Chemical Engineering Doctoral Defense

A Novel Control Engineering Approach to Designing and Optimizing Adaptive Sequential Behavioral Interventions

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abstract

Control engineering offers a systematic and efficient approach to optimizing the effectiveness of individually tailored treatment and prevention policies, also known as adaptive or "just-in-time" behavioral interventions. These types of interventions represent promising strategies for addressing many significant public health concerns. This dissertation explores the development of decision algorithms for adaptive sequential behavioral interventions using dynamical systems modeling, control engineering principles and formal optimization methods. A novel gestational weight gain (GWG) intervention involving multiple intervention components and featuring a pre-defined, clinically relevant set of sequence rules serves as an excellent example of a sequential behavioral intervention; it is examined in detail in this research.

A comprehensive dynamical systems model for the GWG behavioral interventions is developed, which demonstrates how to integrate a mechanistic energy balance model with dynamical formulations of behavioral models, such as the Theory of Planned Behavior and self-regulation. Self-regulation is further improved with different advanced controller formulations. These model-based controller approaches enable the user to have significant flexibility in describing a participant's self-regulatory behavior through the tuning of controller adjustable parameters. The dynamic simulation model demonstrates proof of concept for how self-regulation and adaptive interventions influence GWG, how intra-individual and inter-individual variability play a critical role in determining intervention outcomes, and the evaluation of decision rules.

Furthermore, a novel intervention decision paradigm using Hybrid Model Predictive Control framework is developed to generate sequential decision policies in the closed-loop. Clinical considerations are systematically taken into account through a user-specified dosage sequence table corresponding to the sequence rules, constraints enforcing the adjustment of one input at a time, and a switching time strategy accounting for the difference in frequency between intervention decision points and sampling intervals. Simulation studies illustrate the potential usefulness of the intervention framework.

The final part of the dissertation presents a model scheduling strategy relying on gain-scheduling to address nonlinearities in the model, and a cascade filter design for dual-rate control system is introduced to address scenarios with variable sampling rates. These extensions are important for addressing real-life scenarios in the GWG intervention.

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