CHAPTER 10

CONCLUSION AND FUTURE SCOPE OF THE WORK

10.1 INTRODUCTION

The CGM technology has the potential to revolutionize the management of diabetes, by providing the online feedback about current glucose levels and rate of change. Its accuracy is limited by factors such as, time lag between BG and IG, sensor drift, nonlinear responses and random noise. In this research work, models for prediction of the glucose concentration in blood plasma have been developed via three different approaches and examined consequently. The enhancements in the prediction efficiency of the proposed prediction models were analyzed both with the noisy CGM sensor data and the noise free CGM sensor data obtained with the denoising technique, HFT.

10.2 CONTRIBUTIONS OF THE RESEARCH

1. Development of an algorithm with BG and sensor gain deviation parameters dynamics modeled with an AR process and applying HFT for denoising of CGM data to improve the quality of CGM signal and compare its performance with the MA and Kalman Filter.
2. An algorithm has been formulated that applies a moving window to CGM data to extract the features which would be used to analyze BG variability and incorporate in customized training of a FFNN for the prediction of BG.
3. An algorithm has been devised for the customized training of ANFIS which operates with the dominant features (Mean and Skewness) that
have high priority in representing the BG dynamics based on the minimum RMSE value in the prediction of BG. The traditional chain rule has been replaced with an update procedure which makes use of the contributing factors from the ANFIS layers that are optimized with Differential Evolution.

4. Comparison of the proposed prediction models at normo/hypo/hyperglycemic regions and with different classes of subject data to analyze the performance of the prediction models.

5. Clinical evaluation of the proposed prediction models with real-time data.

In HFT, the present and past values of BG, IG and sensor gain deviation were employed in SS modeling with EKF algorithm, and applied for the training of neural network for denoising of various errors in CGM sensor data. This error removal procedure has assisted the enhancement of prediction efficiency to a maximum of 35.5%.

Amidst the three proposed prediction models, it has been observed that the forecasting performance of ARIMA model was suboptimal with an average RMSE of 20.55 mg/dL and a time lag of 16 minutes. Whilst, FNN and ANFIS have provided enhanced results with average RMSE values of 10.35 and 4.9 mg/dL, respectively and time lags of 9.8 and 5.6 minutes, respectively. The prediction performance of ANFIS model is more significant in varied classes of diabetic data sets.

ANFIS prediction model maintained a consistent and compact fuzzy rule base, which was achieved with pruning of redundant features at the input selection. This maintained the integrity of the derived rule base and ensured that the dynamics of the problem domain has been properly modeled. The enlightened results have indicated the superiority, owing to the
combination of computational intelligence of neural network with the expert system approach, for tracking the BG dynamics. Furthermore, the custom made error propagation applied for the estimation of membership function parameters enabled to achieve the betterment of results, with 98% of points to lie in the Zone (A+B) of CEGA, even in 60 minutes PH.

In the clinical trials, the proposed final ANFIS prediction model is able to predict an average of 67.8% hypoglycemic conditions at 30 minutes PH and an average of 48% of hypoglycemic conditions at 60 minutes PH which would be helpful in avoiding diabetic complications.

ANFISs realized by an appropriate combination of neural and fuzzy systems have provided a valuable modeling approach of complex systems i.e. BG dynamics. The current research work has demonstrated the utility and effectiveness of soft computing approaches in the development of prediction models for BG dynamics.

Since the glucose variability is a main issue to be addressed, to reduce the risks of diabetes mellitus, the prediction model incorporating the features of fluctuations in the input data is the need of today’s diabetic world. This work has amply proven the effectiveness of AI techniques in handling complex physiological systems.

10.3 FUTURE SCOPE

Glucose levels are affected by many variables, such as stress, physical activity, hormonal changes, and periods of growth, medications, illness/infection, fatigue, as well as food intake and insulin tolerance. Since the BG dynamics is due to several sources of disturbances, their impact on BG level is highly correlated, dynamic and nonlinear making it difficult to distinguish the effect each input on BG variation. Thus, the future work is to enhance the proposed models which would be able to take into account the
simultaneous and multiple effects of food, activity, stress and their interactions.

The accuracy of the proposed prediction model could further be increased by optimizing the consequent parameters by Particle Swarm Optimization, Genetic Algorithm etc.

The proposed method might be tested in artificial pancreas and for longer PHs, considering the promising features such as, amount of carbohydrate food, insulin dosage, duration of exercise and emotional factors.

The predictive system could be designed in such a way to detect the underlying changes in the subjects’ glucose insulin dynamics, because of the factors such as stress, illness and unusual exercise. This might be useful for the artificial pancreas project.

HbA1C, is a less variable measure that itself could act as a biomarker for predicting the plasma glucose levels. Hence in future, the concept of proposed works could be extended suitably for the prediction of HbA1C with the dynamic relation between mean plasma glucose and HbA1C values.

In future, Monte Carlo simulation could be applied to generate data of varied nature, which would be used to analyze the performance of the proposed prediction models.

Another area of future work is to apply and test the accuracy of denoising with HFT and the prediction with Custom ANFIS to the non invasive CGM data which suffers with environmental and physiological interferences.

10.4 SUMMARY

This chapter identifies the future work to extend the contributions presented in this thesis. The future work could further improve the results of blood glucose prediction through FNN and custom ANFIS models. Another
area of future work is to make the contributions of the thesis available to both patients and health care professionals.