Decentralized Model Reference Adaptive Control Design for Nonlinear Systems; Application to Cancer Treatment

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Abstract— **The paper gives an approach to decentralized Model Reference Adaptive Control (MRAC) design for nonlinear dynamical systems and illustrates the method with an application to cancer treatment. The nonlinear mathematical model of the cancer dynamics is described by a set of differential equations each of which defines the variation of different cell numbers. The model also includes the treatment effects which are specifically defined by immune, vaccine and chemotherapy. The proposed MRAC design methodology is based upon a stable nonlinear reference model which is produced by a state feedback controller using the so called State Dependent Riccati Equation (SDRE) techniques. The plant dynamics is nonlinear by nature and an adaptation methodology is designed such that response of the nonlinear reference model is followed. The adaptation is performed on a state dependent basis mainly using the adaptation mechanism designed for multi input multi output (MIMO) linear time invariant (LTI) systems. The proposed technique is illustrated to develop mixed immunotherapy, chemotherapy and vaccine therapy drug administration for cancer treatment using a tumor growth mathematical model. Simulation results show the effectiveness of the SDRE based MRAC for MIMO nonlinear systems.**

Keywords— Nonlinear Systems, State Dependent Riccati Equations, Decentralized Model Reference Adaptive Control, Cancer Treatment

I. INTRODUCTION

Adaptive control methodologies are widely used to control dynamical systems and processes. The recent efforts on the adaptive control theory are focused on developing adaptation mechanisms to improve the behavior or performance of physical systems by collecting and exploiting knowledge about the system's function. Within this context, Model Reference Adaptive Control (MRAC) plays an important role in the adaptive controller design schemes. One of the most important advantages of MRAC system is its high-speed of adaptation. The characteristics of high-speed of adaptation of MRAC are valuable for the design of adaptive control of nonlinear systems. It is well-known that the nonlinear systems are more complex and need more calculation than linear systems in the MRAC design. A MRAC of a nonlinear system can be demonstrated via a nonlinear transformation as an equivalent feedback system which is a linear time invariant system.

State Dependent Riccati Equation (SDRE) has been an emerging technique for stabilization of nonlinear systems. Although there are a number of other methods for stabilization of nonlinear systems, the SDRE based control strategy is one of the few successful approaches that have important properties, such as applicability to a large class of nonlinear systems, systematic formulation and allowing the control designer to make tradeoff between control effort and state errors. Autopilot design [1], MRAC design for nonlinear systems [5], satellite and spacecraft control [2], control of pendulum on a cart [6], control of aero elastic systems [3] and optimal administration of drug in Cancer treatment [4] are some of the applications of SDRE techniques in recent years.

In the MRAC schemes, many scientists and engineers explore the context of decentralized adaptive control. Decentralized control has been widely used in industry due to ease of implementation, fault tolerance, and reduced computational effort. These advantages make decentralized control techniques attractive for applications in complex dynamical systems. In particular, decentralized adaptive control is employed to stabilize and track the nonlinear, interconnected subsystems with unknown parameters.

In this paper, we extend the SDRE method to decentralized MRAC design for MIMO nonlinear systems and illustrate the method with an application to cancer treatment. For this purpose, we consider a patient with known mathematical model and model parameters and regard the patient as the reference model of the MRAC. The plant model is composed of coupling matrix, therefore they can be treated as modeling error term in the control design. The design of adaptive controllers for multi input multi output (MIMO) plant models is more complex than in the SISO case. This means that instead of designing an adaptive controller for the MIMO plant, we can design N adaptive controllers for N SISO plant models. This approach is known as decentralized adaptive control. Then the objective is to follow the response of stable reference model for the closed-loop subsystems. The proposed MRAC design

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