm, model of dynamics, identification

Abstract. The identification of time delay in the linear plant is one of the important tasks. It is especially hard problem when the plant is non-stationary. New possibility in this field is opened by application of an evolutionary algorithm. The method of identification proposed in the paper is based on three classes of input signals. In the first case we can obtain and operate on the whole unit step response. In the second way we operate on a random signal of control, and in the last we have the stairs input signal. The identification without and with disturbances is considered.

1 INTRODUCTION

Some linear plants can be considered as a plant with transport delay. The knowledge of this delay is very important. It enables us, for example, to design an appropriate control system. Another domain of application of this knowledge can be in the fault detection. If we have the possibility of indicating changes of the time delay, we can detect faults in the system. In this situation we can consider the above matter as an identification of a non-stationary plant. We need information about the changing parameters of the plant. There are several methods of identification of time delay and the plant dynamics and this problem is being continuously developed (Orlov et al., 2002). New possibility in this domain is opened by application of evolutionary algorithms. They include some special ability to parallel computation of encoded information. This allows for exploration of several promising areas of the solution space at the same time (Goldberg, 1989, Michalewicz, 1996). The evolutionary algorithm works in a periodic manner and it permits to observe in successive iterations of changed parameters of the identified plant.

I consider, in my paper, three classes of input signals. In the first case we can obtain and operate on the whole unit step response. In the second way we operate on a random signal of control, and in the last we have the stairs input signal. We have less information in the each consecutive situation, and the identification is becoming more difficult.

In my paper I considered identification of systems without and with disturbances.

The experimental investigations take advantage of Matlab and its “Genetic algorithm for optimisation toolbox” (GAOT) (Houck et al. 1995a), available from the Internet.

2 GENETIC ALGORITHMS OPERATIONS

The genetic algorithms operate on the codable form of individuals. Each individual sufficiently describes the model. It is composed of 11 parameters – genes (Papliński, 2002), coded as floating point numbers. 5 parameters correspond to coefficients of the nominator, next 5 correspond to coefficients of the denominator and the last one is equal to the time delay. The obtained model corresponds to the transfer function:

$$G(s)=\frac{c_1 s^4+c_2 s^3+c_3 s^2+c_4 s+c_5}{c_6 s^4+c_7 s^3+c_8 s^2+c_9 s+c_{10}}e^{-c_{11}t} \quad (1)$$

The value of each chromosome is contained in an assumed range. The acceptable limits are determined on the base of the priory information about the plant. The maximum order of models is equal to 4 and it is a compromise between accuracy and simplicity.

Papliński J. (2004).
AN EVOLUTIONARY ALGORITHM FOR IDENTIFICATION OF NON-STATIONARY LINEAR PLANTS WITH TIME DELAY.
In *Proceedings of the First International Conference on Informatics in Control, Automation and Robotics*, pages 64-69
DOI: 10.5220/0001126800640069

One of the main operators of the genetic algorithm is the operation of crossover. It is used to create a new solution on the basis of the existing solution. Crossover takes two individuals from old population and produces two new individuals for the next population. The arithmetical crossover with random direction of changes (Papliński, 2003), given in the form:

$$\begin{aligned} \overline{X}' &= a\overline{Y} + (1-a)\overline{X} \\ \overline{Y}' &= a\overline{X} + (1-a)\overline{Y} \end{aligned} \qquad (2)$$

where $a \in [-1, 1]$, is used in the paper

This operation is used in the investigation, presented in the paper, with global probability of the crossover equal approximately to 0,97.

As a selection function we use the normalized geometric selection (Houck et al. 1995b), which defines the probability of selection for each individual as:

$$p_r = \frac{q(1-q)^{r-1}}{1-(1-q)^n} \qquad (3)$$

Where:

- q - the probability of selecting the best individual;
- r - the rank of individual, where 1 is the best;
- n - the population size.

Individuals are graded in population according to the quality of the obtained models. The fitness function is obtained from differences between step responses of the plant and models. The figure of merit has the form

$$J = \frac{1}{\sum_{i=1}^{200}\left(\alpha\left(y_o(t_i) - y_m(t_i)\right)\right)^2} \qquad (4)$$

where

- $y_o(t_i)$ – the response of the plant;
- $y_m(t_i)$ – the response of the model;
- α - the coefficient of importance.

The role of coefficient α is to decrease influence of the initial condition and it is presented in fig.1.

The identified plant works continuously all the time during identification. In the same time for each individual in every generation the fitness function J is determined. The plant works with non-zero initial conditions, the models work always with the initial conditions equal to zero. The coefficient α permits to minimize the influence of initial conditions to the fitness function J.

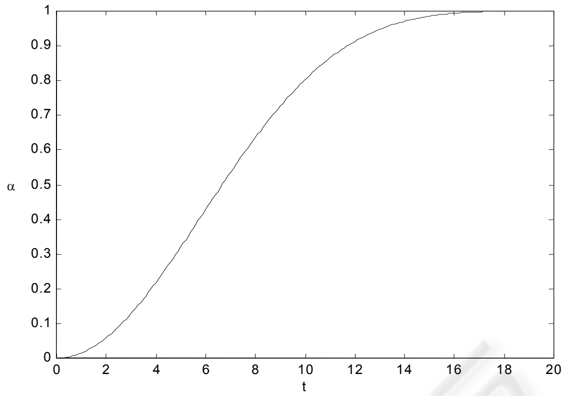

Figure 1: The value of coefficient α.

As a global quality coefficient J_g we used the sum of absolute error of time identifying with the weight factor

$$J_g = \sum\left|t_{del} - t_{ident}\right| \qquad (5)$$

where:

- t_{del} - the time delay of the plant
- t_{ident} - the identified time delay

This figure of merit has only an experimental application and can be used only for the simulated plant, not for the real plant, because we do not know the actual value of the time delay. This criteria permit to compare evolutionary algorithms to each other.

I used, in my investigation, the mechanism of crowd (De Jong, 1975). The technique is employed for insertion into the population. Each check consists of a randomly selected crowding sub-population from the entire population, according to the crowding-factor. The individuals from sub-population are compared to the child and the child replaces the most similar candidate on the basis of similarity count. The similarity count J_s compares individuals as follows

$$J_s = \sum_{i=1}^{11}\left(c_{ic} - c_{is}\right)^2$$

where

- c_{ic} – the I-th coefficient of the child;
- c_{is} – the I-th coefficient of the individual from the sub-population.

This method is beneficial in that it helps to maintain diversity throughout the search. The diversity of population of evolutionary algorithm is specially important for identification of the non stationary plant. In my investigation the crowding-factor equals 2.

Population is made of 80 individuals. The genetic algorithm is terminated at the specified generation.

2 IDENTIFICATION USING THE UNIT STEP RESPONSE

One of the methods of identification can use the step responses of the plant (Papliński, 2002). In this case we need the whole unit step response in each generation of the evolutionary algorithm. It is possible for the slow plant drove by the step signal. Some example of this plant, in simplification, can be a district heating station with a pipe system.

The evolutionary algorithm reads the whole step response of the plant at the beginning of each iteration. It permits to seek optimal solution for the changing plant. In next steps the fitness function of population is determined, and new population is created. The fig.2 presents the trace of the identified time delay for stairs changes in this time in the plant.

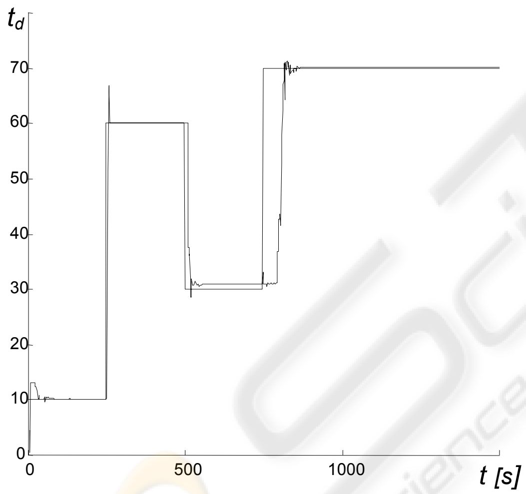

Figure 2: The trace of stairs changes in time delay of the plant and the identified time in model.

3 ON-LINE IDENTIFICATION USING THE TIME SIGNAL WINDOW

The step response identification is restricted to the small class of plants and the situation for which we can use the step input and the complete step response. In the majority of real systems we have only successive samples of signal. It is possible to do identification by using the natural signal overflow in the identified object. The process of identification can be made without any interfering with the plant work. I proposed in the paper the evolutionary algorithm operating on some sliding time signal window. The window contains 200 following samples of input and output signals of the plant. In the successive generation responses of individuals are compare to changing response of the plant.

3.1 Identification with the random input

It seems that the most universal signal in the real systems is random input. This class of signals appears often in systems. Another advantage of it is continuously excitation the plant, what is very important in on-line identification. Experiments to identify time delay were made. The obtained cumulative distribution function F(x) of the global quality coefficient J_g is presented in fig.3.

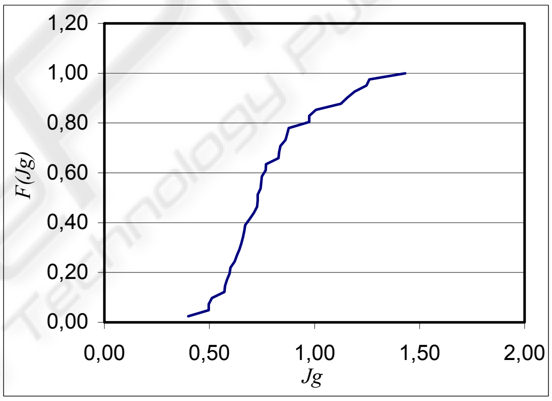

Figure 3: The cumulative distribution function of the global quality coefficient J_g.

The expected value of the global quality coefficient with the 95 percentage of confidence interval is equal to

$$\overline{J_g} = 0{,}79 \pm 0{,}07 \,.$$

The standard deviation of the obtained solution is equal to $\sigma = 0{,}23$. About 20% of identification has $J_g \geq 1$.

Fig.4 and Fig.5 present the trace of the identifying time delay for the average and the worst identification. Even the worst identification guarantees correct identification of the time delay, but only time of identification can be longer.

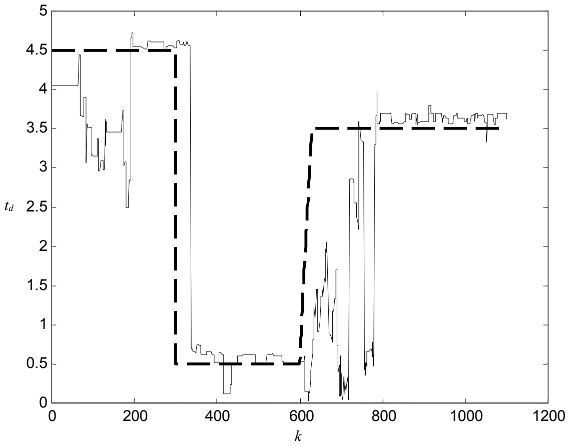

Figure 4: The trace of the identified time delay for the average identification for J_g=0.77.

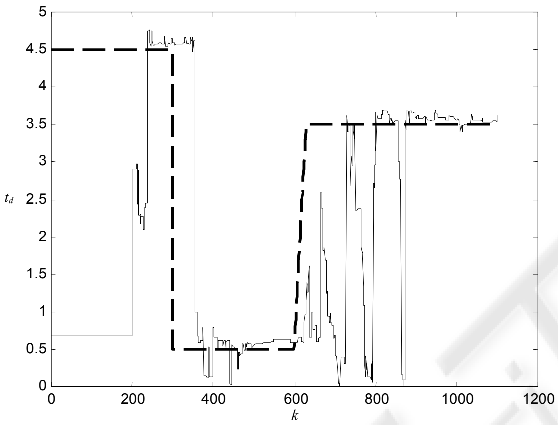

Figure 5: The trace of the identified time delay for the average identification for J_g=1.47.

3.1 Identification with the stairs input signal

Some plants can be controlled by the stairs signal. If we want to do on-line identification the period of sudden change cannot be too large. I made an assumption that the average period is equal to 5. The experiments to identify time delay were made. The obtained cumulative distribution function of the global quality coefficient J_g is presented in fig.6.

The expected value of the global quality coefficient with the 95 percentage of confidence interval is equal to

$$\overline{J_g} = 0{,}9 \pm 0{,}08 .$$

The standard deviation of the obtained solution is equal $\sigma = 0{,}19$. Fig.7 presents the trace of the identified time delay for the worst identification obtained during the experiment..

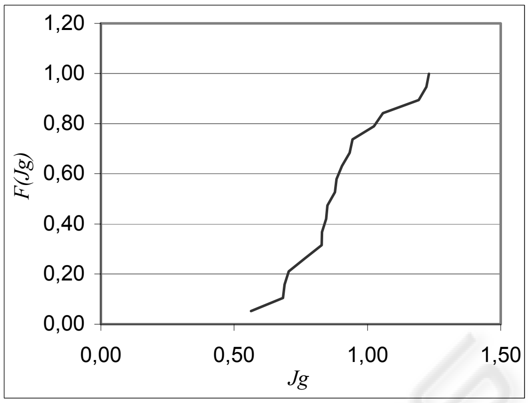

Figure 6: The cumulative distribution function of the global quality coefficient J_g.

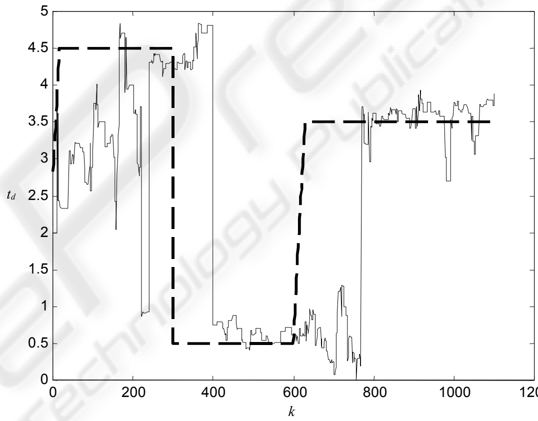

Figure 7: The trace of the identified time delay for the average identification for J_g=1.23 and the plant driven by stairs.

The identification with the stairs input signal is effective. The expected value of the global quality coefficient is now a little worse than in the identification with the random input. It may be caused by use of worse signals to identification.

4 IDENTIFICATION IN THE PRESENCE OF RANDOM NOISE

The results of identification presented above were made with no disturbances. However the disturbances always occur in real systems. I made the assumption that output of plant is measured with random disturbances. The value of the amplitude of disturbances was assumed at the level equal 50% of level of output. I made the investigation for two classes of input:

- the random input;
- the stairs input.

The obtained cumulative distribution functions of the global quality coefficient J_g are presented in fig.8 and fig.9.

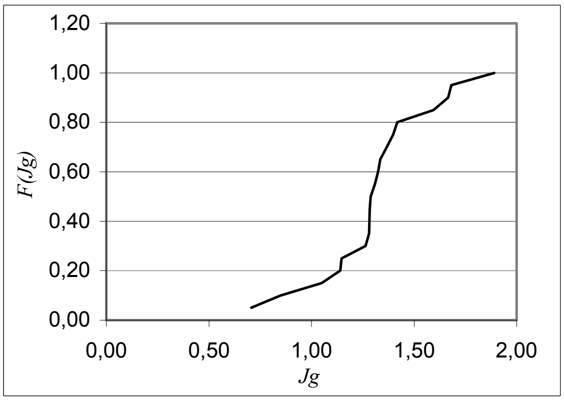

Figure 8: The cumulative distribution function of the global quality coefficient J_g for the random input with disturbances.

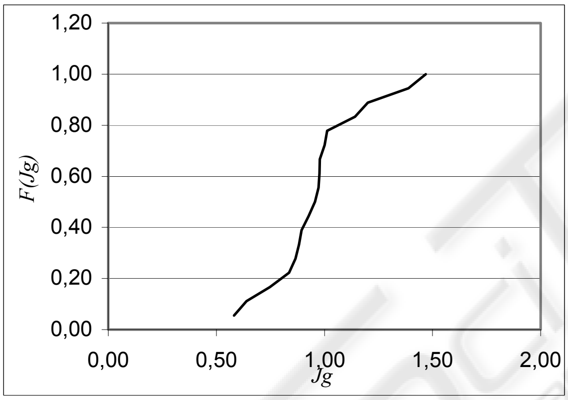

Figure 9: The cumulative distribution function of the global quality coefficient J_g for the stairs input with disturbances.

The expected value of the global quality coefficient with the 95 percentage of confidence interval:

- for the random input is equal
  $\overline{J_g} = 1{,}35 \pm 0{,}11$
  $\sigma = 0{,}24$
- for the the stairs input is equal
  $\overline{J_g} = 0{,}97 \pm 0{,}1$.
  $\sigma = 0{,}23$

The disturbances worsen identification, but do not do it impossible. The random input identification is more sensitive to them. The obtained solutions are bad. The stairs input identification is less sensitive. The trace of the identified time delay, for its worst identification obtained during the experiment is presented in fig.10. This identification is worse than identification without disturbances, but is not bad. We should remember that this figure presents the worst identification of several. The identification was made for 18 times.

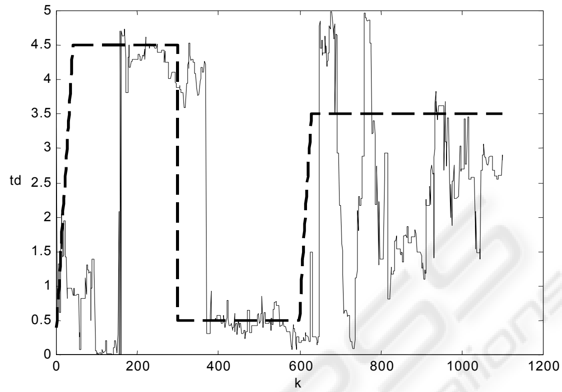

Figure 10: The trace of the identified time delay for the worst identification for J_g=1.47 and the plant drives by stairs with 50% disturbances.

5 CONCLUSION

The investigation presented in the paper shows that evolutionary algorithm can be used in identification of non-stationary plants with transport delays. The unit step responses as well as random input can be use. In the first case the identification is more accurate, but we need the whole step response in every generation. The second method is less accurate, but we also need less information about plants and we can use a wide class of input signals.

The summary solutions, for the on-line identification using the time signal window, are presented in table 1.

Table 1: The summary solutions

The Identification with:	$\overline{J_g}$	σ
the random input	$0{,}79 \pm 0{,}07$	0,23
the random input with disturbances	$1{,}35 \pm 0{,}11$	0,24
the stairs input	$0{,}9 \pm 0{,}08$	0,19
the stairs input with disturbances	$0{,}97 \pm 0{,}1$	0,23

For the identification without disturbances the best class of inputs are random signals. This identification is however sensitive to disturbances.

The implementation of the stairs input signal extends this method to a wider class of inputs. Additionally, this identification is less sensitive to disturbances.

The identification with 50% disturbances shows that evolutionary algorithm can be used in on-line trace of the variable time delay in the non-stationary plant.

REFERENCES

Goldberg D. 1989. Genetic Algorithms in Search, Optimisation, and Machine Learning. Addison – Wesley

Houck, C. R., J. A. Joines, and M. G. Kay. 1995a. Genetic Algorithm for Optimisation Toolbox. www.ie.ncsu.edu/mirage/

Houck, C. R., J. A. Joines, and M. G. Kay. 1995b. A genetic algorithm for function optimisation: A Matlab implementation. North Carolina State University NCSU-IE Technical Report 95-09

Michalewicz Z., 1996. Genetic algorithms + Data structures = Evolution programs. The book, Springer – Verlag Berlin Heidelberg.

Orlov Y., Belkoura L., Richard J.P., Dambrine M., 2002. On-line parameter identification of linear time-delay systems. In 41st IEEE Conference on Decision and Control. Las Vegas, Nevada USA

Papliński J.P. 2002. An evolutionary algorithm used for identification of linear plant with time delay. MMAR, Szczecin Poland

Papliński J.P., 2003. Non-Degenerative Evolutionary Algorithms for Identification of the Plants With Variable Time Delay. 14th International Conference on Proces Control'03 Slovak University of Technology in Bratislava, Štrbskė Pleso, Slovakia,