Experimental Identification of the Mathematical Model of the DC Motor based on the Genetic Algorithm

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Abstract

In this paper it is presented the experimental identification of the mathematical model of the DC motor. The experimental curve of the DC motor was raised and it was proposed to be approximated with transfer function with inertia of the second and the third order. For identification procedure it was used the genetic algorithm. As objective functions there are proposed to be used the Mean of the Squared Error, Integral of Time multiplied by Absolute Error, Integral of Absolute Magnitude of the Error, and Integral of the Squared Error.

Keywords: experimental identification, transfer function with inertia, DC motor, genetic algorithm, objective functions.

1. Introduction

The practice of the automation of the various technological processes demonstrates that a lot of processes are complex and the experimental identification is the only one solution to obtain the mathematical model that describes the control process. Experimental identification supposes that mathematical model is obtained based on the experimental data achieved from the control process as input and output signals.

There are developed many methods that can be used in the experimental identification of the mathematical model, which approximate the industrial process by the transfer functions with the second and the third order inertia.

Nowadays the artificial intelligence approaches such as evolutionary algorithms are started to be used widely in different areas for solving diverse engineering problems [1].

In this paper, it was proposed to use the genetic algorithm for estimation of the mathematical model of the DC motor. It was proposed to be done the comparation of the different fitness functions for estimation of the mathematical model by the Mean of the Squared Error, Integral of Time multiplied by Absolute Error, Integral of Absolute Magnitude of the Error, and Integral of the Squared Error.

2. Genetic Algorithm Description

Evolutionary algorithms represent the search and optimization algorithms that are inspired from the biological principles as: natural selection and genetics [1]. Genetic algorithms are a particular type of evolutionary algorithms that have strong search capabilities, being stochastic global search methods that mimic the process of natural evolution, where a population of candidate solutions to a target problem is evolving.

Genetic algorithm manipulates not just with one potential solution to a problem but a collection of potential solutions that is known as population. Every solution corresponds to a chromosome and each parameter represents a gene, where genetic algorithm evaluates the fitness of each individual in the population using a fitness (objective) function.

The genetic algorithm uses the genetic operators such as *selection, crossover* and *mutation* for the generation of the new chromosomes from the existing population.

The *selection mechanism* for parent chromosomes takes the fitness of the parent into account and this will ensure that the better solution will have a higher chance to procreate and donate their beneficial characteristic to their offspring.

After selection mechanism the *crossover operation* goes, that swaps certain parts of the two selected chromosomes in a bid to capture the good parts of old chromosomes and create better new ones.

The last evolutionary operator is *mutation*, in which one or multiple genes from chromosome are altered. The mutation operator maintains the diversity of population by introducing another level of randomness. In fact, this operator prevents solutions to become similar and increase the probability of avoiding sub-optimum solutions in the algorithm.

3. The Objective Function in Identification Process

The implementation of the procedure of the identification of the mathematical model, based on the genetic algorithm that approximates the control process, starts with definition of the chromosome representation. It was proposed to use in identification procedure the two types of transfer functions:

1. Model of object with inertia of the second order:

$$H(s) = \frac{k}{(T_1 s+1)(T_2 s+1)}, \quad (1)$$

where k is the transfer coefficient of the model, T_1, T_2 – time constants.

In this case the chromosome is formed by three parameters that correspond to the transfer coefficient - k and time constants – T_1, T_2.

2. Model of object with inertia of the third order.

$$H(s) = \frac{k}{(T_1 s+1)(T_2 s+1)(T_2 s+1)}, \quad (2)$$

where k is the transfer coefficient, T_1, T_2, T_3 – time constants.

In this case the chromosome is formed by three parameters that correspond to the transfer coefficient – k and time constants – T_1, T_2, T_3.

The objective is to minimize the error between real output from the process and the output from the model.

In the process of estimation the mathematical model of the control process uses different objective functions as Mean of the Squared Error (MSE), Integral of Time multiplied by Absolute Error (ITAE), Integral of Absolute Magnitude of the Error (IAE), and Integral of the Squared Error (ISE) [2]:

$$MSE = \frac{1}{t}\int_0^t (e(t))^2\,dt, \quad (4)$$

$$ITAE = \int_0^t t|e(t)|\,dt, \quad (5)$$

$$IAE = \int_0^t |e(t)|\,dt, \quad (6)$$

$$ISE = \int_0^t e(t)^2\,dt, \quad (7)$$

$$ITSE = \int_0^t te(t)^2\,dt, \quad (8)$$

where $e(t)$ – is the error between real output from process and output from model.

4. Experimental Data Acquisition

As DC motor it was chosen the FK130SH motor for testing several reaction wheels. The system was implemented based on the NUCLEO-F303K8 platform from ST Microelectronics and the reaction wheel is coupled directly to the motor. The speed of the motor coupled with the reaction wheel is controlled by the STM32F303K8 microcontroller.

The experimental identification involves the acquisition of data, so that the experimental variation of the DC motor speeds at the reference speed of 7330 rpm was obtained as presented in the Figure 1.

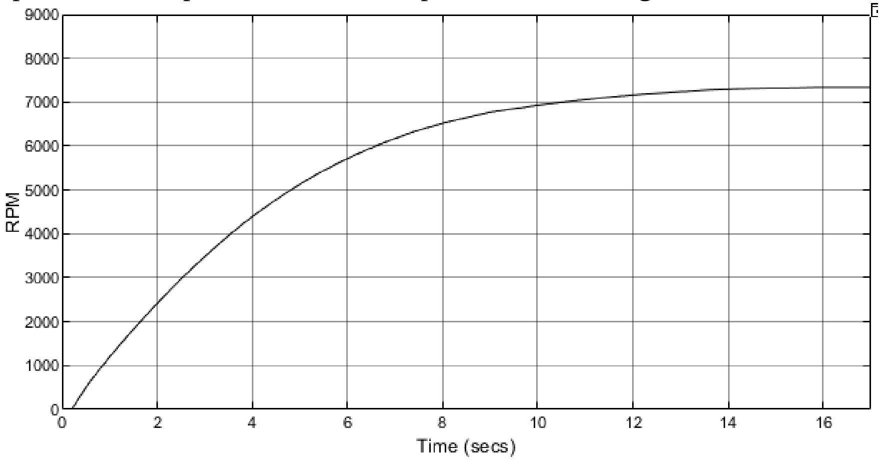

Figure 1. Experimental curve

5. Experimental Identification based on Genetic Algorithm

Based on the experimental curve presented in Figure 1, it was performed the experimental identification using the genetic algorithm. It was proposed to approximate the experimental curve with model of object with inertia of the second order and the third order (transfer functions (1) – (2)). For identification and evaluation of the obtained mathematical models there were used different objective functions as MSE, ITAE, IAE and ISE. The obtained results of experimental identification according to the genetic algorithm and different objective functions are presented in Table 1 and Table 2.

Table 1. Model of Object with Inertia of the Second Order

No.	Objective functions	k	T_1	T_2	Error
1	MSE	1.042	3.749	0.682	1.7%
2	ITAE	1.078	0.209	6.056	8.3%
3	IAE	1.814	73.084	0.669	divergent
4	ISE	0.973	1.458	2.35	2.7%
5	ITSE	1.027	0.522	3.871	0.95%

Table 2. Model of Object with Inertia of the Third Order

No.	Objective functions	k	T_1	T_2	T_3	*Error*
1	MSE	1.026	0.595	3.656	0.283	2.14%
2	ITAE	1.772	0.272	86.3	0.306	divergent
3	IAE	1.879	0.035	78.444	0.043	divergent
4	ISE	1.435	0.196	0.016	32.782	divergent
5	ITSE	1.436	48.791	0.59	0.937	divergent

In Figure 2 and Figure 3 there is presented the obtained transient process in comparison with the original experimental curve. The numbering of the curves corresponds to the numbering from Table 1 and Table 2.

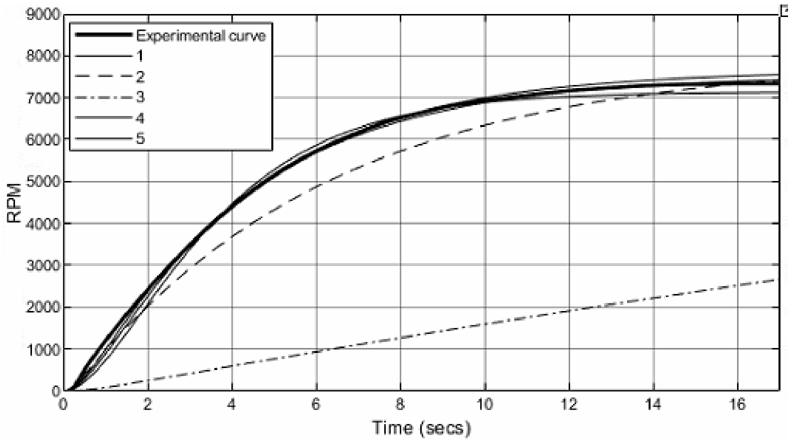

Figure 2. Transient processes in case of approximation with model of object with inertia of the second order

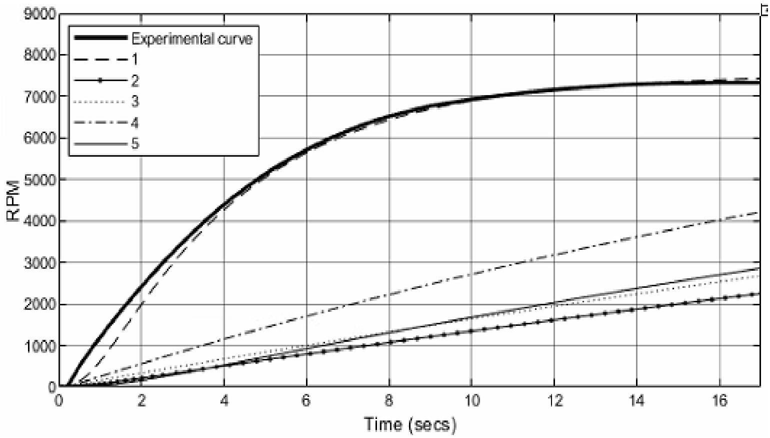

Figure 3. Transient processes in case of approximation with model of object with inertia of the third order

5. Conclusion

In this work it was proposed to be performed the experimental identification of the mathematical model of the DC motor by the genetic algorithm. It was proposed to approximate the experimental curve with model of object with inertia of the second and the third order and it was done the comparison between different objective functions. It was observed that the best results were obtained for the case of approximation of the experimental curve with model of object with inertia of the second order and the best results are obtained for the case of using the MSE and ISE objective functions.

References

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