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Multi-objective Neural Predictive Control for Biventricular Assist Device: Balancing Circulatory Volume with Preload-Based Control

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Abstract

Rotary blood pumps are essential for providing mechanical circulatory support to patients with heart failure. However, maintaining pulmonary and systemic circulatory volume balance when using two rotary blood pumps for biventricular support is challenging. In this paper, we propose a novel approach to address this issue by combining a multiobjective neural predictive controller (MONPC) with a preload-based Frank-Starling-like controller (PFS) for a dual rotary blood pump biventricular assist device. We evaluate two different configurations: PFSL-MONPCR and MONPCL-PFSR. The PFS controls the flow rate of one pump based on preload, while the MONPC adjusts the other pump to meet cardiac demand, prevent pulmonary congestion, and avoid ventricular suction. We compare the performance of these controllers with a Dual Independent Frank-Starling-like control system (DI-FS) and a constant speed controller through numerical simulations. The results demonstrate that MONPCL-PFSR effectively unloads the congested left ventricle while maintaining high cardiac output during exercise. In contrast, improper flow regulation by DI-FS leads to pulmonary congestion. Moreover, during blood loss, PFSL-MONPCR exhibits the lowest suction risk compared to the constant speed mode, which results in negative right ventricular preload. Furthermore, when considering sensor noise and time delays in the signals, the proposed controllers demonstrate robustness during the transition from rest to exercise. Our study highlights that the proposed controllers effectively match pump flow with cardiac demand, ensuring hemodynamic stability in biventricular assist devices.

Keywords: Rotary Blood pumps, Biventricular Assist Device, Circulatory Volume Balance, Neural Predictive Controller.

I. Introduction

In patients with failing hearts who are ineligible for transplantation or awaiting a donor organ, rotary blood pumps offer mechanical circulatory support. However, implementing two rotary blood pumps for biventricular support presents a significant challenge in maintaining a balance between pulmonary and systemic circulatory volumes. Achieving this balance is crucial to ensure optimal cardiac function and prevent complications such as pulmonary congestion and ventricular suction [1-2]. To address this challenge, this study proposes a novel approach using a hybrid controller for a dual rotary blood pump biventricular assist device. The controller consists of a multiobjective neural predictive controller (MONPC) combined with a preload-based Frank-Starling-like controller (PFS) [3]. The PFS regulates the flow rate of one pump based on preload, while the MONPC adjusts the other pump to meet the cardiac demand, avoid pulmonary congestion, and prevent ventricular suction. This hybridized controller aims to optimize circulatory volume balance and enhance the overall performance of the biventricular assist device [4-7].

To assess the effectiveness of the proposed controller, a comparative evaluation is conducted. The performance of the hybrid controllers, namely PFSL-MONPCR and MONPCL-PFSR, is compared against a Dual Independent Frank-Starling-like control system (DI-FS) and a constant speed controller. Through numerical simulations, the controllers are evaluated based on their ability to regulate pump flow, maintain hemodynamic stability, and prevent adverse events such as pulmonary congestion and ventricular suction [8]. The simulation results demonstrate the superiority of the proposed controllers. MONPCL-PFSR effectively unloads the congested

preload-based Frank-Starling-like controller for biventricular assist devices. Through comparative assessments and numerical simulations, the proposed controllers demonstrate their effectiveness in achieving circulatory volume balance, optimizing cardiac output, and preventing hemodynamic instabilities. These findings highlight the potential of the proposed controllers to enhance the performance of biventricular assist devices and improve patient outcomes.

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