Chapter 9

Neuromorphic Smart Controller for Seismically Excited Structures

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ABSTRACT

In this chapter, an application of a neuromorphic controller is proposed for hazard mitigation of smart structures under seismic excitations. The new control system is developed through the integration of a brain emotional learning-based intelligent control (BELBIC) algorithm with a proportional-integral-derivative (PID) compensator and a clipped algorithm. The BELBIC control is based on the neurologically inspired computational model of the amygdala and the orbitofrontal cortex. A building structure employing a magnetorheological (MR) damper under seismic excitations is investigated to demonstrate the effectiveness of the proposed hybrid clipped BELBIC-PID control algorithm. The performance of the proposed hybrid neuromorphic controller is compared with the one of a variety of conventional controllers such as a passive, PID, linear quadratic Gaussian (LQG), and emotional control systems. It is shown that the proposed hybrid neuromorphic controller is effective in improving the dynamic responses of structure-MR damper systems under seismic excitations, compared to the benchmark controllers.

DOI: 10.4018/978-1-4666-2029-2.ch009
INTRODUCTION

The application of control technology to large structures has attracted a great attention from civil engineering because behavior of structural systems can be modified during destructive environmental forces such as earthquakes without significantly increasing the mass of structure (Yao 1972; Soong 1990; Kobori et al. 1991; Soong and Reinhorn 1993; Housner et al. 1994; Housner et al 1997; Adeli & Saleh 1999; Spencer and Nagarajaiah 2003; Agrawal et al. 1998; Kim et al. 2009; Kim et al. 2010), including passive, active, and semiactive (also called smart) systems (Nagarajaiah & Spencer 2003; Kim et al. 2010). Particularly, the smart control scheme has been used most frequently to structural control system design because it possesses the advantages of both passive and active control systems (Spencer et al. 1997). In order to improve the performance of the smart control system, the control algorithm for smart control devices has to be selected carefully (Jansen & Dyke 2000). The control algorithms that have been used for the application of smart control technology could be divided into two categories: model-based and model-free control algorithms. The typical model-based control algorithms for implementation of smart control systems in the field of structural engineering might include: linear quadratic regulator, linear quadratic Gaussian, $H_\infty$, etc. (Chang et al. 2008; Lynch et al. 2008; Wang and Dyke 2008; Ping and Agrawal 2009; Nagarajaiah and Narasimhan 2006; Nagarajaiah et al. 2009) The model-free control system design frameworks such as fuzzy logic theory and artificial neural network have been also extensively applied to smart civil structures (Lin et al. 2007; Shook et al. 2008; Kim et al. 2009; Kim et al. 2010; Karamodin and Kazemi 2010). The reason is that the model-free control system design framework does not require for modeling nonlinear dynamic system of structures equipped with complex nonlinear smart control devices. Another new model-free smart control system design framework is the brain emotional learning-based bio-inspired control algorithm (Kim et al. 2010).

The brain limbic system, which is responsible for emotional reaction of humans (among other bio-organisms), is an available candidate as a structural control algorithm (Kim et al. 2010). Unlike rational thought that is considered to be objective, emotions have been considered a negative trait because emotional thought is considered to be involuntary and there exists little conscious control over such thought. However, scientists have recently learned about the positive aspects of human emotions. Moreover, for a number of years, the emotional signal processing in the brain limbic system has been the subject of research in cognitive science (Picard 1997; Jamali et al. 2009; Kim and Langari 2009). Rational thought can be often controlled via the involuntary emotions (Martinez-Miranda & Aldea 2005). Of special interest is that the impact of the emotional system on the cognitive system is far stronger than the impact of the cognitive system on the emotional system. For instance, one single occurrence of an emotionally significant situation is remembered far more vividly and for a longer period than a task which is repeated frequently (Meystel & Albus 2002). In other words, the emotional processing and learning are able to develop an effect that sustained cognitive inputs are not able to achieve.

To date, great attention has been paid to the application of artificial neural networks (ANNs) to bio-inspired control system design. ANNs model the synaptic connections and the Hebbian learning phenomena at the level of individual neurons that train the input-output relations of complex information. These linkages are being used for decision-making when no conventional or mathematical input-output relations are available, i.e., ANNs are trained via adjusting the weights of the various signal paths based on the error between the desired state and the current state. ANNs that are represented in networks of a number of neurons inside the human brain may be used for modeling...