Identification of the Multitank System Using Genetic Algorithm

Darko Mitić[1], Dragan Antić[2], Saša Nikolić[3] and Marko Milojković[4]

Abstract – **The paper considers the implementation of the genetic algorithms in parameter identification of three tank hydraulic system, defined by highly nonlinear mathematical model. The output orifice resistances and the flow coefficients are estimated for all tanks, based on the experimental measured data. The validation of the model and parameters are performed by digital simulation and comparison with the experimental results.**

Keywords – **Identification, Genetic algorithm, Multitank System.**

I. INTRODUCTION

Genetic Algorithms (GAs) are well known evolutionary search algorithms implemented in many control engineering problems [1, 2]. Since GAs 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 ongoing research [3]. 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.

GAs 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 GA is implemented in the parameter identification of the three tank hydraulic system, which represents the highly nonlinear plants.

The paper is organized as follows. The problem formulation is given in Section 2 including the statement of the plant nonlinear model. Section 3 describes the used GA briefly. Experimental framework is presented in Section 4 both with the results of the identification. Section 5 summarizes the results.

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II. PROBLEM STATEMENT

A. *Three Tank System Description*

Three-tank system has been proposed as a benchmark system for system modeling, identification, control, fault detection and diagnosis, as well as for fault-tolerant control. The system exhibits typical characteristics of a constrained hybrid system and has been proven useful to serve as a test environment for algorithms concerning state estimation, parameter identification, and control systems. Such a system can be viewed as a prototype of many industrial applications in process industry, such as (petro) chemical plants and oil, and gas systems.

The plant corresponds to the multitank systems manufactured by Inteco, Poland [4]. The multitank system (Fig. 1) comprises a number of separate tanks fitted with drain valves. The separate tank mounted in the base of the set-up acts as a water reservoir for the system. Some of the tanks have a constant cross section, while others are spherical or conical, so having variable cross section. This creates main nonlinearities of the system. A variable speed pump is used to fill the upper tank. The liquid outflows the tanks due to gravity. The tank valves act as flow resistors. The area ratio of the valves is controlled and can be used to vary the outflow characteristic. Each tank is equipped with a level sensor based on hydraulic pressure measurement.

The multitank system relates to liquid level control problems commonly occurring in industrial storage tanks. For example, steel producing companies around the world have repeatedly confirmed that substantial benefits are gained from accurate mould level control in continuous bloom casting. Mould level oscillations tend to stir foreign particles and flux powder into molten metal, resulting in surface defects in the final product. The Multitank System has been designed to operate with an external, PC-based digital controller. The control computer communicates with the level sensors, valves and pump by a dedicated I/O board and the power interface. The I/O board is controlled by the real-time software which operates in MATLAB®/Simulink RTW/RTWT® rapid prototyping environment.

Fig. 1. The Multitank system by Inteco

B. The Mathematical Model

The three tank system depicted in Fig. 2. can be decribed using the well known “mass balance” equations:

$$\frac{dH_1}{dt} = \frac{1}{\beta_1(H_1)} q - \frac{1}{\beta_1(H_1)} C_1 H_1^{\alpha_1} \quad (1)$$

$$\frac{dH_2}{dt} = \frac{1}{\beta_2(H_2)} C_1 H_1^{\alpha_1} - \frac{1}{\beta_2(H_2)} C_2 H_2^{\alpha_2} \quad (2)$$

$$\frac{dH_3}{dt} = \frac{1}{\beta_3(H_3)} C_2 H_2^{\alpha_2} - \frac{1}{\beta_3(H_3)} C_3 H_3^{\alpha_3} \quad (3)$$

where q represents inflow to the upper tank, H_i is the fluid level in the *i*-th tank (*i*=1,2,3), C_i is the resistance of the output orifice of *i*-th tank, α_i represents the flow coefficient for the *i*-th tank.

$\beta_i(H_i)$ represents the cross sectional area of *i*-th tank at the level H_i. These values for the single tanks are the following: $\beta_1(H_1) = aw$ is the constant cross sectional area of the upper tank; $\beta_2(H_2) = cw + \frac{H_2}{H_{2\max}} bw$ is the variable cross sectional area for the middle tank, and $\beta_3(H_3) = w\sqrt{R^2 - (R - H_3)^2}$ is the variable cross sectional area of the lower tank.

The specified parameter values are the following: $a = 0.25m,\ b = 0.345m,\ c = 0.1m,\ w = 0.035m,\ R = 0.364m$, and $H_{1\max} = H_{2\max} = H_{3\max} = 0.35m$.

Liquid levels in the tanks H_1, H_2, H_3 are the state variables of the system. There are four controlled inputs: liquid inflow q and valves settings C_1, C_2, C_3. The goal of the identification is to determine values of parameters C_i and α_i (*i*=1,2,3).

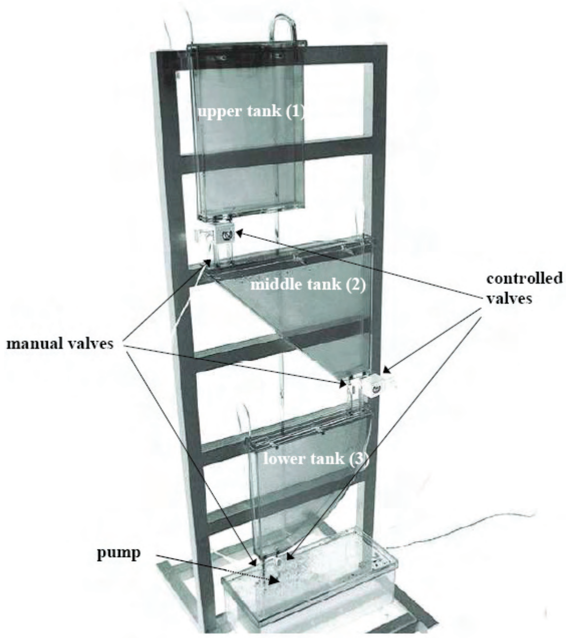

Fig. 2. Plant structure

III. GENETIC ALGORITHM

The principles of the genetic algorithms were first published by Holland in 1962 [5]. 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 [6].

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 [7-10].

The genetic algorithm used in our experiments was with the following parameters: initial population of 400, number of generations 200, stochastic uniform selection, reproduction with 10 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 hydraulic system. So, we used error as the fitness function for the genetic algorithm.

IV. EXPERIMENTAL RESULTS

The tank system consists of a number of tanks placed above each other (Fig. 2). Some of the tanks have a constant cross section, while others are spherical or prismatic, so having variable cross section. Liquid is pumped into the upper tank from the supply tank by the pump driven by a DC motor. The liquid outflows the tanks only due to gravity. The output orifices act as flow resistors, but can also be controlled from the computer.

The levels in the tanks are measured with pressure transducers. The signals from the sensors are connected to the analog inputs of the RT-DAC4 multipurpose PC I/O board. There are four control signals send out from the board to the multitank system: three valve controls and one pump control signal. The appropriate PWM control signals are transmitted from digital outputs of the I/O board to the power interface, and next to the valves and to the DC motor. The speed of the pump motor is controlled by a sequence of PWM pulses configured and generated by the logic of XILINX chip of the RT-DAC4 board.

The plant is closed system, where the liquid that enters the reservoir from the tanks returns to the tanks via the pumps. However, these pumps will be switched off automatically when the liquid level of upper tank or lower tank exceeds a given upper limit.

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

$$J = \frac{1}{T}\int_0^T \left(H_k - H_k^m\right)^2 dt \qquad (4)$$

where H_k represent the measured liquid level for the *k*-th tank and H_k^m represent of the simulation results for the same tank. Parameters of the hydraulic system are obtained by adjusting the model in order to minimize the criteria function (4) by the genetic algorithm.

The complete block diagram, which illustrates the process of identification, is given in Fig. 3.

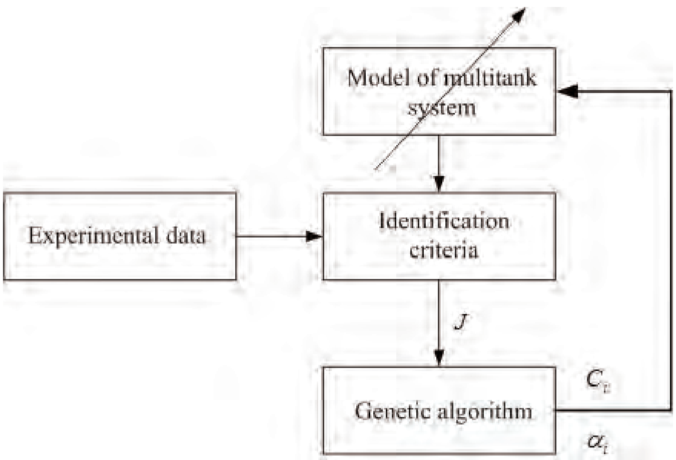

Fig. 3. Priniciple of tank parameters identification

For fixed valves settings the parameters C_i and α_i (i=1,2,3) of the mathematical models of the tank system have to be identified experimentally by using the genetic algorithm. Experimental time was 60 seconds. For each tank the outflow experiment has been performed, the data are collected and the characteristic curves has been fitted to the data.

After the experiments, following parameters for the multitank system were obtained: for upper tank $C_1 = 6.9501\cdot 10^{-5}$, $\alpha_1 = 0.33692$, for middle tank $C_2 = 6.3214\cdot 10^{-5}$, $\alpha_2 = 0.30125$, and for bottom tank $C_3 = 6.3954\cdot 10^{-5}$, $\alpha_3 = 0.32478$.

These results are used in digital simulation in order to validate the proposed solution. Figures 4, 5 and 6 present both the measured and simulation liquid levels of three tanks, respectively. It is obvious that the proposed GA gives good accuracy in estimation of the system parameters. Some larger error in the end of the experiment can be explained as the consequence of additional nonlinearities arising on the low levels of liquid in the tanks.

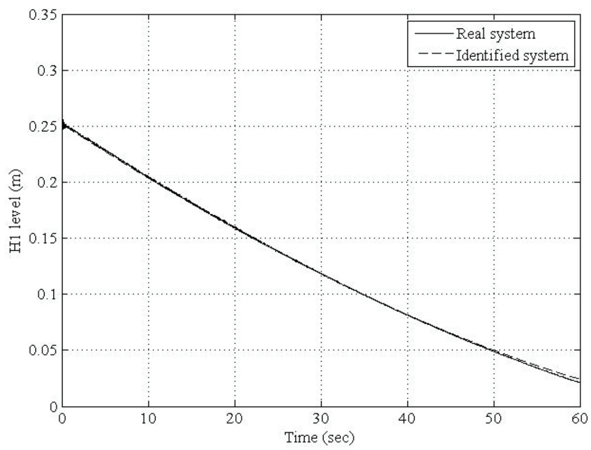

Fig. 4. The upper tank

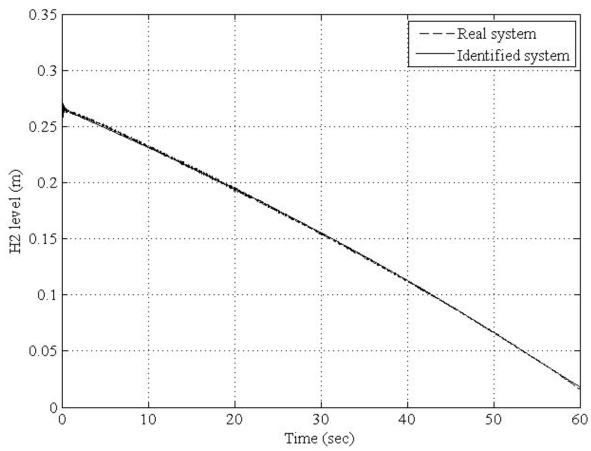

Fig. 5. The middle tank

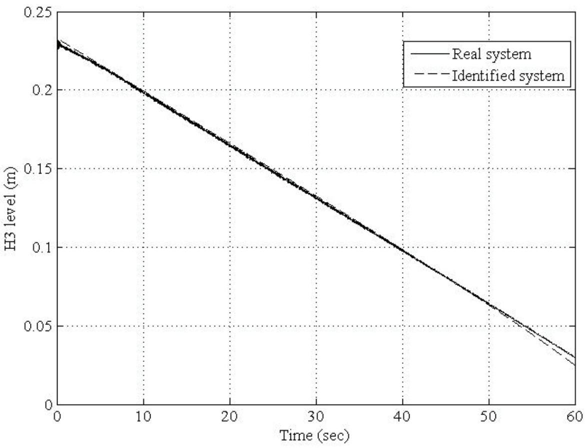

Fig. 6. The bottom tank

V. Conclusion

The paper treats the problem of parameter identification of hydraulic system consisting of three tanks 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 lyquid levels 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 GA gives good accuracy in estimation of the system parameters.

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