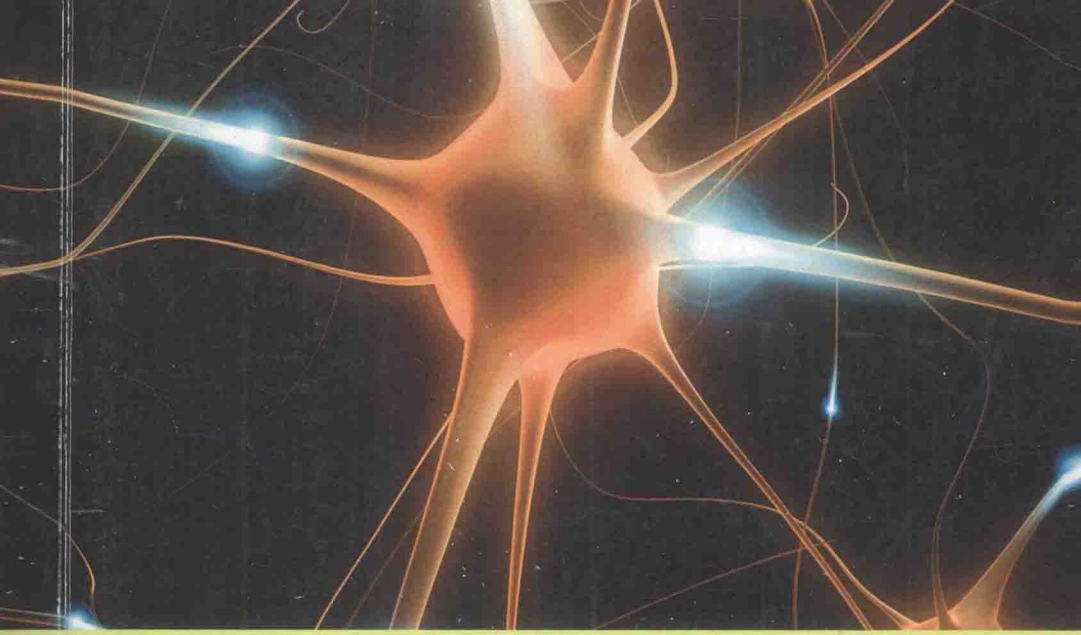

Sukumar Kamalasadan

Novel Intelligent Adaptive Designs for the Control of Smart Systems

System-Centric Adaptive Control Designs based on Intelligent Supervisory Loops: Mathematical Modeling, Algorithm Development and Applications

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Preface

The main focus of this book is to develop a new generation of intelligent adaptive control that can lend itself into a system-centric controller. A system-centric controller could perform case based control with respect to changing system dynamics unlike other controllers that work within a specified system domain. To this end, in this book a new class of intelligent adaptive control for systems with complex and multimodal dynamics including scheduled and unscheduled 'Jumps', is developed. Those systems are often under the challenge of unforeseen changes due to wide range of operations and/or external influences. The underlying structural feature is an introduction of an Intelligent Supervisory Loop (ISL) to augment the Model Reference Adaptive Control (MRAC) framework. The emphasis is to design ISL to enhance controllers acting in one domain so that architecture that lends itself from static controllers to intelligent and smart controller's viz., system-centric controllers can be developed. The advantage of such architecture is that such controller can evolve based on system complexities.

Four novel design formulations are developed and discussed in this book which evolved from different methods of conceiving ISL, structured into intelligent control algorithms, and then investigated with comprehensive simulation models of a single link flexible robotic manipulator, a six degree of freedom F16 fighter aircraft and a power system. The first scheme is a Fuzzy Multiple Reference Model Adaptive Controller (FMRMAC). It consists of a fuzzy logic switching strategy introduced to a MRAC framework. The second is a novel Neural Network Parallel Adaptive Controller (NNPAC) for systems with un-modeled dynamics and mode swings. It consists of an online growing dynamic radial basis neural network, which controls the plant in parallel with a direct MRAC. The third scheme is a novel Neural Network Parallel Fuzzy Adaptive Controller (NNPFAC) for dynamic 'Jump' systems showing scheduled mode switching and un-modeled dynamics. This scheme consists of a growing online dynamic Neural Network (NN) controller in parallel with a direct MRAC, and a fuzzy multiple reference model generator. The fourth scheme is a Composite Parallel Multiple Reference Model Adaptive Controller

(CPMRMAC) for systems showing unscheduled mode switching and un-modeled dynamics. This scheme consists of an online growing dynamic NN controller in parallel with a direct MRAC, and an NN multiple reference model generator. These designs are evolved from the first authors doctoral dissertation.

Extensive feasibility simulation studies and investigations have been conducted on the four proposed schemes, and with results consistently showing that the four design formulations developed are feasible, effective and have immense potential for complex systems control such as power and energy systems, robotic manipulators and fighter aircraft. These systems are true representatives of an important and challenging class of dynamic systems that require the new generation of adaptive controllers. Overall, these controller designs are a new beginning of intelligent and adaptive systems termed as system centric controllers that changes based on change in system dynamics. The broader impact includes a potential breakthrough in emerging and largely untapped system-centric controllers for modern power system and smart grid conrol, intelligent aircraft control, precise and intelligent control of robots and other complex systems.

Pensacola
January 2010

S.K.

DEDICATION

By S. Kamalasadan

TO MY WIFE

Manya

AND

TO MY PARENTS

P. Krishna Warrier and Kamaladevi

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I am deeply grateful to the department of Electrical Engineering and Computer Science at the University of Toledo. A special thanks to Dr. Khalid S. Al-Olimat who proof read the book and extended valuable comments. I would also like to express my sincere gratitude to the department of Engineering and Computer Technology at the University of West Florida, for the support to contine our research activities and accomplish our goal to attract federal research fundings based on this research work.

Last but not the least, words and measures can never express our deepest gratitude to my wife. She has been a force of strength all along, and without her it would have been an uphill task for me to complete this work. I am also deeply indebted to my parents. Their incessant support allowed me to achieve new heights in life and built my character and career. I will always honor their love and immutable encouragement in whatever endeavor I undertake in my life.

.....**S.K.**

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CHAPTER ONE

INTRODUCTION

Control engineering deals with developing proper controllers (control attributes) for fast, accurate and effective guidance of static or dynamic systems (system characteristics) to perform according to a given set of specifications or requirements (desired performance). If the systems characteristics are known and are more or less static in nature, the controller design is less challenging. There are several control techniques developed based on linear system theory, which can control such systems even when their characteristics change to certain extend. On the other hand, control of dynamic systems is often hard as such controllers should accomplish that task, especially if the system is difficult to model or vary rapidly. This can be quite challenging as it implies that the controller should have the ability to assess system conditions on a continuous basis, which calls for powerful control techniques. And such controllers become complex in nature, which in turn may hamper their speed and accuracy. On the other hand, most practical systems do exhibit time varying response and behave differently at different times. This is mainly due to system nonlinearities, failure or drift of parameters, presence of external disturbance, and/or environmental changes.

1.1 Stationary (Constant Parameter) Controllers

Stationary or constant parameter controllers, deal with plants, which can be modeled with fixed parameter models. They are used to meet specific and predictable operating conditions of the plant. As such, the performance of such stationary controllers would normally deteriorate, and may even become unstable under dynamic conditions that were not predicted a priori. A different

approach in the form of *Robust Control* [1] and *Optimal Control* [2] emerged to overcome this difficulty, which developed fixed controllers with a novice form of tolerating a limited range of plant parameter variations. Research in this direction has a long history and by now there is a strong body of theoretical knowledge associated with designing such controllers. In spite of this, since these controllers are designed on the basis of a priori operating domain, they inevitably fail as the system continues to depart from around that domain.

1.2 Dynamic Controllers

In contrast to stationary controllers, dynamic controllers are those which change their control characteristics in real-time. These controllers utilize several techniques and structures to cope with systems that show complex dynamics. There are three main approaches in this class of controllers, viz., a) Gain scheduling controllers b) Self Tuning Regulator (STR) and c) Model Reference Adaptive Control (MRAC). It has been proven as outlined below, that these approaches are especially effective when the plant parameters are uncertain, unknown or rather time varying.

1.2.1 Gain Scheduling and Self Tuning Regulators (STR):

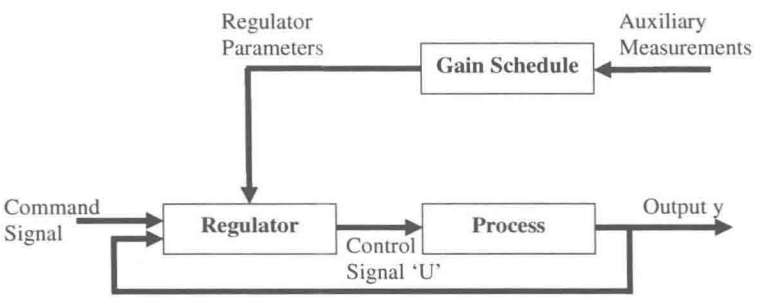

Figure 1.1 Block Diagram of System with Gain Scheduling Controller

Gain scheduling is a divide and conquer approach that is performed for the design of dynamic controllers for nonlinear systems. These methods have been applied in wide range of real-