Clarkson University
Department of Chemical and Biomolecular Engineering
SEMINAR

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

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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. undergo HF. Heart transplantation is a well-recognized treatment for advanced HF, but only about 2500 patients in the U.S. receive heart transplantation due to the shortage of donor hearts. As an alternative treatment, the left ventricular assist device (LVAD)—a mechanical circulatory pump—can be used to assist the failing left ventricle. The presented research aims to improve the quality of life for LVAD recipients through two directions.

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

In the second part, stochastic modeling of the cardiovascular system managed by an LVAD is conducted to investigate hemodynamics of the heart under LVAD support and to consider the effect of intrapatient and interpatient variability in hemodynamics. The stochastic model is developed based on one of UQ methods in part I. Based on model predictions from the stochastic model of the heart, an adaptive self-tunning controller is designed to automatically adjust the working condition of the LVAD to accommodate different blood needs with respect to physical activities of patients. Additionally, to broaden the application of feedback controller in clinics, a data-driven, model-free adaptive control (MFAC) strategy is developed, which capitalizes on easily collected data from the LVAD and patients to automatically adjust the pump speed in response to time-varying blood demands. For the controller design, a Gaussian process regression (GPR) based estimation approach was developed and used to estimate the left ventricular end-diastolic pressure (LVEDP) in real-time, using data of pump flow and heart rates. 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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Jeongeun Son is a Ph.D candidate in the Department of Chemical Engineering at Clarkson University. She received her Bachelor of Science and Master of Science degrees, both in chemical engineering at Inha University, South Korea. Her research focuses on process control, uncertainty quantification, and multiscale modeling of biomedical systems.