Neuro-fuzzy Control for the Reduction of the Vibrations on Smart Irrigation Systems

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Abstract. Center-pivot irrigation systems are highly efficient in terms of the quality of the watering process and/or the water consumption. However, several serious problems can occur during the use of such systems, principally due to the vibrations which are caused either by the wind excitation and/or other, mainly steep, external loadings, which in turn can be caused by failures of the roads or fields, such as potholes, cavities etc. For the suppression of these vibrations, fuzzy and adaptive neuro-fuzzy control can be used. The application of the control mechanisms can be done on simplified models, such as beams or trusses. In the present investigation, a Sugeno-type hybrid neuro-fuzzy controller is implemented and tested on a smart beam model using SIMULINK, under a triangular loading similar to the one, which can be caused by a pothole. The numerical results indicate that the control is not only efficient, but smooth as well.

Keywords: Smart structures, Structural control, Fuzzy control, Neural control, Adaptive Neural Fuzzy Inference (ANFIS), Irrigation systems.

1 Introduction

Center-pivot irrigation systems, also called waterwheels or sprinkler irrigation systems are very popular for the watering of crops. Such systems are highly efficient, as they combine perfect irrigation and maximum water conservation. However, the use of these systems can confront several problems due to the vibrations, which are caused by the wind and/or other external loadings.

To study and reduce these vibrations, one can consider smart beam models, as simplified models of the center-pivot irrigation systems. The smart beams embody piezoelectric elements along with control mechanisms that provide the intelligent behavior. Linear systems can be studied by classical control methods, however classic mathematical theory of control meet many restrictions, as nonlinearity in the

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system or/and the controllers increases dramatically the complexity of the problem. In this case, fuzzy and hybrid neuro-fuzzy controllers can be used instead.

Several controllers have been developed by our team in previous investigations (Tairidis, et al., 2009), (Stavroulakis, et al., 2011) etc. Strong computational tools for the simulation of smart structural systems can be considered among others MATLAB, SIMULINK or other similar software. Once the controllers are built, some fine tuning may be necessary and can be based on several concepts, which can be among others the trial-and-error method or global optimization methods, such as particle swarm optimization or genetic algorithms (Tairidis, et al., 2015), (Marinaki, et al., 2011), (Tairidis, et al., 2016). A systematic approach on this topic is the use of adaptive fuzzy controllers. The fine-tuning in this case can be systematized by embedding the fuzzy inference controller into suitable neural network architecture and, subsequently, using adequate training procedures.

The ANFIS system of MATLAB is a well-established implementation of the adaptive neuro-fuzzy concept. In the present paper, the advantages of the application of adaptive neuro-fuzzy controllers optimized using the ANFIS method for vibration suppression are investigated. Namely, a Sugeno-type hybrid neuro-fuzzy controller is implemented on a given smart beam model and tested using SIMULINK. The investigation is based on the study of a smart beam with piezoelectric sensors and actuators, which was carried out by our team (Tairidis, et al., 2009), (Tairidis, et al., 2013). The system, which is examined here, consists of a cantilevered beam which is subjected to a triangular external load.

2 Mechanical Model and Control

In this section, the simplified mechanical model with the embedded piezoelectric components, along with the control system is presented. The beam model is considered to have similar behaviour in vibrations with each part (right and left) of a small center-pivot irrigation system (Fig. 1), like the ones used in Greek agriculture.

Fig. 1: A typical small center-pivot irrigation system in Greece

2.1 Mechanical Model of the Smart Beam

The simplified model of the smart structure consists of a composite beam with bonded piezoelectric sensors and actuators (see Fig. 2). The cantilevered beam with the fixed (clamped) boundary condition on one end and the free boundary condition on the other end is considered. The beam model is derived from the Euler-Bernouli theory (Thomson, 1981), (Gere, 2012).
The discretization of the model is based on the finite element method. This investigation considers a simplified beam model, where piezoelectric components, i.e. sensors and actuators are used for the measurements and application of control forces, respectively. A cantilevered beam subjected to a vertical time-dependent loading and equipped with one neuro-fuzzy controller at the free end.

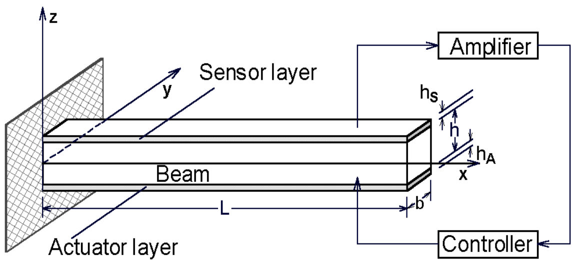

Fig. 2: Schematic representation of the smart beam

After assembling the mass and stiffness matrices for all elements, the equation of motion is given as:

$$\mathrm{M}\ddot{X} + \Lambda\dot{X} + \mathrm{K}X = F_m + F_e \tag{1}$$

where M and K are the mass and stiffness matrices, F_e is the control force vector produced by electromechanical coupling effects, Λ is the viscous damping matrix and F_m is the external loading vector.

The state space representation of (1) is given by

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned} \tag{2}$$

where x is the state vector, u is the control vector and y are the available measurements.

The control law is a linear or nonlinear feedback of the form

$$u = Ky \text{ resp. } u = f(y) \tag{3}$$

where K is the unknown controller gain, resp. $f(y)$ is the nonlinear controller.

2.2 Structural Control

The control of structures is mainly based on some critical assumptions, such as linearity hypothesis for both the structural system, as well as the feedback of the controller. The core benefit of classical control techniques is the availability of the appropriate mathematical tools, not only for the design of a specific controller, but for its study as well. However, the lack of information and measurements for the whole dynamical system degrades dramatically the effectiveness and the feasibility of these methods.

The nonlinearities can be caused from the presence of smart materials in the host structure or in other structural components such as the sensors or the actuators. Another source of uncertainties in the model can be the excitation, i.e. the possible external loadings. This type of uncertainties is very common in practical applications at almost every real-life system. Thus, the design and production of efficient and robust nonlinear controllers, which could be function properly for a wide range of applications and which will be able to tolerate a certain number of nonlinearities, is important and desirable.

The design of these nonlinear controllers is mainly based on intelligent and soft computing tools, such as fuzzy and neuro-fuzzy control, as the tools, which are provided by the classical control, are not fully developed.

This type of controllers permits us to realize more complex control scenarios based on different control strategies or mixtures of them (Abe, 1996). More specifically, fuzzy inference rules systematize existing experience and can be used for the rational formulation of nonlinear controllers (Driankov, et al., 1996), however, knowledge or experience on the controlled system is required for the application of this technique. On the other hand, neural networks can be trained to approximate almost every nonlinear mapping, which means that they can be used for fine-tuning.

Hybrid techniques, which combine the best characteristics of the previous two methods, have also been proposed and tested by our team (Papachristou, et al., 2011), (Stavroulakis, et al., 2011), (Tairidis, et al., 2013). Adaptive neuro-fuzzy controllers can be considered as a more systematic approach for smart structural control. Adaptive Neuro Fuzzy Inference System (ANFIS) of MATLAB is efficient, robust, as well as a well-established implementation of the adaptive neuro-fuzzy concept (Muradova, et al., 2017).

2.3 Neuro-fuzzy Control Using ANFIS

The control system consists of a Sugeno-type neuro-fuzzy inference system, which takes as inputs the displacement and the velocity and returns the control force as output, thus it is a multiple input – single output (MISO) controller. The training and the optimization of the controller are achieved via a training process within the adaptive neural fuzzy inference system (ANFIS) package of MATLAB. Namely, a representative set of data is used for training, i.e. for the adjustment (fine-tuning) of the system parameters. In order to collect this data, the model is first simulated without any control and its vibrations are measured.

The form of the membership functions of the inputs after the training process is shown in Fig. 3, while the graphical representation of the rules of the neuro-fuzzy system along is shown in Fig. 4.

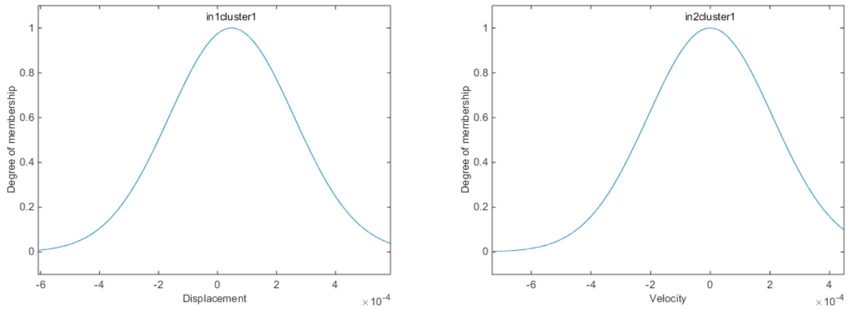

Fig. 3. Membership functions of the inputs (displacement and velocity) of the controller

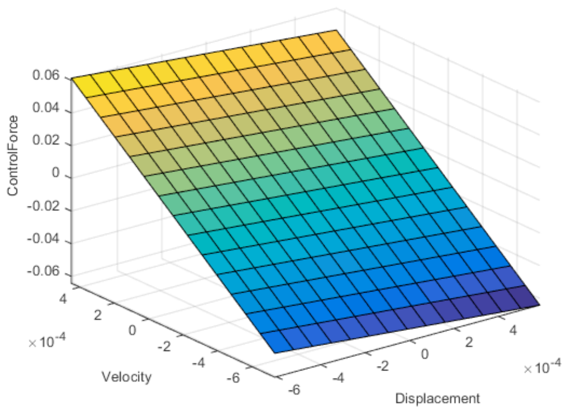

Fig. 4. Graphic representation of the rules of the Sugeno controller

3 Numerical Results

In the present paper, a problem of a cantilever beam (Fig. 2) is considered, as a simplified model of a small center-pivot irrigation system (Fig. 1). The beam has a total length equal to 17.5m and a square cross-section with dimensions 0.1m×0.1m. The elasticity modulus is $73\times10^{9}N/m^{2}$, while the mass density of the host beam equals to $2700Kg/m^{3}$.

A triangular-shaped external force, concentrated at the free end of the cantilever, is applied. The beam has been discretized using the finite element method. The objective of the proposed adaptive Sugeno neuro-fuzzy controller is the reduction of the vibrations.

In Fig. 5, one can observe that the reduction of displacements and velocities is significant after the application of the neuro-fuzzy controller. Note that with the intermittent line is denoted the vibration of the beam without control, while with the continuous line are shown the results of the Sugeno controller. In Fig. 6, one can see the loadings applied on the system. The external force, which has triangular shape and is applied only for the first two seconds of the simulation, is presented with the intermittent line, while the Sugeno control force is given with the continuous line.

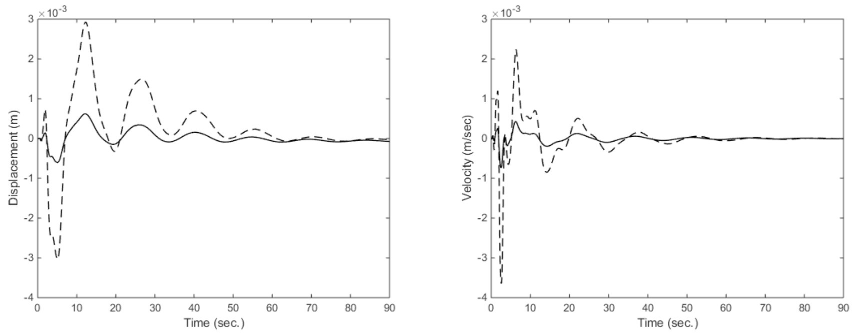

Fig. 5. Vibration suppression at the free end of the beam in terms of displacement and velocity

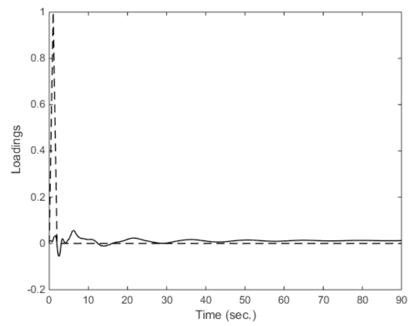

Fig. 6. Triangular external loading and control force

4 Conclusions

From the numerical results of the previous section, one can conclude that adaptive neuro-fuzzy systems can be very useful and effective in the design of smooth and robust controllers. One systematic approach is the hybrid adaptive neuro-fuzzy inference system, which is presented here. The vibration suppression, which was achieved in terms of displacement and velocity of the smart center-pivot irrigation system, indicates the efficiency of the method. The characteristics of the control can be further tuned by using global optimization methods.

The main application of the proposed system can be on the irrigation of large field crops units, which are mainly encountered at the northern and the central part of Greece. Center-pivot irrigation systems can be used among others for the watering of cultivations of cotton, alfalfa (also known as medicago sativa or lucerne), wheat of the genus Triticum, etc. In Crete, these techniques can be used for irrigation systems inside greenhouses or even for the control of such lightweight structures due to extreme wind loadings.

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References

1. Abe, M. (1996) Rule-based control algorithm foa active tuned mass damper. Journal of Engineering Mechanics, 122, p.705-13.
2. Driankov, D., Hellendoorn, H., and Reinfrak, M. (1996) An introduction to fuzzy control (2nd ed.). Munchen: Springer.
3. Gere, J. M. (2012) Mechanics of Materials. USA: Stanford University.
4. Marinaki, M., Marinakis, Y. and Stavroulakis, G. E. (2011) Fuzzy control optimized by a Multi-Objective Particle Swarm Optimization algorithm for vibration suppression of smart structures. Struct Multidisc Optim, 43, p.29-42.
5. Muradova, A. D., Tairidis, G. K. and Stavroulakis, G. E. (2017) Adaptive Neuro-Fuzzy Vibration Control of a Smart Plate, Numerical Algebra, Control and Optimization. Numerical Algebra Control and Optimization, 7, p.251-71.
6. Papachristou, I., Salonikidis, S., Tairidis, G. and Stavroulakis, G. (2011) Adaptive fuzzy control of smart structures - ANFIS. Athens: 7th International Congress on Computational Mechanics (GRACM).
7. Stavroulakis, G., Papachristou, I., Salonikidis, S., Papalaios, I. and Tairidis, G. (2011) Neurofuzzy Control for Smart Structures. In Soft Computing Methods for Civil and Structural Engineering, eds. Y. Tsompanakis, and B. Topping, (p.149-72. Stirlingshire: Saxe-Coburg Publications.
8. Tairidis, G. K., Foutsitzi, G., Koutsianitis, P., and Stavroulakis, G. E. (2015) Fine tuning of Fuzzy Controllers for Vibration Suppression of Smart Plates using Particle Swarm Optimization. Volos: 8th GRACM International Congress on Computational Mechanics proceedings.
9. Tairidis, G. K., Foutsitzi, G., Koutsianitis, P., and Stavroulakis, G. E. (2016) Fine tuning of a Fuzzy Controller for Vibration Suppression of Smart Plates using Genetic Algorithms. Advances in Engineering Software, 101, p.123-35.
10. Tairidis, G. K., Papachristou, I., Katagas, M., and Stavroulakis, G. E. (2013) Neuro - fuzzy control of smart structures. 10th HSTAM International Congress on Mechanics. Chania.

11. Tairidis, G. K., Stavroulakis, G. E., Marinova, D. G. and Zacharenakis, E. C. (2009) Classical and soft robust active control of smart beams. In Computational Structural Dynamics and Earthquake Engineering, eds. M. Papadrakaikis, D. C. Charmpis, Y. Tsompanakis, and N. D. Lagaros, p.165-77. London: CRC Press.
12. Thomson, W. T. (1981) Theory of Vibration with Applications. 2nd edition. New Jersey: Prentice-Hall.