Journal of Diabetes Science and Technology
Volume 7, Issue 3, May 2013
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ORIGINAL ARTICLE

An Early Warning System for Hypoglycemic/Hyperglycemic Events Based on Fusion of Adaptive Prediction Models

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Abstract

Introduction:

Early warning of future hypoglycemic and hyperglycemic events can improve the safety of type 1 diabetes mellitus (T1DM) patients. The aim of this study is to design and evaluate a hypoglycemia/hyperglycemia early warning system (EWS) for T1DM patients under sensor-augmented pump (SAP) therapy.

Methods:

The EWS is based on the combination of data-driven online adaptive prediction models and a warning algorithm. Three modeling approaches have been investigated: (i) autoregressive (ARX) models, (ii) autoregressive with an output correction module (cARX) models, and (iii) recurrent neural network (RNN) models. The warning algorithm performs postprocessing of the models' outputs and issues alerts if upcoming hypoglycemic/hyperglycemic events are detected. Fusion of the cARX and RNN models, due to their complementary prediction performances, resulted in the hybrid autoregressive with an output correction module/recurrent neural network (cARN)-based EWS.

Results:

The EWS was evaluated on 23 T1DM patients under SAP therapy. The ARX-based system achieved hypoglycemic (hyperglycemic) event prediction with median values of accuracy of 100.0% (100.0%), detection time of 10.0 (8.0) min, and daily false alarms of 0.7 (0.5). The respective values for the cARX-based system were 100.0% (100.0%), 17.5 (14.8) min, and 1.5 (1.3) and, for the RNN-based system, were 100.0% (92.0%), 8.4 (7.0) min, and 0.1 (0.2). The hybrid cARN-based EWS presented outperforming results with 100.0% (100.0%) prediction accuracy, detection 16.7 (14.7) min in advance, and 0.8 (0.8) daily false alarms.

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Abbreviations: (ANN) artificial neural network, (AR) autoregressive, (ARMA) autoregressive moving average, (ARX) autoregressive with external input, (cARN) autoregressive with an output correction module/recurrent neural network, (cARX) autoregressive with an output correction module, (CC) correlation coefficient, (CGM) continuous glucose monitor, (CHO) carbohydrate, (EWS) early warning system, (HbA1c) glycosylated hemoglobin, (MDII) multiple daily insulin injection, (PH) prediction horizon, (RMSE) root mean square error, (RNN) recurrent neural network, (SAP) sensor-augmented pump, (T1DM) type 1 diabetes mellitus, (TL) time lag

Keywords: adaptive models, diabetes, early warning system, glucose prediction

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Abstract cont.

Conclusion:

Combined use of cARX and RNN models for the development of an EWS outperformed the single use of each model, achieving accurate and prompt event prediction with few false alarms, thus providing increased safety and comfort.

J Diabetes Sci Technol 2013;7(3):689–698