DEPARTMENT OF CHEMICAL AND BIOMOLECULAR ENGINEERING

PhD Dissertation Defense

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Stochastic Modeling and Control of the Cardiovascular System Managed by a Left Ventricular Assist Device

Heart failure (HF) is a condition that the heart is unable to pump blood adequately for the body's circulation demand. It is estimated that about 6.5 million patients in the U.S. have HF. Heart transplantation is a well-recognized treatment for advanced HF, but only about 2500 patients receive heart transplantation due to the shortage of donor hearts. As an alternative treatment, a left ventricular assist device (LVAD)—a mechanical circulatory pump—can be used to assist the failing left ventricle. This research aims to improve the quality of life for LVAD recipients through two directions.

In the first part, an uncertainty quantification (UQ) algorithm was developed to quantify the effect of uncertainties on model predictions, which lays the foundation to build stochastic models of the cardiovascular system under the LVAD support to improve model prediction accuracy. The UQ algorithm designed in this study integrated polynomial chaos expansion with a generalized dimension reduction method to improve computational efficiency, while maintaining UQ accuracy. The efficiency of the proposed approaches was validated using different benchmark studies in chemical and biological engineering systems.

In the second part, stochastic modeling of the cardiovascular system managed by an LVAD was conducted to investigate hemodynamics of the heart under LVAD support and to consider interpatient and intrapatient variability in hemodynamics. The stochastic model was developed using one of UQ methods discussed in the first part of this dissertation. Based on model predictions from the stochastic model, an adaptive self-tunning controller to adjust the working condition of the LVAD was designed to accommodate different physical activities of patients. Additionally, to broaden the application of feedback controller in clinics, a data-driven, model-free adaptive control (MFAC) strategy was developed, which capitalizes on easily collected data from LVADs and patients. For control design, a Gaussian process regression (GPR) based estimation approach was developed to estimate the left ventricular end-diastolic pressure (LVEDP) in real-time. Our research shows that the performance of the proposed controller can be guaranteed for constant and time-varying blood demand without the need for invasive sensors.

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