INTERACTIVE LEARNING FRAMEWORK FOR DYNAMIC SIMULATION AND CONTROL OF FLEXIBLE STRUCTURES

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1. INTRODUCTION

The power of digital computation has had major positive influence on engineering education. As early as 1974, an increasing interest in interactive computer programs may be noticed at almost all control institutes. Mostly of these programs are developed by the institutes themselves for educational purposes or as a tool for researchers (Lemmens and Van Den Boom, 1979). Lemmens and Van Den Boom (1979) highlighted that there are several converging reasons for constructing an interactive system. Among them, in control theory specifically to instruct students in aspects of modern control theory that need the use of computers, to create a library facility for control software and provide means by which results of one program can be used or analysed by another, to provide the possibility to compare methods eg. identification methods and also to save students' time by providing existing software which obviates time consuming calculations and graph plotting. Hough and Marlin (2000) stated that the use of simulation is particularly effective in process control education because of the complex behaviour of control systems. More work on computer-based interactive learning particularly in process control has been reported by a number of researchers (Book *et al*., 2002; Jovan and Petrovcic, 1996).

This paper presents the development of an interactive learning environment for dynamic simulation and active vibration control (AVC) of flexible structures. The work aims to facilitate the learning process of the subject area through the development of an interactive environment that can help users to simulate and visualise behaviour of flexible structures with given physical characteristics, as well as to test and validate controller designs, and furthermore, to allow users to execute such processes repeatedly in a friendly and easy manner.

Flexible structures are utilised in a wide range of engineering systems: for example, these in civil engineering applications include skyscrapers and bridges, in aerospace structures include propellers, aircraft fuselage and wings, satellite solar panels and helicopter blades and in electro-mechanical systems include turbo generator shafts, engines, gas turbine rotors and electric transformer cores (Hossain, 1996). This is due to the advantages such structures offer in comparison to their rigid and bulky counterparts, including fast response, low energy consumption, reduced mass and low cost (Tokhi and Azad, 1995).

Flexible structure systems are known to exhibit an inherent property of vibration when subjected to disturbance forces, leading to component and/or structural damage (Tokhi and Leitch, (1992). Therefore, the purpose of vibration control in flexible structures is to dampen the response of the structure to external excitation. In all cases there are the alternatives of passive or active control solutions. Active vibration control consists of artificially generating cancelling sources to destructively interfere with the unwanted source and thus result in a reduction in the level of vibration at desired location(s) (Tokhi and Leitch, 1992). In this context, and due to time-varying phenomena in practical applications, adaptive control techniques are preferred.

Adaptive systems are designed to modify their behaviour in accordance with the changing properties of controlled processes and their signals. An adaptive mechanism is characterised by two complementary processes; identification and control. In the process of identification a suitable model is developed that exhibits the same input/output characteristics as the controlled process (plant). In the process of control a control process is determined, implemented and tested on the plant on the basis of the identified model and control/performance objective (Tokhi and Veres, 2002).

The finite difference (FD) method is utilised to develop simulation algorithms characterising the dynamic behaviour of one-dimensional (1D) and two-dimensional (2D) flexible structures (Mohd. Hashim *et al.*, 2002; Mat Darus and Tokhi, 2001). The design and implementation of an interactive system incorporating the simulation algorithms, modelling and control strategies, and a graphical user interface, are described using Matlab. The environment allows the user to specify the boundary conditions and physical properties of the structure, and provides the response of the structure to user-specified disturbances in the time and frequency domains and in 2D and 3D views. The result of the simulation is then utilized in the modelling stage, and then in development of suitable controllers for the flexible structure. Several parametric and non-parametric controller design strategies are investigated for vibration suppression of the flexible structure. The performance of the controller is described in time and frequency domains for analysis and further study.

2. DESIGN OF THE INTERACTIVE LEARNING ENVIRONMENT

This section will discuss the design of the system by highlighting the main components of the environment. A flowchart of the system is shown in Figure 1, and the corresponding system inputs are described in Figure 2.

The system comprises three main sub-menus, where each sub-menu represents the process that takes place in the design of controller in the AVC of a specified flexible structure. The controller design law is described in (Hossain, 1996; Tokhi and Leitch, 1992; Tokhi and Veres, 2002). The sub-menus are simulation, identification and control stage. Each is discussed below.

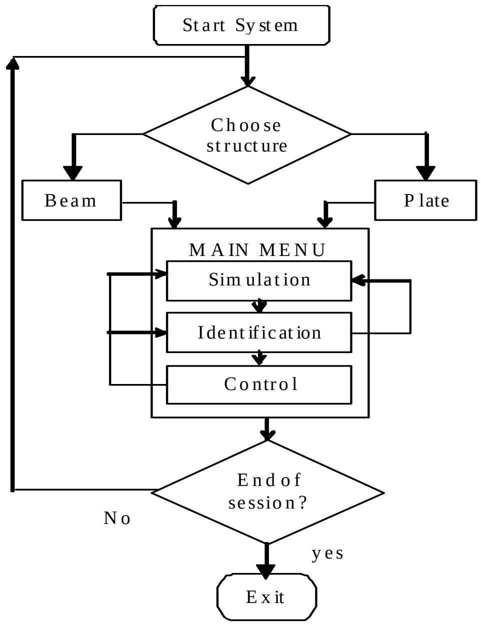

Figure 1: Flowchart of the system

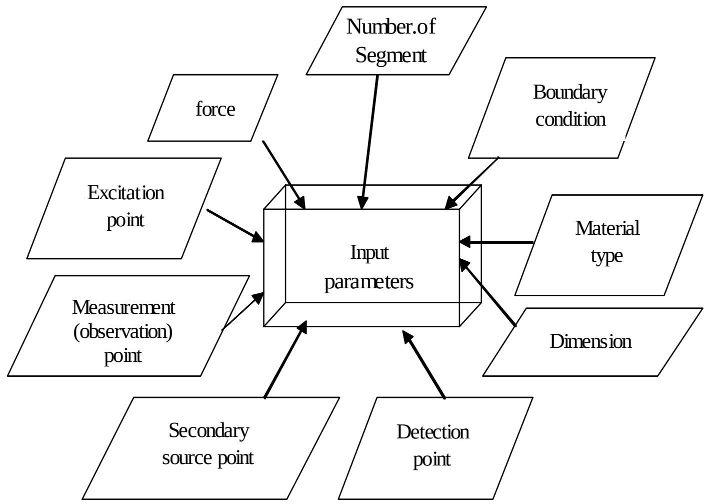

Figure 2: System inputs

2.1 Simulation

A flowchart and corresponding interface for the simulation process are shown in Figures 3 and 4 respectively. In this process, the input parameters are taken from the user, where the user can specify and attempt various inputs, shown in Figure 2. The output response will be displayed in time and frequency domains, and in 3D view, as shown.

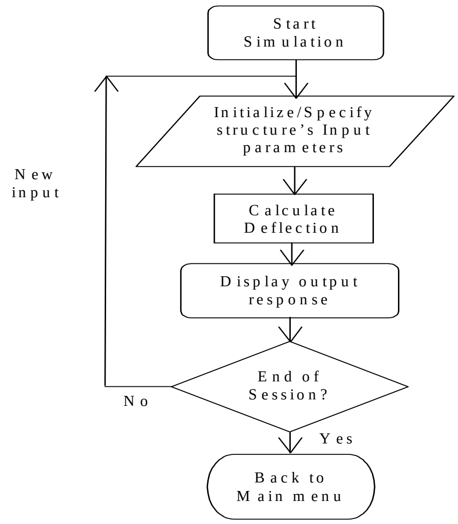

Figure 3: Flowchart of sub-menu

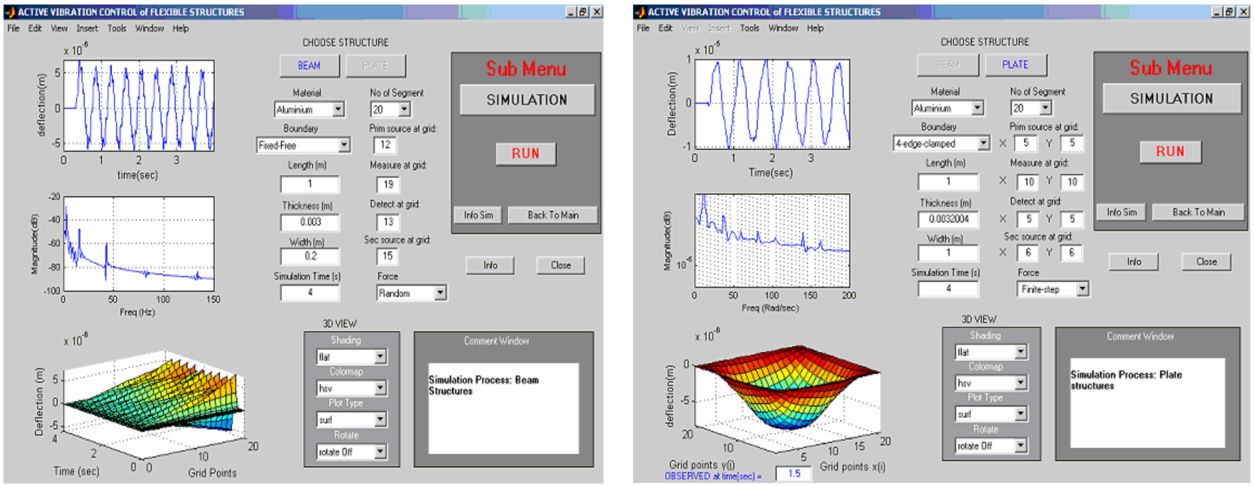

Figure 4: Interface of sub-menu Simulation for beam and plate structures.

2.2 Identification

A flowchart of the identification process and the corresponding interface are shown in Figures 5 and 6 respectively. In this process, a suitable model is developed that exhibits the same input/output characteristics as the controlled process (plant) (Tokhi and Leitch, 1992). A number of techniques have been devised by researchers to determine models that best describe input-output behaviour of a system. Parametric and non-parametric identification are two major classes of system modelling techniques. Identification consists of determination of the numerical values of the structural parameters which minimize the distance between the system to be identified and its model. The parametric methods investigated in this work involve recursive least square (RLS) and genetic algorithms (GAs). On the other hand, non-parametric models utilised here are neural network (NN) and adaptive neuro-based fuzzy inference system (ANFIS) (Mohd Hashim and Tokhi, 2004a,b; Mohd Hashim *et al.*, 2004). The models obtained are validated using several techniques such as calculating mean squared error and correlation tests (Billings and Voon, 1986).

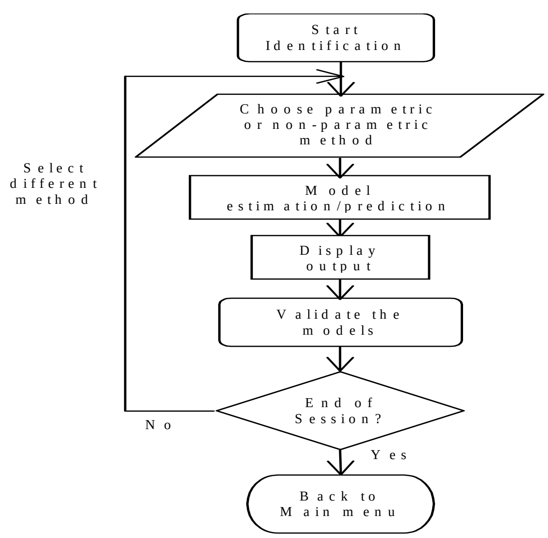

Figure 5: Flowchart of sub-menu System Identification.

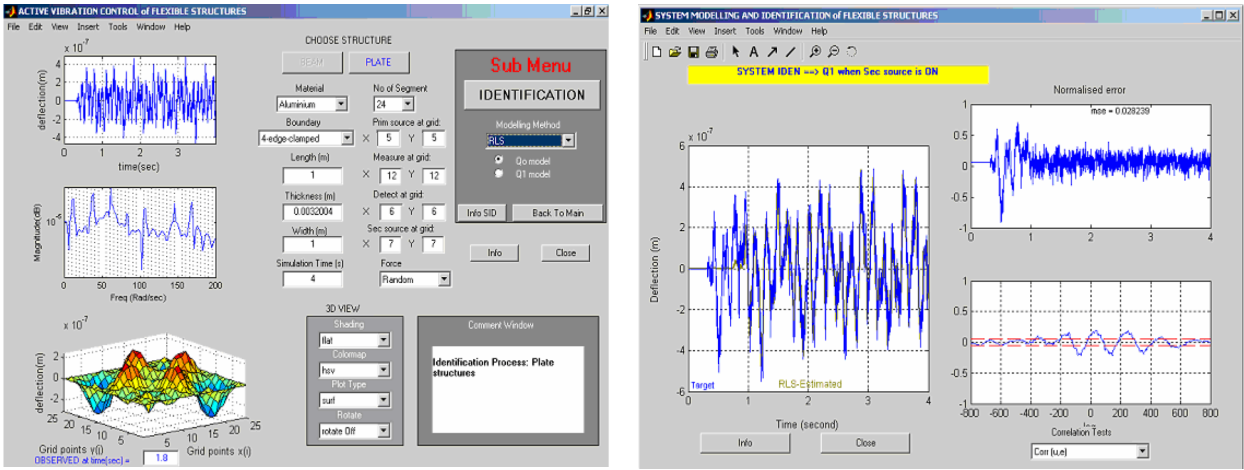

Figure 6: Interface of sub-menu System Identification

2.3 Control

A flowchart and corresponding interface for the control process are shown in Figures 7 and 8 respectively. In this process, the controller transfer function is calculated based on the identified model parameters obtained in the parametric identification stage. For non-parametric approach, the controller is designed based on the networks obtained through the training process. In this sub-menu, the controller is designed based on the method chosen in the system identification stage. The output response is displayed in time and frequency domains, and in 3D for both conditions, before and after the controller is applied.

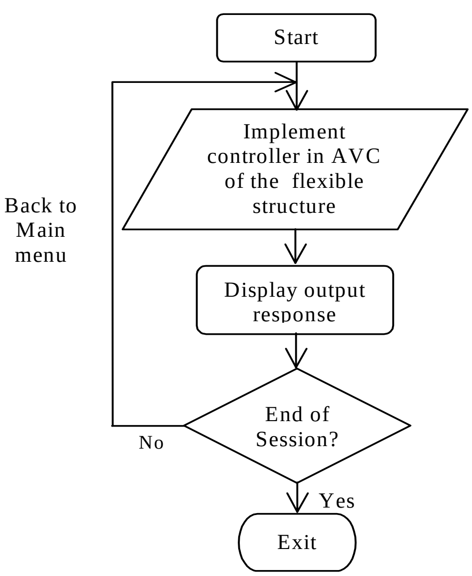

Figure 7: Flowchart of sub-menu Control

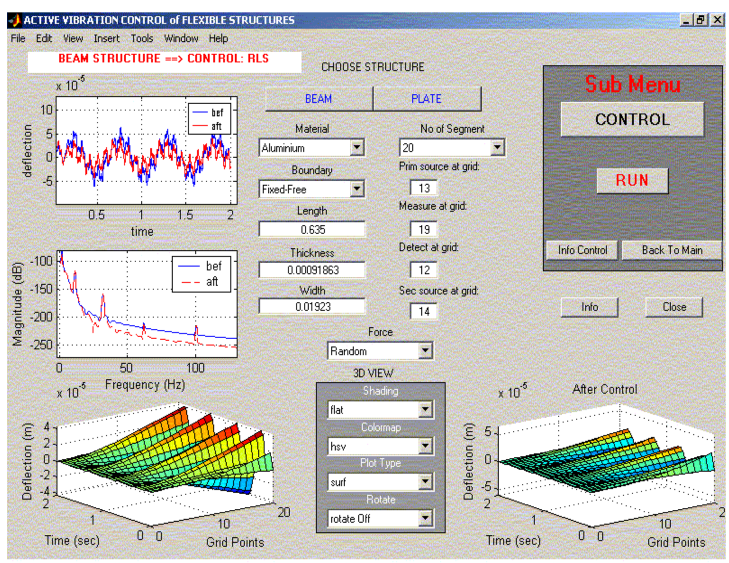

Figure 8: Interface of sub-menu Control

3. CONCLUSION

An interactive learning environment for dynamic simulation and active vibration control of flexible structures has been developed. The FD method has been used to discretise the governing partial differential equation formulation of the dynamics of the structures. The design and implementation of the interactive system incorporates three stages involved in AVC of flexible structures, namely simulation, modelling and control. Both parametric and non-parametric approaches in modelling the system have been investigated. The models obtained were further utilised for controller design. The environment thus developed forms a useful interactive and user-friendly learning and education facility in studying the dynamic features of 1D and 2D structures as well as their control aspects.

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