

System Identification of Model Steel Bridge with Genetic Algorithms

Sertaç TUHTA¹, Furkan GÜNDAY², Hakan AYDIN³

^{1,2,3}*Department of Civil Engineering, Ondokuz Mayıs University, Turkey*

Abstract—Today, civil engineering structures suffer from dynamic effects. Earth on structures have been severely damaged by the earthquake. Thus, there has been loss of life and property. This has particularly affected countries located on active fault lines. Pre- and post-earthquake measures have been developed in world. For these reasons, it is necessary to determine the dynamic performance of structures around the world. There are various methods for determine the dynamic performance. System identification is one of these methods. Mathematical model of the structural system is obtained by system identification method. Genetic algorithms can be a system identification method. It is known as genetic algorithms, an algorithm for the mathematical projection of the natural, in other words, Genetic algorithms are a part of Artificial Intelligence. In this study, steel model bridge was used as test subject. MATLAB software is used. In this study, it is aimed to estimate the output of steel model bridge with genetic algorithms. As a result of study, it was observed that a nearly 99% compliance was achieved.SAE is %0.78548.In the light of all results, it is seen that genetic algorithms method will be useful in system identification method in civil engineering field.

Keywords—System Identification, Genetic Algorithms, ARX Model, Steel Bridge

I. INTRODUCTION

Most of structures located in regions prone to earthquake hazards suffer from various types of destruction caused by seismic loads. Under such earthquake occurring [5]. There are many studies that take this into account. In the regions of seismic hazards, structures are expected to have vibrations due to seismic loads [15]. In civil engineering field, currently there are many varieties of structural and architectural structures. Such structures can be managed to resist to both static and dynamic loads effectively [16]. More work should be done to clarify the performance of structures under seismic loads [13]. More researches are being conducted to get required performance of structures under seismic loading, by means of looking at different point of view and directions [14]. In recent years, in the world and our country, the determination of the effect of vibrations on structures and structural behavior has become very important [17]. Buildings located in seismically active regions are under high risk of severe damages caused by harmful earthquake loads [6]. Civil engineering structures are exposed to a variety of natural and artificial effects throughout their lifetime. These effects are the forces that can affect the dynamic characteristics of the structure and thus the service life [18]. In all construction systems, damage starts at the material level. As the damage in the system increases, it reaches a value defined as

deterioration [19]. Generally forced and ambient vibration methods are used in the purpose of vibration testing of structures [20]. The authors pointed out the reasons for their studies. The authors also pointed out that this point should be focused on. This study was carried out considering these negative situations.

System identification (SI) is a modeling process for an unknown system based on a set of input outputs and is used in various engineering fields [8], [9]. Subspace system identification is introduced as a powerful black-box system identification tool for structures [21]. The application of the method for supporting excited structures is emphasized in particular. The black- box state- space models derived from the identification of subspace systems are used to estimate the modal properties (i.e. modal damping, modal frequency and mode shapes) of the structures [7], [10].

Depending on the input and output sizes of these systems, in order to obtain a behavioral model, it is necessary to determine and measure the magnitudes affecting the structures. Model identification, system-related, based on physical laws based on the preliminary information and the size of the system (introduction magnitude or input signal) from the system's response to these magnitudes (output magnitude or output signal) It is exploited. Physical laws are defined by differential or algebraic equations. In this way model, not only the relationship between the input and output sizes, but also by determining the model structure are expressed. On the other hand, the lack of any preliminary information about the system or the system is too complex. In case of having, identification methods (such as parametric definition) are used in determining the model of the system. In this case, the model is obtained by using input and output sizes. This technique can be applied by making some preliminary assumptions regarding the choice of system grade, input and output sizes [12].

Bridges are a must among transportation structures. Indispensable in our lives. Secure bridge design is therefore very important. Further periodic maintenance is also very important, rather than the initial design. Therefore, the current status of the bridges needs to be determined quite accurately. However, correct diagnosis and correct periodic maintenance and retrofitting can be performed. It is also known that bridges are highly exposed to dynamic loads. System identification of bridges is of high importance for all these reasons. In this study, the acceleration response (output

acceleration) of a steel bridge sample was investigated experimentally and by genetic algorithms method.

The genetic algorithm is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution. You can apply the genetic algorithm to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective function is discontinuous, nondifferentiable, stochastic, or highly nonlinear. The genetic algorithm can address problems of mixed integer programming, where some components are restricted to be integer-valued.[4].

In this study, it is aimed to examine an example of genetic algorithms method which is an innovative and modern method.

II. METHODOLOGY

In this section theoretical background of genetic algorithm is explained.

Principles of Genetic Algorithms

In Matlab, GA primarily addresses the following steps. The algorithm begins by creating a random initial set. Then creates a series of new residents. At each step, the algorithm uses members of the current generation to form the next group. To create a new community, the algorithm performs the following steps:

- Fitness records every member of the current population via a fitness account. These values are called raw fitness points.
- Fitness scales to convert initial fitness marks to a more useful value range. These measured values are called prediction values.
- Parents choose members called parents according to their expectations.
- Population some people with low physical fitness in the current population were selected as elites. These elite individuals move to the next population.
- Parents produce children from parents. Children are produced by making random changes to a single parent mutation or by combining the input vectors of a pair of parental passages.
- Generation replaces the current population with children to create a new generation.

The algorithm stops when one of the stop criteria is met. See the "Stop conditions" section for the algorithm.

Genetic Algorithm Terminology

- Fitness function is the function you want to improve. For standard optimization algorithms, a goal is known as a function. The toolbox program tries to find the minimum compliance function. Type the matching function as an unknown file or function and pass it to the main genetic algorithm function as an argument for a function identifier.
- The individual is any point where you can apply the fitness function. The value of an individual's fitness function is his group. For example, the $f(x_1, x_2, x_3) = (2x_1+1)^2 + (3x_2+4)^2 + (x_3+1)^2$ the vector $(2, 1, 3)$, whose length is the number of variables in the problem, is an individual. The score of the individual $(2, 1, 3)$ is $f(2, 1, 3) = 90$. An individual is sometimes referred to as a genome, and an individual is also called a vector gene.
- The population is a group of individuals. For example, if the population size is 50 and the number of variables in the fitness function is 2, you represent the population with a matrix of 50 to 2. An individual may appear the same more than once in the population. For example, an individual $(2, 1, 3)$ may appear in multiple rows of an array.
- With each update, the genetic algorithm implements a series of calculations on existing populations to create a new society. Each consecutive population is called a new generation.
- Diversity refers to the average distance between individuals of the population. If the average distance is large, the diversity of the population is high; otherwise, the variety is low. Diversity is important for the genetic algorithm because it allows the algorithm to search for a wider area of the field.
- The fitness value of an individual is the value of the fitness function of that individual. Because the Toolbox program finds minimal fitness functions, the best value for the population is the smallest value for anyone in the community.
- To create the next generation, the genetic algorithm selects specific individuals called parents in the current population and uses them to create individuals called children in the next generation. In general, the algorithm is likely to choose parents who have better fitness values.

Nonlinear ARX Model

Nonlinear ARX models extend linear ARX models to a nonlinear state. The structure of these models allows you to model complex nonlinear behavior using flexible nonlinear functions such as wavelet and sigmoidal networks. For information about when nonlinear models will be available, see about defining nonlinear models. A linear SISO ARX model has the following structure:

$$y(t)+a_1y(t-1) +a_2y(t-2) +\dots+a_nay(t-na) =b_1u(t)+b_2u(t-1) +\dots+b_nbu(t-nb+1) +e(t) \tag{1}$$

Where, u , y and e are the input, output, and noise. This structure implies that the current output $y(t)$ is predicted as a weighted sum of past output values and current and past input values. na is the number of past output terms, and nb is the number of past input terms used to predict the current output. The input delay nk is set to zero to simplify the notation. Rewriting the equation as a product gives:

$$y_p(t)=[-a_1,-a_2,\dots,-a_{na},b_1,b_2,\dots,b_{nb}] * [y(t-1),y(t-2),\dots,y(t-na), u(t),u(t-1),\dots,u(t-nb-1)]^T \tag{2}$$

where $y(t-1),y(t-2),\dots,y(t-na),u(t),u(t-1),\dots,u(t-nb-1)$ are delayed input and output variables, called regressors. The coefficients vector $[-a_1,\dots,b_{nb}]$ represents the weighting applied to these regressors. The linear ARX model thus predicts the current output y_p as a weighted sum of its regressors. The structure of a nonlinear ARX model allows the following additional flexibility: Instead of the weighted sum of the regressors representing a linear entity, the nonlinear ARX model has a more flexible nonlinear mapping function, F .

$$y_p(t)=F(y(t-1),y(t-2),y(t-3),\dots,u(t),u(t-1),u(t-2),\dots) \tag{3}$$

Input F is a regression model. When you select a nonlinear ARX architecture, you can select one of the many nonlinear functions available. For example, F may represent a weighted amount of waves operating at a reference distance from their means. For more information, see Nonlinear estimates available for nonlinear ARX models. Nonlinear ARX processors can contain more complex nonlinear expressions for both delayed input and output variables and delayed input and output variables. Examples of these nonlinear frequencies are $y(t-1)^2$, $u(t-1)*y(t-2)$, $abs(u(t-1))$ and $max(u(t-1)*y(t-3),-10)$. Structure of nonlinear models ARX. The nonlinear ARX model consists of the typical regression units and the nonlinear estimator. The nonlinear estimator includes both linear and nonlinear functions that work on the constraints of the model to output the model. The block diagram represents the structure of the nonlinear ARX model in a simulation scenario. Nonlinear ARX model given in figure 1.

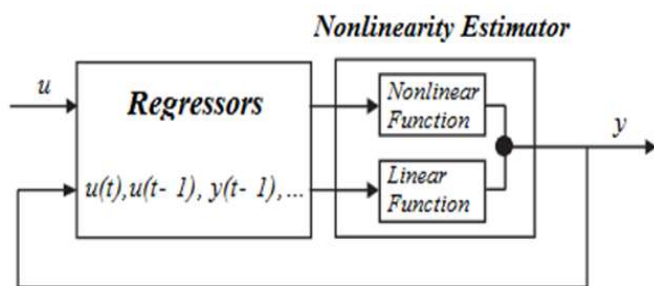


Fig 1. Nonlinear ARX model

The software computes the nonlinear ARX model output y in two stages:

-Calculates regression values from current and historical input values and historical output data. In the simplest case, the input and output undo indicators such as $u(t-1)$ and $y(t-3)$ are reversed. These regressors are called standard regressors. You can specify standard regressors using form commands and delays. For more information, see ARX model written orders and delay. You can also specify custom regressors that are nonlinear functions of input and output lag. For example, $u(t-1)*y(t-3)$. Use Matlab to create a series of polynomial type regressors.

By default, all undo units are entered in both the nonlinear linear and nonlinear function blocks. You can specify a subset of regressors as input to the nonlinear function block.

-Plan the undo units to output the model using a nonlinear estimated block. A nonlinear gradient block may include parallel and nonlinear blocks. For example: $F(x)=L^T(x-r)+d+g(Q(x-r))$ Here, x is a vector of the regressors, and r is the mean of the regressors x . $L^T(x)+d$ is the output of the linear function block and is affine when $d \neq 0$. d is a scalar offset. $g(Q(x-r))$ The block output represents a nonlinear function. Q is a well-calculated projection matrix. The exact shape of $F(x)$ depends on whether you have selected the nonlinear evaluator. You can choose from nonlinear capabilities available, such as tree fragmentation networks, wavelet networks, and multi-layer neural networks. You can also exclude a linear or nonlinear function block from a nonlinear estimator.

When estimating the nonlinear ARX model, the software calculates the values of model parameters such as L , r , d , Q and other parameters that specify g . The resulting nonlinear ARX models are objects that store all form data, including form handlers and nonlinear estimator parameters. For more information about these objects, see typical nonlinear structures.

Nonlinear ARX models are usually used as the black box structure. The nonlinear function of the nonlinear ARX model is a flexible nonlinear estimator with immaterial parameters. You can estimate nonlinear ARX in an application, system ID, or at the command line by using the command. You can use the input and output data in the time domain sampled correctly (without input) to estimate nonlinear ARX models. Your data may contain one or more I/O channels. You cannot use frequency field data to predict. Nonlinear ARX Model Orders and Delay you can use requests and delays for the nonlinear ARX model to determine the standard undo units in the form. Application and delays are defined as follows:

na - Number of past output terms used to predict the current output.

nb - Number of past input terms used to predict the current output.

nk - Delay from input to the output in terms of the number of samples.

The meaning of na , nb and nk is similar to the parameters of

the linear ARX model. Requests are defined as a standard number of SISO data and ny -by- nu mat arrays of MIMO data where ny and nu are the number of outputs and inputs. If you are not sure which values should be used for orders and delays, you can estimate them as described in the pre-step orders- estimating order forms and delaying access. This estimate is based on linear ARX models and provides only initial guidance. The best applications for a linear ARX model may not be the best applications for a nonlinear ARX model. System Identification Toolbox calculates standard undo units using form and delay commands. For example, suppose you specified $na=2$, $nb=3$ and $nk=5$ for the SISO model with u input and y output. The toolbox calculates standard retroactivity tools such as $y(t-2)$, $y(t-1)$, $u(t-5)$, $u(t-6)$ and $u(t-7)$. In addition to standard undo units, you can specify custom undo units. For more information, see estimate nonlinear ARX models in the application and estimate nonlinear ARX models in the command line in Matlab.

III. DESCRIPTION OF MODEL STEEL BRIDGE

The bridge model has a deformed belt geometry. Steel was used as the material in the bridge model. The legs tilted inward along the long axis of the deck provided console operation of the end portions of the deck. The legs have a 45-degree bending. The profiles along the axis of the deck are made of box profile with a thickness of 2.5cm. Round lattices with a thickness of 2 cm are used in trusses. In the Diagonal and Cross Connection elements, iron elements of 10mm and 12mm in diameter are used. In this study, 6.10 m span, 1,88 m high steel model bridge was used. The model steel bridge given in figure2.



Fig 2. Model steel bridge

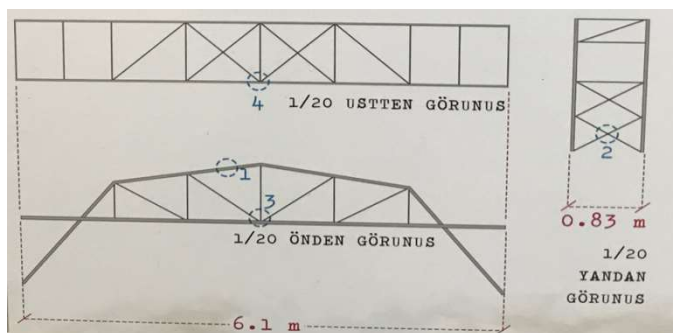


Fig 3. Model steel bridge geometric information

The model steel bridge geometric information given in figure3. The data acquisition units and accelerometers used for measurement are also shown in figure4.



Fig 4. Datalogger and accelerometers

TESTBOX 2010 was used as the data collection device used in experimental measurements.

Experimental data were taken by accelerometers on model steel bridge. Experimental inputs were taken by ground seismometer. Experimental measurements are shown in Figure 2.

IV. ANALYSIS RESULTS

The input values for the model steel bridge experimental measurements are as in figure 6. The input acceleration values were measured from ground level seismometer.

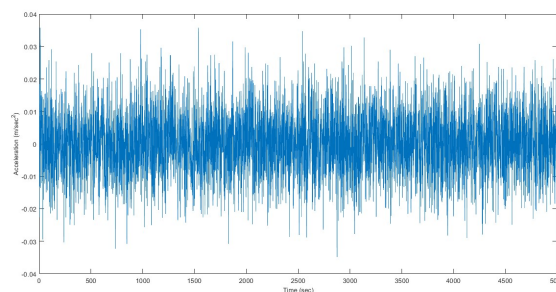


Fig 6. Input

The data used in the geneticalgorithmexamplearegivenbelow.

GA Parameters;

ErrorTolerance=0.4

PopulationSize=30

Mutation Rate=0.2

No of Iterations=50

Discrete-time ARX model: $A(z)y(t) = B(z)u(t) + e(t)$

$$A(z) = 1 + 0.1 z^{-1} + 0.2 z^{-2} + 0.3 z^{-3} + 0.4 z^{-4}$$

$$B(z) = 0.1 z^{-1} + 0.2 z^{-2} + 0.3 z^{-3}$$

Polynomialorders: $na=4$ $nb=3$ $nk=1$ Number of

freecoeficients: 7

$$A = [1 \ 1.9231e-05 \ 0.012036]$$

$$B = [0 \ 0.066949 \ 0.026833]$$

Genetic algorithm was applied to the input data and output was obtained. The resulting output is shown in figure 7.

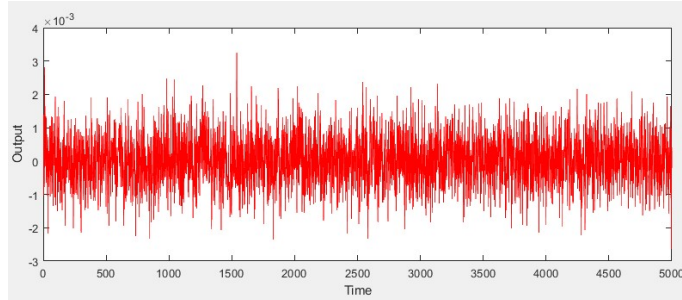


Fig 7. Output from GA

Matlab software and Testlab software were used to obtain the data.

Sum of absolute errors is % 0.78548, SAE=0.78548%.

V. CONCLUSIONS

In order to predict the output data without attempting any experiments were constructed models in genetic algorithms methods. The models were trained with input and output data. Using only input data in trained model steel bridge was predicted successfully.

As a result, model steel bridge's output data can be predicted using genetic algorithms models without attempting any experiments in a quite short period of time with tiny error rates. Sum of absolute error is % 0.78548. These conclusions have shown that genetic algorithms are practicable methods for predicting model steel bridge's output data.

Genetic algorithms can give time and labor practicality to system identification method. It can also provide a modern perspective.

In the light of this information, it can be said that genetic algorithms method can be used for system identification of other civil engineering structures.

REFERENCES

- [1] Marquardt, D. W. (1963). An algorithm for least-squares estimation of nonlinear parameters. *Journal of the society for Industrial and Applied Mathematics*, 11(2), 431-441.
- [2] A. R. Conn, N. I. M. Gould, and Ph. L. Toint. "A Globally Convergent Augmented Lagrangian Algorithm for Optimization with General Constraints and Simple Bounds", *SIAM Journal on Numerical Analysis*, Volume 28, Number 2, pages 545-572, 1991.
- [3] A. R. Conn, N. I. M. Gould, and Ph. L. Toint. "A Globally Convergent Augmented Lagrangian Barrier Algorithm for Optimization with General Inequality Constraints and Simple Bounds", *Mathematics of Computation*, Volume 66, Number 217, pages 261-288, 1997.
- [4] MATLAB. (2010). version 7.10.0 (R2010a). Natick, Massachusetts: The MathWorks Inc.
- [5] Tuhta, S., Gunday F., Aydin H., Dynamic Analysis of Model Steel Structures Retrofitted with GFRP Composites under Microtremor Vibration *International Journal of Trend in Scientific Research and Development (IJTSRD)* Volume: 3 | Issue: 2 | Jan-Feb 2019.
- [6] Tuhta, S., Abrar O., Gunday F., Experimental Study on Behavior of Bench-Scale Steel Structure Retrofitted with CFRP Composites under Ambient Vibration, *European Journal of Engineering Research and Science*, 2019.
- [7] J. Kim, System Identification of Civil Engineering Structures through Wireless Structural Monitoring and Subspace System Identification Methods, PhD thesis, University of Michigan, 2011.
- [8] G.F. Sirca Jr., H. Adeli, System identification in structural engineering, *Scientia Iranica A* (2012) 19 (6), 1355-1364.
- [9] Tuhta, S., &Gunday, F. (2019). Multi Input Multi Output System Identification of Concrete Pavement Using N4SID. *International Journal of Interdisciplinary Innovative Research Development*, 4(1).
- [10] Tuhta, S., Alameri, I., &Gunday, F. (2019). Numerical Algorithms N4SID for System Identification of Buildings. *International Journal of Advanced Research in Engineering Technology Science*, 1(6).
- [11] Tuhta, S., Gunday, F., Aydin, H., &Alalou, M. (2019). MIMO System Identification of MachineFoundation Using N4SID. *International Journal of Interdisciplinary Innovative Research Development*
- [12] Tuhta, S., &Gunday, F. (2019). Mimo System Identification of industrial Building Using N4sid with Ambient Vibration. *International Journal of Innovations in Engineering Research and Technology*.
- [13] Gunday, F., "OMA of RC Industrial Building Retrofitted with CFRP using SSI" *International Journal of Advance Engineering and Research Development*, 2018.
- [14] Gunday, F., "GFRP Retrofitting Effect on the Dynamic Characteristics of Model Steel Structure Using SSI" *International Journal of Advance Engineering and Research Development*, 2018.
- [15] Dushimimana, A., Gunday, F., &Tuhta, S. (2018). Operational Modal Analysis of Aluminum Model Structures Using Earthquake Simulator. Presented at the International Conference on Innovative Engineering Applications.
- [16] Gunday, F., Dushimimana, A., &Tuhta, S. (2018). Analytical and Experimental Modal Analysis of a Model Steel Structure Using Blast Excitation. Presented at the International Conference on Innovative Engineering Applications.
- [17] Tuhta, S., &Gunday, F. (2019). Application of Oma on The Bench scale Aluminum Bridge Using Micro Tremor Data. *International Journal of Advance Research and Innovative Ideas in Education*, 5(5), 912-923.
- [18] Kasimzade, A., Tuhta, S., Gunday, F., & Aydin, H. (2019). Investigation of Modal Parameters on Steel Structure Using FDD from Ambient Vibration. Presented at the 8th International Steel Structures Symposium, Konya.
- [19] Kasimzade, A., Tuhta, S., Aydin, H., &Gunday, F. (2019). Determination of Modal Parameters on Steel Model Bridge Using Operational Modal Analysis. Presented at the 8th International Steel Structures Symposium, Konya.
- [20] Tuhta, S., Gunday, F., & Abrar, O. (2019). Experimental Study on Effect of Seismic Damper to Reduce the Dynamic Response of Bench Scale Steel Structure Model. *International Journal of Advance Research and Innovative Ideas in Education*, 5(5), 901-911.
- [21] Tuhta, S., Gunday, F., & Aydin, H. (2019). Numerical Algorithms for System Identification of Benchmark Steel Structure. Presented at the iSTE-CE'xx2019- International Conference on Innovation, Sustainability, Technology and Education in Civil Engineering.