Progress toward Realizing the Artificial Pancreas

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Type 1 diabetes mellitus (T1DM) is a disease that results in lifetime dependence on exogenous insulin due to the inability to naturally produce insulin in the pancreas. The effects of untreated T1DM initially are elevated blood glucose levels and acidosis; as the ability to produce insulin is completely lost, those with T1DM must receive insulin to survive. Intensive therapy managed by multiple daily injections and monitoring of blood glucose, has had success, but remains an annoyance to the subject and often results in poor control. A fully automated system, or artificial pancreas (AP), will alleviate the burden for the subject and also allow for better and safer control.

Recent developments in glucose sensors and insulin pumps have facilitated the development of the AP, which will integrate sensing and insulin delivery technology with a set of control strategies and several safety layers. The integral parts of the artificial pancreas include communication, modeling, control algorithms, monitoring, and safety algorithms. Several control strategies have been explored by this research group, including many variations on model predictive control (MPC), learning algorithms that can deal with diurnal insulin variability, and hybrid systems that incorporate new forms of insulin. These control strategies may incorporate either a priori or personalized models.

In addition to the base control algorithm used in the AP, several additional components to maintain the safety of the system and address challenges must be incorporated. Many advances in safety algorithms have been formulated. The estimation of the amount of insulin in the body, or insulin-on-board (IOB), has been incorporated as a constraint on delivery of insulin. An extremely important safety algorithm is one in which hypoglycemia, or low blood sugar, is predicted; this can become a very dangerous condition very quickly, and must be monitored closely. A safety mechanism that has been developed to intervene in times of emergency is a telemedicine approach in which text messages are sent to either the subject’s doctor or guardian when subjects do not respond to safety alarms.

In order for all of these features to be incorporated, the Artificial Pancreas System (APS©) has been designed. The APS is the communication medium that has emerged from the collaboration of engineers from UCSB and doctors and clinicians from the Sansum Diabetes Research Institute (SDRI) to tie together all of the hardware and software involved in the AP (see Figure 1). Recently, the APS has allowed this group to clinically investigate a realization of an MPC strategy that can be imbedded on a chip in a future device.

The development of the AP has progressed very quickly. Many challenges remain, including addressing subject variation, the effects of different meals, stress, and exercise. Also, the devices used in the AP are continually improving, but often have inaccuracy and communication problems. Incorporating an appropriate control strategy, model, failsafes and monitoring for adverse events will be a feat, but one that is well on its way to being accomplished.

Figure 1: Schematic representing the components of a closed-loop system with RF communication links. RF is radio frequency, RS-232 is a standard for serial binary data transfer, and USB is Universal Serial Bus.