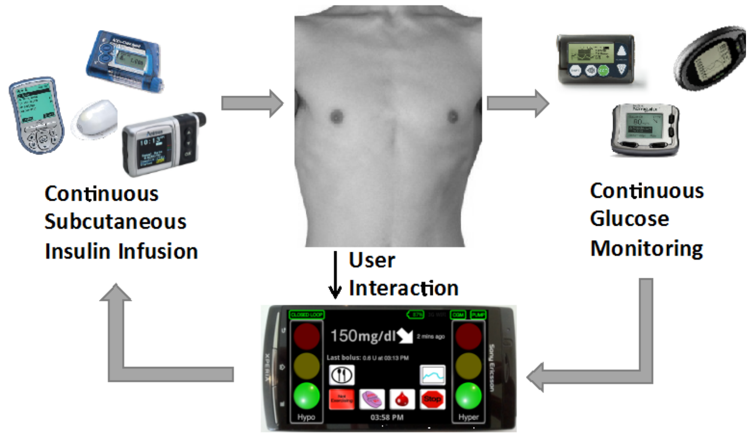
Optimization and Control Group for Medical Devices & Networks

Closed-Loop Medical Devices & The Artificial Pancreas



Our research relates to theory and application of stochastic models and methods for stochastic control and optimization in various application domains, including medical devices for the treatment of diabetes, resource management in wireless systems, and network traffic engineering. In conjunction with the UVa Center for Diabetes Technology, our group has contributed to the development of algorithms for closed-loop and advisory mode control of type 1 diabetes, i.e. the "artificial pancreas", with NIH and JDRF funded clinical trials underway. Additionally, our group is a member of the Broadband Wireless Access and Application Center (BWAC) at UVa, which addresses issues of information management in mission-critical wireless systems. Our work within the BWAC addresses protocol mechanisms for dynamically allocating bandwidth for end-users operating in constrained networks, with applications in reporting health data to back end systems.

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"Developing 'smart' algorithms for medical and wireless technologies to better understand the human condition."

Closed-loop Medical Devices

A major activity of our group is the design of *closed-loop* medical devices, where treatment for the patient evolves as a dynamic process in response to feedback, such as drug infusion systems for analgesia, control of blood pressure, and pacemakers. There is a clear need for these types of advanced treatment options. However, the development and validation of closed-loop medical devices remains a major challenge, especially in the translation of bench top prototypes to clinical practice. Ultimately, clinical outcomes delivered by a closed-loop system have to be compared with current caregiver-centric approaches, and patient safety is a fundamental requirement for regulatory approval. Many factors complicate the design of safe and effective closed-loop systems, including (i) complexity of the physical plant (scale, scope, nonlinearity, time-variability), (ii) complex interactions between structural design and the controllability and observability of the plant (e.g. sensor and actuator selection/placement for nominal performance and assurance), and (iii) unknown or difficult-to-characterize exogenous disturbances and sensor/actuator fault modes. In addition, most closed-loop medical devices must be adapted to the unique physiology and clinical requirements of individual patients. Our group's main activity in this area is in the development of an "artificial pancreas" device for the treatment of type 1 diabetes. Outpatient clinical trials based on our technology are underway.

Stochastic Optimization and Control – The Human Connection

Humans benefit from control systems every day. The ability to automatically reject external disturbances and maintain system operation around a desired operating point is profoundly useful. In designing any control system it is essential to have in mind a model for the disturbances that push the system being controlled away from the desired operating point, and many different disturbances that push the system being controlled away from the desired operating point, and many different disturbance models have been studied over the years. However, when it comes to disturbances that are the result of human behavior, there appears to be a lack of clear guidelines on what models and how to design control systems around them. We are working to design controls systems where the principle disturbances are the result of routine human behavior, i.e., titration of pharmaceuticals, kinetics/potential energy balance in hybrid automobiles as a function of driver behavior load management in 'network' infrastructures and control of blood glucose concentration for patients with type 1 diabetes. The main challenge in this arena is to identify probabilistic model structures for human disturbances that both fit with available data bout human behavior and admit the synthesis of safe and effective control algorithms.

QoS and Resource Management for Wireless Telemetry of Medical Data

Real-time assessment of wireless service quality is a challenge, especially for highly mobile hosts with transient service requirements. For some mission critical applications, such as telemetry of medical data for remote diagnosis and treatment, traditional measures of quality of service, especially those suited for persistent streaming applications, can be inadequate. In some applications the purpose of QoS assessment is to provide an accurate, instantaneous prediction of whether the image upload will be successfully received and acknowledged within a given latency window based on the location and speed of the ambulance. In this setting, the explicit assessment of bandwidth is an unnecessary and potentially misleading approach to characterizing the available service. Our group addresses these issues along with the related issues of resource allocation and provisioning in the development of wireless health and medical devices.

RECENT RESEARCH DEVELOPMENTS

- S.D. Patek, L. Magni, E. Dassau et al., Modular closed-loop control of diabetes, *IEEE Transactions on Biomedical Engineering*, 59(11):2986-2999, 2012.
- M.Breton et al. (including S.Patek), Fully integrated artificial pancreas in type 1 diabetes modular closed-loop glucose control maintains near normoglycemia, *Diabetes*, 61(9):2230-2237, 2012.
- S.D. Patek et al., In silico preclinical trials: methodology and engineering guide to closed-loop control in T1DM*, J Diabetes Science and Technology*, 3:2269-282, 2009.

RECENT GRANTS

- NSF-Control Subject to Human Behavioral Disturbances
- Lilly USA LLC – Development of Lilly-Specific CGM-Based Insulin Dosing Algorithm for Type I Diabetes Mellitus
- MITRE (BWAC Membership Project) – Reliable Long-Term Wireless Monitoring of Motion Disorders in Patients with Chronic Conditions

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