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A LITERATURE REVIEW ON BLOOD GLUCOSE LEVEL MONITORING

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ABSTRACT

For human being glucose is vital and the main source of energy present in the blood. The normal level of blood glucose is 72 to 99 mg/dl during fasting and less than 140 mg/dl after the food. Diabetes is the condition where blood glucose level is more than the normal range due to the production of insufficient insulin from the body of human being. Therefore it is necessary to regulate blood glucose to a normal range in diabetic patient. In this regard, many researchers have investigated on the regulation of Blood glucose using PID controller. The PID Controller can be used to control any process. It is done by properly tuning the parameters of PID controller until the required outcome is obtained for a particular plant or process. From the literature it is observed that the researchers have worked on Tuning parameters of PID to regulate blood glucose level to a normal range by using various techniques like routh's approximation model reduction method, PID-Fuzzy Logic Controller, Zeigler Nichols and cohen-coon method, Genetic Algorithm. Here, an attempt has been made to highlight the contribution of various researchers towards the design and regulation of the blood glucose level.

Keywords: Blood Glucose Level, Diabetes, Fuzzy Logic Controller, Genetic Algorithm, PID Controller,

1. INTRODUCTION

Diabetes is one of the common disease found all over the world. It's a chronic disease which effects the regulation of blood glucose level. Each and every country is fighting against this common disease to find a permanent solution. According to WHO in 2014, 8.5% of adults aged 18 years and older had diabetes. In 2019, the diabetes was the direct cause of nearly 1.5 million deaths. Between 2000 to 2019, there was a 3% increase in mortality rates due to diabetes. India is having nearly 80 million diabetic patients which is second highest in the world and the death rate due to diabetes in India is nearly 7,00,000 in the year 2020. Diabetes disease is the condition when human body contains more glucose level then the normal. The normal level of glucose level in blood is about 72 to 99 mg/dl when fasting and less than 140mg/dl after eating. To maintain this normal level of glucose in diabetes patient, determination and regulation of glucose level in blood is necessary.

There are two types of diabetes namely:

i. Type1 diabetes

ii. Type2 diabetes

i) Type1 Diabetes:

In type1 diabetes the pancreas fails to generate insulin in human body because the β cells in pancreas get destroyed due to some reasons like inflammation. The insulin is the main hormone which pushes glucose from blood to tissues. But when the β cells got damaged the insulin secretion will not be there so the glucose content in blood gets build up and crosses the maximum limit. If it crosses the normal range it becomes high sugar level leading to the condition called as hyperglycemia. This diabetic condition is also called as Type1 diabetes.

ii) Type2 Diabetes: Here, the pancreas produces the insulin but the body will not be in the position to utilize it to convert glucose into energy. This also increases the glucose level in blood which in turn causes hyperglycemia. The main reasons for type 2 diabetes are: Overweight, Depression, no physical activity, heredity.

There is also a situation where glucose level in blood becomes lower than the normal value. this condition is called as hypoglycemia. This condition happens when the insulin produces more but there will be not enough glucose content in blood. This condition may become more worst which may even lead to death.

Therefore it is necessary to control and regulate the blood glucose level in normal range. To maintain this in diabetic patients the proper medications are used but the medications used for the treatment of diabetes are having side effects like low sugar, Stomach upset, Weight gain, Tiredness or dizziness, risk of liver disease, Kidney complications, Diarrhoea, gas, risk of anemia. Therefore, instead of going for drugs it is better to treat patients with artificial pancreas. The modeling of artificial pancreas require with a necessary controller.

Nowadays, to regulate and control the sugar level within normal value a controller is required. This controller should regulate the blood sugar level for the normal range. The main parameter to be considered is sugar level and biological hormonal effect. For this purpose PID controller, may adopted for this purpose.

2. METHODOLOGY

The PID controller generates controlled output according to the reference input and error. The output depends on Proportional constant Kp , Integral constant Ki and Derivative constant Kd . By proper tuning of the PID controller parameters Kp, Ki, Kd the controlled output and error can be controlled to get the desired output. The general block diagram of PID controller is as shown in Fig. 1.

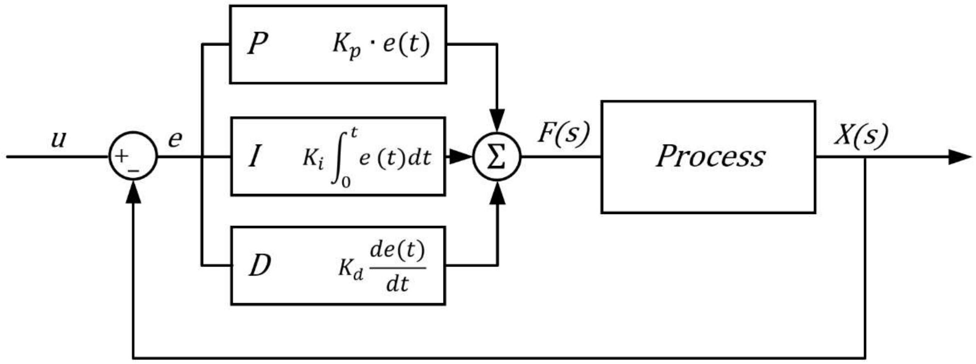

Fig. 1: General Block Diagram of PID controller

Significance of PID controller is, it will control the process or plant output such that there should be zero error between reference input and activated output. It will control the process by tuning the parameter values k_p, k_d, k_i. By proper tuning of the controller parameters, can easily control any process as per requirement. The process need to be modeled for controlling accurately.

The mathematical models for diabetic patients are derived from different clinical analysis. One can control the blood glucose level in diabetic patient models by properly tuning the PID controller. The parameters are tuned until normal glucose level is obtained. Many researchers have worked on tuning PID controller to regulate blood glucose level model. Few of the works are discussed below.

3. LITERATURE SURVEY

Peng Li, et.al.,[1], has developed PID based control of glucose concentration in subjects with type 1 Diabetes patient using a simplified model known as In Silico Trial. The developed PID controller works with routh's approximation model reduction method. Here, the order of the system can be reduced and so that parameters required will be less as in table 1.

Table 1: Parameters requirement for patient models

Model name	Insulin infusion	Meal absorption
Original model	8	10
Simplified model	4	3

In this for both insulin infusion and meal absorption the cobelli model equations are used. The insulin infusion model after the routh's approximation the transfer function becomes

$$G_I(S) = \frac{0.0903s + 0.0126}{s^2 + 0.0339s + 3.0919 \times 10^{-4}} \ .$$

For meal absorption model the transfer function after routh,s approximation becomes

$$G_M(S) = \frac{2.557\times10^{-6}}{s^2 + 0.0358s + 2.216\times10^{-4}}.$$

Based on the above insulin-glucose model the PID controller is tuned to control the blood glucose concentration.

The outcome is the Blood glucose level is regulated but the duration of hyperglycemia is about 187 minutes and hypoglycemia is 87 minutes and the peak overshoot is more than 2% and settling time is about 1500 minutes which is quite large.

Mohamed Al-Fandi et.al.,[2] has developed Optimal PID-Fuzzy Logic Controller for Type 1 Diabetic Patients, **w**here an optimal PID fuzzy logic controller is used. Here, the parallel search design of PID controller is used with fuzzy logic controller. The result shows that the performance is almost similar to beta cells and it reduces genetic algorithm search space. Here the Limitations are Peak overshoot and error is more and it takes more settling time which is more than 1500 minutes.

The tuning of Digital PID Controller for Blood Glucose Level of Diabetic Patient was presented by **Rohith Sharma et.al.,[3]**. The tuning of PID controller was done using Zeigler Nichols and cohen-coon method. The best method is implemented by converting to digital form. For Zeigler Nichols method the advantage is of fast response. For cohen-coon method the advantage is less overshoot and less settling time. Here, the Drawbacks are For zeigler-nichols the system has very high overshoot, and for cohen-coon method the system doesn't able to reduce overshoot completely to zero and also settling time is not acceptable.

The Design of CCII PID Controller for the Control of Glucose Blood Level Using GA [**Sheetal Tiwary et.al.,** [4]. Current conveyor second generation PID controller has been designed using genetic algorithm for blood glucose level control. The outcome of the proposed PID controller is that it provide better performance as compared to conventional method. In conventional method the peak overshoot is 2.322% but in proposed method it 10.92% which is very large. The settling time is also more and is about 2 hour.

Dr. S Vivekanandan, et.al., [5] designed Optimal Control Identification of IMC and PID Controllers for Insulin Infusion. Here, the control variables are optimized and PID controller is tuned by Genetic Algorithm. In this research work two different control strategies are used namely, Internal model control and PID control. The outcome of the method is using IMC controller external disturbance is minimized and by using PID controller optimal infusion rate is achieved. The overshoot is reduced to almost zero and the desired level of blood glucose level is achieved. The settling time taken is nearly about 200 minutes but still it is large. In some cases the overshoot has not become zero.

The Fuzzy-PID Control for the Regulation of Blood Glucose in Diabetes demonstrated by **Chengwei li, et.al.,[6]**. Here the model used is Bergman model, where the fuzzy based PID controller has been used to maintain the normal blood glucose range. The outcome is the settling time is still 200 minutes but more error. The overshoot is also more of about 19%. The fuzzy PID controller is found to be more effective than conventional PID controller, where control of the glucose level is faster than Conventional PID.

M Nalini, et.al., [7] , proposed Blood Glucose Regulation System Using Model Predictive Controller. Model predictive controller is used to regulate the glucose level instead of PID controller.

The diabetic patient model has been developed using bergmann's minimal model was considered. The transfer function of the system is given by

$$G(S) = \frac{-0.001548}{S^3 + 0.30631S^2 + 0.01151S^1 + 9.92 \times 10^{-5}}$$

For MPC there are three inputs and one output. The step input is given as reference input, meal is given as disturbance and glucose level of patient is given as manipulated variable to the MPC. The blood glucose was controlled to the set point from the proposed implementation. The outcome of the proposed method is, it takes nearly 40 minutes to settle down to 70mg/dl with the disturbance was set to 90mg/dl. The peak overshoot is nearly 14%.

T. **Schauer, et.al., [8]** presented the Model-Based Predictive Control of Blood-Sugar Level in Intensive Care. Here both insulin infusion and glucose infusion models are developed and implemented. The outcome is the simulation was done to bring blood sugar level from 10mmol/l to 5mmol/l. The model was done to control blood sugar level in patients under intensive care. The blood glucose level was brought to required level in about 50 minutes. Here the future prediction was not analyzed. If the glucose goes less then the minimum level then the infusion of glucose from the model is not analyzed in simulation studies.

Sandra M Lynch, et.al., [9] carried out the simulation study on Estimation-based Model Predictive Control of Blood Glucose in Type I Diabetics. The Model predictive controller has been used to regulate blood glucose level. The bergman model was chosen and is simulated and tested with MPC. The outcome of the method is that, the settling time was about 3 hours and the controlling action took 2 hour to bring back the sugar level to normal range. The results for both hypoglycemic and hyperglycemic condition were checked. The drawbacks are It took more like 3hour for settling and for controlling action which is not good at the time of intensive care. Also the future prediction analysis is not shown clearly.

The Control of blood glucose level in diabetic patient using predictive controller and delay differential equation by **Mojgan Esna Ashari, et.al., [10]**. A non linear predictive controller was used to regulate in the present implementation. Here, the uncertainty and physiological data are also considered. The outcome was the sugar level and insulin level through out the day was analyzed and when the blood glucose changes it was brought back, however the drawbacks are it took more time with larger iterations to regulate.

Zlatko trajanoski, et.al., [11] presented the Neural Predictive Controller for Insulin Delivery Using the Subcutaneous Route. Here an amalgamation of Neural network and non linear predictive controller has been used. The Neural network is used for identification and simplification of non linear system. The system is regulated by predictive controller. The outcomes are the control of glucose level using neural predictive controller was simulated and the time required for control is nearly 3hr, which is quite large. The system identification process requires 2 hr which is difficult for online implementation. The hardware implementation part is not justified.

Modelling and Simulation Study of Glucose Insulin Control in Type 1 Diabetic Patient Used for Developing Artificial Pancreas [**Cifha crecil dias, et.al., [12]**] . Here, both PID controller and Model predictive controller were used and compared with Bergman minimal model, augmented model and sorensen model. The outcomes are the PID controller was simulated for each model and the results are derived. For Bergman model it took 50 minutes for regulation, for augmented model it took nearly 400 minutes for regulation. whereas for sorensen model it took 30 minutes and almost it is in normal range. The model predictive controller was simulated for each model. For bergman model it took 30 minutes for regulation, where it is in normal range. For augmented model it took 300 minutes for regulation. whereas for sorensen model it took 50 minutes. The Limitations are in all the cases the required time for regulation is more of about nearly 30 to 50 minutes. If the glucose is level is too low then the analysis is not performed.

Based on the above literature survey it has been felt there is a sufficient scope to implement a controller to regulate the blood glucose level more efficiently, this motivated to do the research work in this area.

Table 2: Comparison chart of various PID controller for blood glucose level regulation

Sl. No.	**Title of the paper**	**Methodlogy**	**Outcomes**	**Drawbacks**
1.	Peng Li, et.al., - "PID control of glucose concentration in subjects with type 1 Diabetes patient based on a simplified model: An In Silico Trial".	PID controller with routh's approximation model reduction method for the control of glucose concentration.	The Blood glucose level is regulated but the duration of hyperglycemia is about 187 minutes and hypoglycemia is 87 minutes and the peak overshoot is more than 2% and settling time is about 1500 minutes.	1. Here non-linearlity condition of human is not considered And future prediction is not carried out
2	Mohamed Al-Fandi et.al. - "Optimal PID-Fuzzy Logic Controller for Type 1 Diabetic Patients"	Here an optimal PID fuzzy logic controller is used	It takes settling time of 1500 minutes	1. Time for regulation is more. 2. Glucose level control at the time of intensive care is not

				considered
3	Rohith Sharma et.al., - "Tuning of Digital PID Controller for Blood Glucose Level of Diabetic Patient"	Tuning of PID controller using Zeigler Nichols and cohen-coon method has been done. Then the best method is implemented by converting to digital form.	1. For zeigler-nichols the overshoot is 26.67%, settling time is 17 minutes. 2. For cohen-coon method the overshoot is 25.30%, settling	1.Hypoglycemic condition is not analyzed. 2.Release of glucose is not designed and the peak overshoot is more.
4	Dr. S Vivekanandan, et.al., "Optimal Control Identification of IMC and PID Controllers for Insulin Infusion".	Optimization of control variables has been done and PID controller is tuned by Genetic Algorithm.	Here the settling time is nearly 200 minutes. For some cases the overshoot is not zero.	1.Glucose level control at the time of intensive care is not considered. 2.Future prediction is not done
5	Chengwei li, et.al., "Fuzzy-PID Control for the Regulation of Blood Glucose in Diabetes".	Fuzzy based PID controller is designed to maintain the normal blood glucose range.	Here the settling time is still 200minutes. The error is more. The overshoot is more of about 19%	1.Hypoglycemic condition is not analyzed 2.The peak overshoot is more.
7	M Nalini, et.al., "Blood Glucose Regulation System Using Model Predictive Controller"	Here the authors used model predictive controller for the regulation of blood glucose level instead of PID controller	It took nearly 40 minutes to settle down.	1.The Time for regulation is more. 2.Glucose level control at the time of intensive care is not considered.

8	T. Schauer, et.al., - “Model-Based Predictive Control of Blood-Sugar Level in Intensive Care”	Here the authors used model predictive controller for insulin infusion and glucose infusion.	The blood glucose level was brought to required level in about 50 minutes.	1.The non-linearlity condition of human is not considered
9	Sandra M Lynch, et.al., “Estimation-based Model Predictive Control of Blood Glucose in Type I Diabetics: A Simulation Study”.	Here Model predictive controller is used to regulate blood glucose level.	It took more like 3hour for settling and for controlling action	1. The Time for regulation is more. 2. Future prediction is not done
10	Mojgan Esna Ashari, et.al., - “Control of blood glucose level in diabetic patient using predictive controller and delay differential equation”	A non linear predictive controller is used to regulate.	The sugar level and insulin level through out the day was analyzed and when the blood glucose changes it was brought back.	1. Glucose level control at the time of intensive care is not considered 2. The peak overshoot is more.

CONCLUSION

Diabetes is one of the common chronic disease which effects the regulation of blood glucose level. Each country is fighting against this common disease to get a permanent solution. Therefore there is a need to design the controller to regulate the blood glucose level to a normal range for a diabetic patient model. As discussed in the survey, there is a need of a better PID controller with less settling time to control blood glucose level under both Hyperglycemic and Hypoglycemic conditions. Along with this there is a need to develop PID controller with better Peak Overshoot and also perform for patient model with non-linearity conditions. Finally, Authors are still looking out for best suitable model for blood glucose level monitoring with satisfactorily performance .

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