Abstract of the Thesis

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Abstract

More than 500 million individuals in the world have diabetes today, with an estimated number of 783 million by 2045. Monitoring of Blood Glucose (BG) is an essential activity, particularly in individuals with Type 1 diabetes (T1D), who need exogenous insulin to manage the condition. Frequent BG monitoring is possible with Continuous blood Glucose Monitoring; however, it relies on invasive blood sampling, which can be painful and prone to infection. The existing CGM systems use only the current BG level to compute insulin bolus doses, without accounting for variation in carbohydrate intake during meals. This condition, in most cases, causes T1D patients to have hypoglycaemic and hyperglycaemic episodes. Otherwise, uncontrolled elevated BG leads to severe complications, including eye disease, neuropathy, nephropathy, and cardiovascular disease. In general, good glycaemic control in the management of diabetes has been a great challenge. To address these issues, this study focuses on developing a non-invasive CGM device that measures BG, predicts future BG levels, and calculates insulin boluses based on these predictions to improve glycaemic control.

The proposed Continuous Blood Glucose Monitoring system involves a non-invasive, single-

sensor device operating at 940 nm to obtain physiological signals and produce a structured dataset. The dataset is used with the Shapley additive explanations method to identify key features in the estimation of blood glucose. A distributed architecture provides lightweight machine learning-based continuous estimation of BG levels, and a forecasting architecture predicts future BG levels with a 60-minute horizon. Bolus insulin doses are calculated using the forecasted BG, carbohydrate intake, and subject-specific characteristics. Intermittent insulin boluses are tested across 10 virtual adult cohorts in the UVA/Padova T1D simulator under different meal and insulin conditions.

The analysis indicates that the proposed system estimates BG levels with a mean absolute difference (MAD) of 1.79 mg/dL and a RMSE of 6.08 mg/dL. In CGM, a deep learning-based hybrid architecture is also proposed for BG forecasting. This architecture demonstrates improved performance, achieving RMSE values of 3.42, 6.45, and 17.73 mg/dL for 15-, 30-, and 60-minute prediction horizons (PHs), respectively, and 12.57, 20.72, and 34.41 mg/dL for real cohorts. Additionally, the Mean Absolute Error (MAE) for 15-, 30-, and 60-minute PHs is 2.11, 4.47, and 11.78 mg/dL for virtual cohorts, respectively, and 7.9, 14.13, and 25.5 mg/dL for real cohorts. The proposed approach improves glycaemic stability, with 98.86% of time in the euglycemic range (70-180 mg/dL), and reduces the risk of hyperglycaemia and hypoglycaemia, as indicated by mean values of the High BG Index (HBGI) at 0.46, Low BG Index (LBGI) at 1.27, and BG Risk Index (BGRI) at 7.49. Control-Variability Grid Analysis (CVGA) confirms the clinical applicability, showing that all virtual patients' BG levels are within zones A and B.

The proposed Continuous Blood Glucose Monitoring system offers a convenient and non-invasive solution for managing T1D. This system enhances glycaemic control by using forecasting to make insulin dosing decisions. It holds significant potential for future use in intelligent, personalized diabetes care systems.

This PhD thesis will help develop intelligent diabetes management by combining non-invasive blood glucose monitoring, machine-learning-based glucose prediction, and predictive insulin therapy into a single, streamlined package. The proposed distributed blood glucose measurement architecture accurately estimates glucose levels without invasive measurements, and, under the proposed DCRNet forecasting model, future glucose level estimates are reliable. The main achievement of the research is the Intermittent Insulin Bolus (IIB) therapy proposed in this work, which is based on 60-minute-ahead glucose forecasts and suggests insulin doses in advance for patients with Type 1 Diabetes. The proposed approach achieves approximately 98% glycemic control, highlighting its potential to improve glucose regulation, reduce the risk of hypo- and hyperglycemia, enhance patient safety, and foster the development of next-generation artificial intelligence (AI)- enabled closed-loop diabetes management devices.

List of Publication(s):

[1] **Ketan Lad**, Maulin Joshi, and Amit Joshi, “Optical Sensor Based Continuous Blood Glucose Estimation Using Lightweight Distributed Architecture,” SN Computer Science, vol. 5, no. 8, Dec. 2024, https://doi.org/10.1007/s42979-024-03318-x.

[2] **Ketan Lad** and Maulin Joshi, “DCRNet: Hybrid Deep Learning Architecture for Forecasting of Blood Glucose,” Journal of Electronics, Electromedical Engineering, and Medical Informatics, vol. 8, no. 1, pp. 53–68, Dec. 2025, https://doi.org/10.35882/jeeemi.v8i1.1245.

[3] **Ketan Lad** and Maulin Joshi (2023). Continuous Blood Glucose Monitoring Using Explainable AI Techniques. In M. S. Raval, M. Roy, T. Kaya, & R. Kapdi (Eds.), Explainable AI in Healthcare. Chapman and Hall/CRC. https://doi.org/10.1201/9781003333425.