Cyber-Physical Platform Development for Multivariable Artificial Pancreas Systems

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ABSTRACT

This paper describes a distributed sensor platform for a new breed of artificial pancreas devices. In recent work, a multi-variable adaptive algorithm has been proposed which incorporates physical activity of the patients for accurate prediction and control of glucose levels. In order to facilitate this algorithm, the authors integrate a smartphone and multiple sensors including activity trackers and a glucose monitor into a distributed system. The proposed sensor platform provides real-time data access for the artificial pancreas control algorithm hosted on a remote device.

Keywords Activity Trackers, Artificial Pancreas, Bluetooth LE, Remote Database, Sensors Fusion

INTRODUCTION

With a 9.3% of the US population suffering from diabetes (10% have Type 1 diabetes (T1D) and need insulin injections), research on blood glucose level management and insulin control algorithms is rapidly gaining momentum (Centers for Disease Control and Prevention, 2014). Currently, multiple insulin pumps exist wherein patients manually adjust the insulin amount needed to keep glucose levels in desired range. However, a commercial automatic artificial pancreas is not available. An Artificial Pancreas (AP) system (Turksoy, Quinn, Littlejohn, & Cinar, 2014a; Turksoy et al., 2014b; Turksoy et al., 2014c; Cobelli, Renard & Kovatchev, 2011) can predict the glucose level evolution in blood and infuse the right amount of insulin in response to that level, when needed. One critical component of the AP is the control algorithm that computes the amount of insulin to be infused at a specific time. Too much insulin will result in hypoglycemia, whereas not enough insulin will cause hyperglycemia. Hypoglycemia (blood Glucose Concentration (GC) <70 mg/dl) can lead to dizziness, fainting, diabetic coma or death.

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Acute hyperglycemia (GC>250 mg/dl) can lead to ketoacidosis in short term, and blood vessel damage in long term, causing complications such as cardiovascular diseases, neuropathy, blindness, wound ulcers, and kidney failure.

With an open loop algorithm as in (Farmer, Jr., Edgar, & Peppas, 2008), continuous assessment and decision making by the patient or care provider is necessary to adjust the insulin dose. A closed-loop control algorithm, can provide a real autonomous system. With drastic variations that can come from something as simple as eating or exercising, the control algorithm needs a way to anticipate them. One proposed solution given in (Thabit & Hovorka, 2012) is the practice of announcements, every time one of the destabilizing activities is about to take place. Nevertheless, with the constant interaction of the user, the automatic operation will cease.

In this work, we opt for another innovative scheme, a fusion of sensors (Elmenreich, 2007) to implement a multi-variable adaptive identification and control system introduced in (Turksoy et al., 2014c). The control algorithm will be able to predict rapid changes in glucose levels even when exercising. We incorporate fitness tracking sensors (such as heart rate, accelerometer, galvanic skin response or temperature sensors) as well as the glucose sensor data to the AP control algorithm.

The outline of the paper is as follows: Section 2 discusses relevant work in AP systems. Section 3 provides the overview of the proposed platform and introduces the system components. Section 4 describes the communication protocols and the data acquisition using the smartphone. Section 5 presents the database interface for both local and remote data storage, and an interface for the AP control algorithm is shown in Section 6.

RELATED WORK

Several companies offer insulin pumps wherein patients implement Continuous subcutaneous insulin infusion (CSII) by manually adjusting basal and bolus (for meals) insulin doses infused. Subcutaneous glucose sensors that report blood glucose concentration (GC) every 5 minutes to a continuous glucose monitor (CGM) provide the opportunity to automate insulin delivery by developing automatic control algorithms based on CGM glucose information. The current level of commercially available “automatic control” in CSII in the United States is an insulin pump that can shut off insulin delivery if the user’s reported GC drops below a threshold limit (usually 70 mg/dl). An improvement to this system (available to patients only in Australia) shuts off insulin delivery based on GC predictions 30 minutes in the future. Advanced hypoglycemia alarm systems have also been proposed (Buckingham et al., 2010; Cameron et al., 2012; Eren-Oruklu et al., 2012). While automatic AP is not commercially available, several research groups in the US and the world are conducting clinical studies with AP prototypes. AP prototypes use GC predictions based on recent GC readings and use model-based control algorithms to determine the best insulin infusion flow rate to bring GC as close as possible to the desired reference trajectory or range. Some controllers integrate proportional-integral-derivative (PID) controllers with glucose and insulin estimators (Steil et al., 2006; Steil et al., 2011), others use model-based and model-predictive control (Cobelli, Renard & Kovatchev, 2011; Breton et al., 2012; Bequette, 2012) or rule-based fuzzy logic (Maushet et al., 2013; Phillip et al., 2013) mental “models”. Some research teams have also proposed dual-hormone APs that use glucagon and insulin (Ward, Castle & El Youssef, 2011; Russell et al., 2012).

AP systems that rely solely on GC measurement cannot respond to changes that will affect GC until these factors modify GC, unless manual changes are made when they are known to occur. Examples of manual changes include insulin boluses before a meal and reducing insulin
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