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ADRC or Adaptive Controller – A Simulation Study on Artificial Blood Pump

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Abstract—Active disturbance rejection control (ADRC) has gained popularity because it requires little knowledge about the system to be controlled, has the inherent disturbance rejection ability, and is easy to tune and implement in practical systems. In this paper, the authors compared the performance of an ADRC and an adaptive controller for an artificial blood pump for end-stage congestive heart failure patients using only the feedback signal of pump differential pressure. The purpose of the control system was to provide sufficient perfusion when the patients' circulation system goes through different pathological and activity variations. Because the mean arterial pressure is equal to the total peripheral flow times the total peripheral resistance, this goal was converted to an expression of making the mean aortic pressure track a reference signal. The simulation results demonstrated that the performance of the ADRC is comparable to that of the adaptive controller with the saving of modeling and computational effort and fewer design parameters: total peripheral flow and mean aortic pressure with ADRC fall within the normal physiological ranges in activity variation (rest to exercise) and in pathological variation (left ventricular strength variation), similar to those values of adaptive controller.

Keywords: active disturbance rejection control, adaptive control, physiological controller, rotary blood pump, left ventricular assist device.

I. Introduction

Rotary blood pump (RBP) is a mechanical pump to restore the perfusion for end-stage heart failure patients. Some studies have showed that the passive variation of pump flow at a fixed speed due to the change of cardiovascular parameters could not match the physiological demands of patients [33]. Physiological controller, which adjusts the pump flow automatically, is critical for the permanent application of RBP and provides better life quality of patients [1]. The controller needs to adjust the pump flow properly for different patients in the situations such as: patients sleep, rest, or exercise slightly (e.g. walking or climbing stairs); and when the recipient's sick heart gets better or worse. In these conditions, some properties of human circulatory system may change dramatically such as the total peripheral resistance, so is the body need for blood [2]. Many physiological controllers have been proposed for RBP to achieve the robust performance at the presence of large disturbance. The algorithms of those controllers can be classified as two types, model-based controller, and model free controller. Model-based controller design use a simplified mathematical model of plant (i.e. RBP plus cardiovascular system) [3, 22, 24-28]. Some models include time-varying parameters to accommodate the large variations of circulation system in different physiological conditions with the cost of online computational effort [3]. Because of the dependence on model, the performance of model-based controller is also contingent upon the accuracy of the model. Model-free controllers, use only the input (e.g. pump speed, pump current) and the output (e.g. pump flow, pump pressure rise, heart rate, etc.) information of the RBP plus cardiovascular system, but typically needs extensive tuning of controller in advance because of the nature of the implemented fuzzy logic [28-30]. The exception is the model free adaptive controller proposed by Gao and Chang [31-32], which has four design parameters that are special to the structure of the controller. All these model-based or model-free controllers have demonstrated robust performance at the presence of large disturbance in numerical simulation and/or in-vitro experiments. However, their dependence on model [3, 22, 24-28], extensive tuning in advance [28-30], multiple design parameters [31-32], or intensive computational effort [3] present challenge for clinical application.

Active disturbance rejection controller (ADRC) was proposed by Han [4-6], further simplified and parameterized by Gao [7-8]. The effectiveness of ADRC is evident in many case studies, where the technique is employed to solve a number of benchmark problems in various industrial problems with promising results [9-19]. The applications demonstrate that ADRC