Chemical Engineering Dissertation Defense

System Identification and Control Systems Engineering Approaches for Optimal and Practical Personalized mHealth Interventions for Physical Activity

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Abstract

Physical inactivity is a major contributor to chronic illnesses and mortality globally. However, most interventions to address it rely on static, aggregate models that overlook idiographic (i.e., individual-level) dynamics, limiting intervention effectiveness. Leveraging mobile technology and control systems engineering principles, this dissertation provides a novel, comprehensive framework for personalized behavioral interventions that have been tested experimentally under the Control Optimization Trial (COT) paradigm. Through careful design of experiments, elaborate signal processing and model estimation, and judicious formulation of behavior intervention optimization as a control system problem, this dissertation develops tools to overcome challenges faced in the large-scale dissemination of mobile health (mHealth) interventions. A novel Three-Degrees-of-Freedom Kalman Filter-based Hybrid Model Predictive Control (3DoF-KF HMPC) controller is formulated for physical activity interventions and evaluated in a clinical trial, demonstrating its effectiveness.

Furthermore, this dissertation expands on understanding the underlying dynamics influencing behavior change. Engineering principles are applied to develop a conceptual approach to generate dynamic hypotheses and translate these into first-principle dynamic models. The generated models are used in concert with system identification principles to enhance the design of experiments that yield dynamically informative data sets for behavioral medicine applications. Additionally, sophisticated search, filtering, and model estimation algorithms are applied to optimize and personalize model structures and estimate dynamic models that account for nonlinearities and ``Just-in-Time'' (JIT; moments of need, receptivity, and opportunity) context in behavior change systems. In addition, the pervasive issue of data missingness in interventions is addressed by integrating system identification principles with a Bayesian inference model-based technique for data imputation. The findings in this dissertation extend beyond physical activity, offering insights for promoting healthy behaviors in other applications, such as smoking cessation and weight management.

The integration of control systems engineering in behavioral medicine research, as demonstrated in this dissertation, offers broad impacts by advancing the field's understanding of behavior change dynamics, enhancing accessibility to personalized behavioral health interventions, and improving patient outcomes. This research has the potential to radically improve behavioral interventions, increase affordability and accessibility, inspire interdisciplinary collaboration, and provide behavioral scientists with tools capable of addressing societal challenges in mHealth and preventive medicine.

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