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GENETIC ALGORITHMS APPLIED IN PARAMETERS DETERMINATION OF THE 3D CRANE MODEL *

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Abstract. *This paper considers the implementation of the genetic algorithms in determine parameters of model 3D Crane system, defined by highly nonlinear mathematical model. The validation of the model and parameters are performed by digital simulation and comparison with the experimental results. Proposed method for determining parameters of the model has many advantages, such as satisfactory control performance under a wide range of operating conditions, reducing fluctuations during the positioning of payload cart.*

Key words: *genetic algorithms, 3D crane system*

1. INTRODUCTION

The genetic algorithms are well known evolutionary search algorithms implemented in many control engineering problems [1-3]. Since genetic algorithms represent optimization procedures, they can be applied to identification problems.

There are two inter-related problems existing in system identification: the choice of a suitable model structure and the estimation of model parameters. Techniques for the selection of structure and for non-linear in the parameters estimation are still the subject of

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ongoing research [4]. There are many classical methods for system identification, such as least-squares and maximum-likelihood. Most of these are for linear or linear in the parameters non-linear systems, and they often fails in the search for a global optimum if the search space is not differentiable or linear in parameters. Furthermore, for these methods, initial information on the system parameters is needed for convergence; estimated parameters may be biased if the noise is correlated; and they cannot easily be applied to nonlinear systems.

The genetic algorithms can be applied to continuous and discrete-time system, both on-line and off-line and both time domain and frequency domain systems, and can directly identify physical parameters or poles and zeroes of the system. In this paper, one genetic algorithm is implemented in the parameters model of 3D crane, which represents the highly nonlinear plants.

2. 3D CRANE DESCRIPTION

The 3D crane [5] shown in Fig. 1 is a non-linear electromechanical system having a complex dynamic behavior and creating challenging control problems. The system is controlled from a PC. Therefore it is delivered with hardware and software which can be easily mounted and installed in a laboratory. You obtain the mechanical unit with power supply and interface to a PC and the dedicated A/D, D/A board configured in the Xilinx® technology. The software operates under MS Windows® NT using MATLAB® and RTWT toolbox package.

The 3D Crane setup consists of a payload hanging on a pendulum-like lift-line wound by a motor mounted on a cart. The payload is lifted and lowered in the z direction. Both the rail and the cart are capable of horizontal motion in the x direction. The cart is capable of horizontal motion along the rail in the y direction. Therefore the payload attached to the end of the lift-line can move freely in three dimensions. The 3D crane is driven by three DC motors. There are five identical measuring encoders measuring five state variables: the cart coordinates on the horizontal plane, the lift-line length, and two deviation angles of the payload.

Fig. 1 3D crane system by Inteco

The encoders measure movements with a high resolution equal to 4096 pulses per rotation (ppr). These encoders together with the specialized mechanical solution create a unique measurement unit. The deviation of the load is measured with a high accuracy equal to 0.0015 rad.

The power interface amplifies the control signals which are transmitted from the PC to the DC motors. It also converts the encoders pulse signals to the digital 16-bit form to be read by the PC.

The PC equipped with the RT-DAC/PCI multipurpose digital I/O board communicates with the power interface board. The whole logic necessary to activate and read the encoder signals and to generate the appropriate sequence of pulses of PWM to control the DC motors is configured in the Xilinx chip of the RT-DAC/PCI board. All functions of the board are accessed from the 3D Crane Toolbox which operates directly in the MATLAB®/Simulink® environment.

The user has a rapid access to all basic functions of the 3DCrane control system from the Main Control Window. It includes tests, drivers, models and application examples. The main driver is located in the RTWT Device Driver column. The driver is a software go-between for the real crane MATLAB environment and the RT-DAC/PCI acquisition board.

The driver has three PWM inputs (DC motor controls) for the X, Y and Z axes. There are 8 outputs of the driver: X position, Y position, Z position, two angles and additionally three safety switches. According to a pre-programmed logic the internal XILINX program of the RT-DAC/PCI board can use the switches to stop the DC motors. When one wants to build his own application one can copy this driver to a new model.

The schematic diagram of the 3D crane system is shown on Fig. 2.

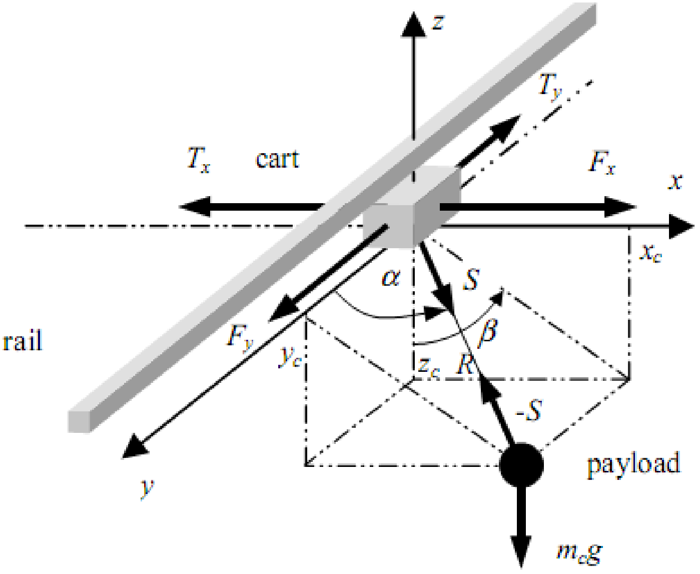

Fig. 2 3D crane system: coordinates and forces

Denote also: m_c - mass of the payload; m_w - mass of the cart; m_v - mass of the moving rail; x_c, y_c, z_c - coordinates of the payload; S - reaction force in the lift-line acting on the cart; F_x - force driving the cart; F_y - force driving the rail with cart; F_R - force controlling the length of the lift-line; T_x, T_y, T_R - friction forces. The following symbols are used in the sequel:

$$\mu_1 = \frac{m_c}{m_w},\ \mu_2 = \frac{m_c}{m_w + m_s}, \tag{1}$$

$$u_1 = \frac{F_x}{m_w},\ u_2 = \frac{F_y}{m_w + m_s},\ u_3 = \frac{F_R}{m_c}, \tag{2}$$

$$T_1 = \frac{T_x}{m_w}, T_2 = \frac{T_y}{m_w + m_s}, T_3 = \frac{T_R}{m_c}, \tag{3}$$

$$N_1 = u_1 - T_1, N_2 = u_2 - T_2, N_3 = u_3 - T_3\,. \tag{4}$$

The position of the payload is described by the equalities:

$$x_c = x_w + R\cos\alpha\,, \tag{5}$$

$$y_c = y_w + R\sin\alpha\sin\beta\,, \tag{6}$$

$$z_c = -R\sin\alpha\cos\beta\,. \tag{7}$$

The dynamic of the crane is given by the equations (Fig. 2):

$$\begin{aligned} m_c\ddot{x}_c &= -S_x \\ m_c\ddot{y}_c &= -S_y \\ m_c\ddot{z}_c &= -S_z - m_c g \\ m_w\ddot{x}_w &= F_x - T_x + S_x \\ (m_w + m_s)\ddot{x}_w &= F_y - T_y + S_y \end{aligned}\quad , \tag{8}$$

where S_x, S_y and S_z are components of the force S:

$$\begin{aligned} S_x &= S\cos\alpha \\ S_y &= S\sin\alpha\sin\beta \\ S_z &= -S\sin\alpha\cos\beta \end{aligned}\quad . \tag{9}$$

3. GENETIC ALGORITHM

The principles of the genetic algorithms were first published by Holland in 1962 [6]. The mathematical framework was developed in the late 1960's, and is presented in Holland's book, *Adaptation in Natural and Artificial Systems* published in 1975 [7].

Genetic algorithms are optimization techniques based on simulating the phenomena that takes place in the evolution of species and adapting it to an optimization problem. These techniques imply applying the laws of natural selection onto the population to achieve individuals that are better adjusted to their environment. The population is nothing more than a set of points in the search space. Each individual of the population represents a point in that space by means of his chromosome. The individual's degree of adaptation is given by the objective function. Applying genetic operators to an initial population simulates the evolution mechanism of individuals. "Survival of the fittest" philosophy is used to speed up the evaluation process.

The genetic algorithms have been used in many diverse areas such as function optimization, image processing, system identification, system modeling..., and have demonstrated very good performances as global optimizers in many types of applications [8-11]. In order to understand more details about how are used genetic algorithms in our work [7, 12].

4. EXPERIMENTAL RESULTS

The cart velocities in *X* and *Y* directions are much alike. The payload moves slower down and up. The angles of the payload are not closed-loop controlled and in consequence the payload oscillates freely. That the payload would not fluctuate, it is projected a classic PI controller for all three axes [5], i.e., x, y, z. The following simple linear model of the crane dynamics in the *X*-axis, *Y*-axis, *Z*-axis are assumed:

$$\begin{gathered} G_x(s) = \frac{K_x}{s(T_x s + 1)} \\ G_y(s) = \frac{K_y}{s(T_y s + 1)} \\ G_z(s) = \frac{K_z}{s(T_z s + 1)} \end{gathered} . \tag{10}$$

Model parameters values are determined by genetic algorithm and compared with parameters obtained from the MATLAB Toolbox. Schematic picture of the whole 3D Crane system in MATLAB environment is shown in Fig. 3.

During the process of parameter identification of the controller in our experiments, as a criteria function, mean squared error can be used:

$$J = \frac{1}{T}\int_0^T (\theta_i - \theta_i^m)^2 \, dt , \tag{11}$$

where θ_i represent the measured position for the x, y and z axis of the cart and θ_i^m represent of the simulation results for position for the x, y and z of the cart. Parameters of the controller are obtained by adjusting the model in order to minimize the criteria function (11) by the genetic algorithm. The complete block diagram, which illustrates the process of identification [9, 13], is given in Fig. 4.

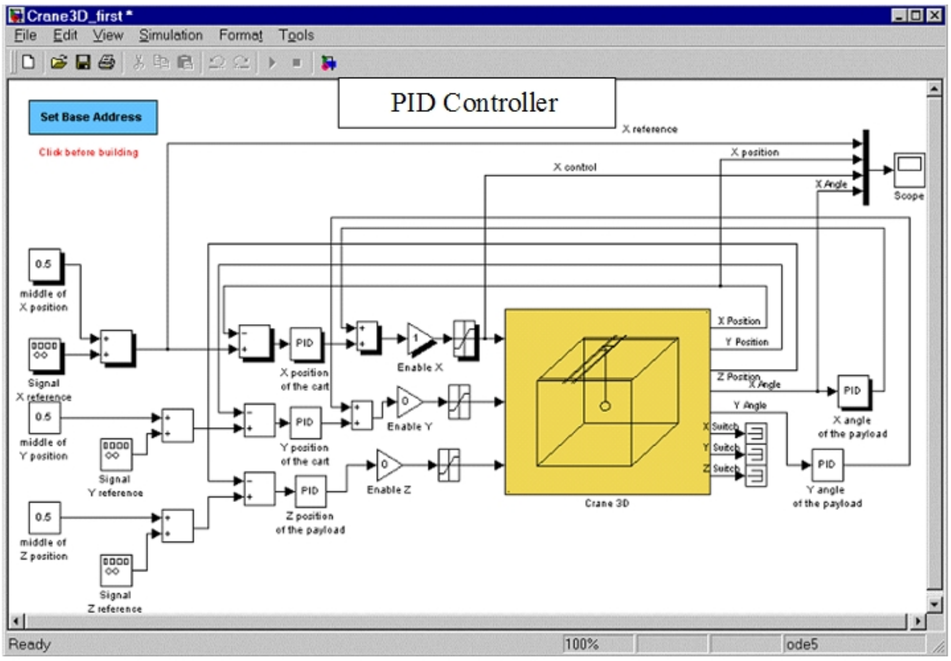

Fig. 3 Schematic window in MATLAB of the 3D Crane

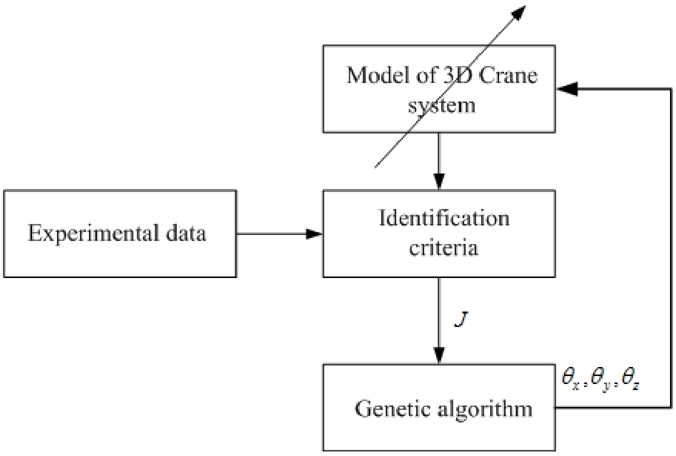

Fig. 4 Priniciple of parameters controller identification

The genetic algorithm used in our experiments was with the following parameters: initial population of 300, number of generations 200, stochastic uniform selection, reproduction with 8 elite individuals, Gaussian mutation with shrinking and scattered crossover. The goal of the experiment was to make a error as small as possible for a chosen input, i.e., to obtain the best parameters of the model of 3D crane system. So, we used error (11), as the fitness function for the genetic algorithm.

Experimental time was 30 seconds. After the experiments, following model parameters of 3D Crane system were obtained: parameters for X axes $K_x = 0.1697$, $T_x = 0.7122$, parameters for Y axes $K_y = 0.1711$, $T_y = 0.1272$, and for Z axes $K_z = 0.1022$, $T_z = 0.0174$ when payload is lifted. These results are used in digital simulation in order to validate the proposed solution.

The results of the payload positions after optimisation by using genetic algorithm are shown on the following Figures.

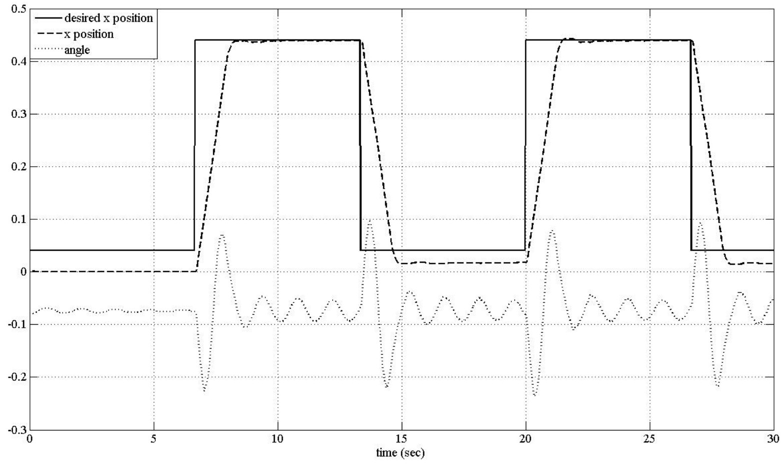

Fig. 5 Desired x position of the cart and x angle of the payload are tracked

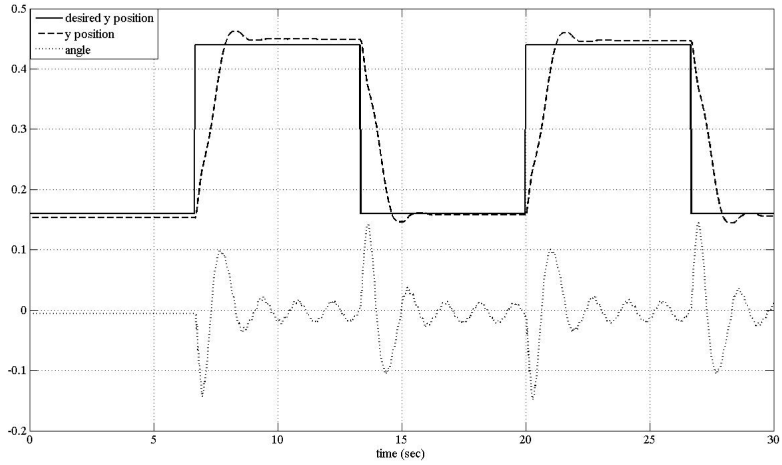

Fig. 6 Desired y position of the cart and y angle of the payload are tracked

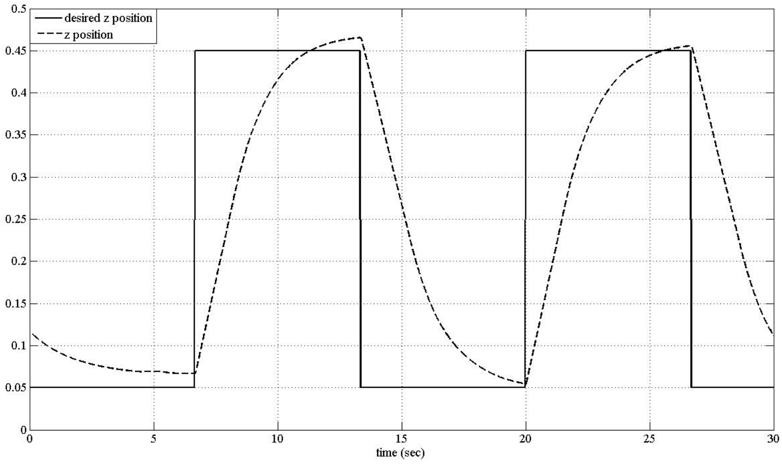

Fig. 7 Desired *z* position of the cart

5. CONCLUSION

This paper treats the problem of determining model parameters for calm simultaneously stabilizes the payload in its hanging down position a cart of 3D crane system by using genetic algorithm optimisation techniques. The system model is highly nonlinear, so the traditional identification techniques can fail in estimation process. The proposed genetic algorithm requires nothing more than position measure and do not pose any restrictions to the identification problem. The obtained parameter values are used in digital simulation and the model verification is done by comparing the experimental data with simulated ones. The proposed genetic algorithm gives good accuracy in estimation of the model parameters.

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ODREĐIVANJE PARAMETARA MODELA 3D KRANA KORIŠĆENJEM GENETIČKIH ALGORITAMA

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U ovom radu razmatra se primena genetičkog algoritma pri određivanju parametara modela 3D krana, definisanog kao visoko nelinearnog sistema. Validnost modela i parametara potvrđena je simulacijom i upoređena je sa eksperimentalnim rezultatima. Predloženi način određivanja parametara modela ima mnoge prednosti, kao što su zadovoljavajuće performanse u širokim uslovima rada, smanjenje oscilacija tereta prilikom pozicioniranja kolica.

Ključne reči: *genetički algoritmi, 3D kran sistem*