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Enhanced Optimal Insulin Regulation in Post-Operative Diabetic Patients: An Adaptive Cascade Control Compensation-Based Approach With Diabetic and Hypertension

A. ALAVUDEEN BASHA, (Member, IEEE), AND S. VIVEKANANDAN, (Member, IEEE)
School of Electrical Engineering, Vellore Institute of Technology, Vellore 632 014, India

Corresponding author: S. Vivekanandan (svivekanandan@vit.ac.in)

ABSTRACT In this paper, a cascade control strategy is adapted to control the glycaemic level for post-operative patients in the presence of hypertension. The perioperative strain and sudden pressure distinction may lead to hyperglycemia and osmotic diuresis along with hyperinsulinemia. Also, the recent medical diagnostics show that diabetes and blood pressure occur together, and these two have substantial overlap in its disease mechanism, also there is a need to monitor both the parameters simultaneously and control the glucose level in an optimal manner. The overall control, (cascade) control strategy can be considered with two different types of loops, an inner loop that provides the amount of disturbance created by hypertension and regulates the variance of insulin level in shots of variation. The advisory control algorithms incorporate the cascade methodology along with expert knowledge to treat this disease by using the Fuzzy logic controllers (Mamdani-type) to regulate the proper insulin infusion. The outer loop aims to manage the inner loop parameter variation and control the optimal infusion to the patients. The extensive cascade simulations are demonstrated, and the projected control scenario provides a better outcome and possibly attain better glycaemic control for diabetic cum hypersensitive patients.

INDEX TERMS Diabetics, fuzzy logic, hypertension, glucose control, optimal insulin analysis.

I. INTRODUCTION

In recent years, the growth of diabetes mellitus has drastically increased worldwide. The rate of diabetics' recurrence was approximately 3% in 2000 and its growth is estimated to be 5% by the year 2030. This rapid change indicates the increment of diabetic patients from 170 million to 360 million in approximately in 2030 [3]. Guru Shankar *et al.* did research related to hypertension and identified that diabetes and hypertension have a large perspective. The data analysis has been done on around 12,550 adults and the final outcome predicts that it is almost three times higher than its normative counterparts, also the research clearly indicates that the diabetic people comprehend a clear sign of increased hypertension. Moreover, the consolidation predicts that hypertension and diabetes mellitus are the vital risk factors for CVD (Cardio Vascular Diseases) including atherosclerosis and its complications. This analysis extended that the post-operative stress for a diabetic person will create more complications in the management. These complications prove the complications prove that diabetes and hypertension having a possible amount of common area of metabolism and shows its etiology mechanism. In recent research for diabetes with hypertension study shows that 42.4% only having normal diabetics and normal blood pressure and the 57.9% population having noticeable blood pressure along with the diabetics, in addition this study proves that most commonly the blood pressure occurred for type II diabetic patients in the average of 50 to 80% in common and around 41 % type I diabetes people have normal blood pressure correspondingly. The pathophysiological mechanism (Fig.1) exhibit that the flow of disease development of both hypertension and diabetics and these flow mechanism is to lead to aggravating both the attained factors influence for further developing of cardiovascular complications (CVD) and leading to kidney failures [5]–[8]. Also, this disease mechanism indicates that

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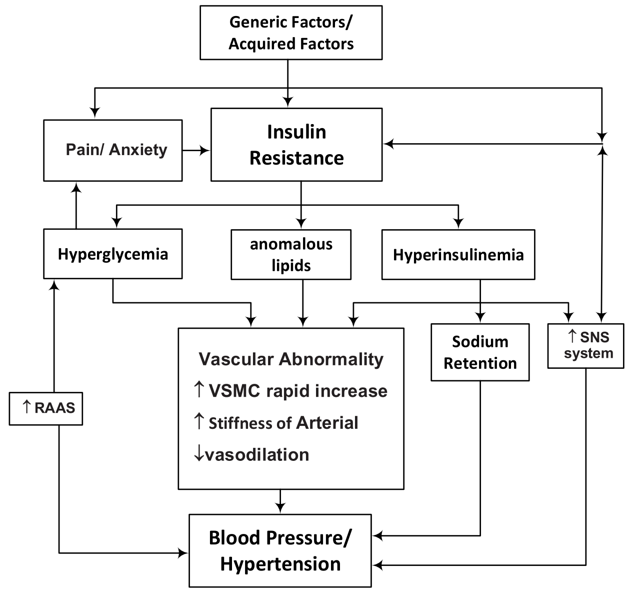

FIGURE 1. **Pathophysiologic scheme and productive of diabetic mellitus in hypertension. (ch.34: Hypertension and diabetes mellitus. 407-418 science direct, 2007 [113]).**

the blood glucose (BG) and blood pressure (BP) can vary depends on the circumstance and these two parameters need to measure and observe its variations continuously, especially the glucose level need to maintain a prescribed level in the post-operative scenario. To achieve this aim implementing complex control (cascade) scheme with improved fuzzy logic control in this work.

The cascade control structure is mainly used to minimize the disturbance and achieve the primary goal and it is used complex structure in process industries for multivariable different process parameters [9] based on the process condition. The methodology of this system is used and implemented in the control to produce the optimal infusion of the insulin based hypertension variation. The BG and BP variation is cumulated and both these parameters will provide a possible intervention for the post-operative situation. Based on the values the continuous monitoring mechanism adopted for both the measurements and the control strategy will control the insulin infusion. The cascade control structure is complex in its nature and the control law needs the comprehensive estimation of its parameter, to achieve the optimal solution the parameters ware tunes in precise based on the variation of its secondary control [10]. To attain the precise and optimal control, considered 50 different post-operative BG and BP samples have been collected in the interval of every hour from various hospitals data and the collected details calculated in average, the parameters are used to control the cascade law to obtain the optimal insulin rate.

II. MATHEMATICAL MODEL OF DIABETIC AND HYPERTENSION

In this section, a transient overview of diabetic and hypertension mathematical model and its mathematical expressions has been presented as two sections along with selected parameters.

A. DIABETIC MODEL

The Mathematical modeling of the human body is a complex task and human system involving several dimensions on its stochastic process, based on the collective factors the design has implemented, especially the blood glucose model and hypertension models are designed as an independent system to regulate the glucose elevation and Hypertension level in the human system. Based on the uncertainty condition the human body fluctuates the glucose level and the pancreas generate improper insulin, To control the glucose level a manual deposition is required to regulate the proper level in the body.

In this condition, the infusion of insulin carry on in manual injection or with the help of automatic system to the perioperative patient and this centimes feeding control and maintain the proper level and this system called as artificial pancreas [11]. The artificial model designed based on the patient conditions and the recommended observations by the physician, this mathematical model finds the correlation between the human body and its insulin resistance along with the connection between them. The human diabetic model will work as per the mechanics concerned with the motion of bodies and this action is acting with the help of diabetic cycle along with the control action. In this paper, we have considered Bergman minimal model [13], [14] which is used to design the insulin regulation to the human body in an artificial manner and this mathematical model indicates the importance of diabetic patients to manage its glycaemic levels. Basically, the observed parameters are approximated and cumulated with the stable process and the cumulated values of the perioperative patient along with sensor system delay errors. The infusion depends on the plasma glucose measurement and the insulin availability of the patient body compactness.

$$\frac{dG_{gl}(t)}{dt} = -p_1\left[G_{Gl}(t) - G_{bd}\right] - X_{plG}G_{Gl}(t) + \left[d(t) + (t)\right] \quad (1)$$

$$\frac{dX}{dt} = -p_2X_{plG}(t) + p_3I \quad (2)$$

$$\frac{dI_{Gl}(t)}{dt} = -n\left[I_{ic}(t) - I_{bd}\right] + \gamma\left[G_m(t) - h\right] + r(t) \quad (3)$$

In the mathematical model $G_{gl}(t)$ and $I_{Gl}(t)$ is denoted as plasma glucose and insulin concentration correspondingly, also X_{plG} is denoted proportional to the insulin concentration in a compartment for remote operation and $I_{ic}(t)$ & $U_{ic}(t)$ are concentrations of insulin in (μ U/ml) & r called as external input insulin (U/h), The value of I is basal value of insulin level in (ml U/L), $G_{Gl}(t)$ is an input glucose infused in an external manner to the human body (mm/min), I_{bd} and G_{bd} considered as preparatory insulin and glucose levels before infusion. The patient parameters P_1, P_2, P_3 shown in table 1 denotes random samples and change of insulin 'n' is narrated

TABLE 1. Diabetic patient model parameters.

	P_1	P_2	P_3
Sensitive Case	0.0280	0.0250	0.0000130
Hyper sensitive Case	0.00	0.0251	0.0000131

as rate, and these ware used in plasma (Min $^{-1}$). Table.1 show the sensitive and hypersensitive patient parameters estimated in the study of patients subjects, based on the parameters of the process model [G_{pGl}] has developed by Lynch et all as per the equation.4 [15]

$$G_{pGl}(s) = \frac{-3.79}{(40s+1)(10.8s+1)} \tag{4}$$

Similarly, the below transfer function indicates the intake meal disturbance as

$$G_{pGl(Meal)}(s) = \frac{8.44}{s(20s+1)} \tag{5}$$

B. HYPERTENSION MODEL

Hypertension management in the post-operative condition is a complex situation and need to maintain the blood pressure as per the prescribed level based on the physician advised values along with the patient's history and acceptance level.

In post-operative condition, the pressure variation is continuously identified and needs to be monitored, alongside these parameters should be compared and diagnosed with blood glucose to avoid sudden variation in blood pressure and vice versa. To control and maintain the blood pressure we need to infuse external drug and most commonly sodium nitroprusside (SNP) drug is used for quick action and it is one of the prominent drug using in emergency cases in all types of conditions and SNP will generate immediate action within minutes of time period to regulate the blood pressure. The SNP drug dose starts began with 0.5 μg /kg/min and it can go up to 1 μg /kg/min, these levels will vary depending on the patient's requirement and control.

To identify the proper infusion we need to ascertain the mathematical model and the modeling of BP and this model in general denoted as SNP (sodium nitroprusside) model, The modeling is an complex task in biomedical field involves multiple interconnected system. W.S Slate *et*. al. (1980) [17] did a research and developed an SNP model with the dynamic infusion for hypertension stabilization based on the related analysis of the patients data. The concluded model as described below based on the behavioral properties the human system,

$$G_{Pbp}(s) = \frac{Pdc(s)}{I_{snp}(s)} = \frac{kpe^{-T_I s}(1+\alpha e^{-T_c s})}{\tau_t s+1} \tag{6}$$

The model elucidations are as follows;

- $\Delta P_{dc}(s)$ indicates the variation of blood pressure (mmHg)
- I_{snp} *(s) denotes the infusion amount of* SNP rate (ml. h $^{-1}$),
- k_p is defined as sensitivity
- α signifies as recirculation index,
- τ_t represent as the time constant,
- T_I means a delay in transport
- T_c indicates recirculation time.

The parameters of the model categorize as sensitive and hypersensitive cases based on the attained values in terms of seconds. These parameters [18] are shown table 2 and the model values vary from individuals because the values are approximated based on estimated values [19].

TABLE 2. Hypertension patient model parameters.

Variable	Hyper Sensitive case	Sensitive case
k_p	-9.02	-0.7144
α	0.00	0.42
τ_t	20.04	29.85
T_I	30.01	44.9
T_c	29.75	40.04

III. DESIGN OF THE CASCADE CONTROL LAW SCHEME

The conceptual framework of the proposed cascade control technique is composed and the Cascade controller is an important controller used various process fields to minimize the inaccuracies and this control system handle multiple process measurement with the single manipulated output.

In this strategy, three different meals are considered a day as Breakfast (8 - 9 AM), lunch (1-2 PM) and dinner (8-9PM). From these the time interval is considered as 6 Hours equally and the control algorithm adopted with different meals and customs depend on the average values. The proposed cascade control identifies the glucose variation from the BP disturbance and improves insulin doses based on the programmed previous meal average. The main control objective is to regulate and maintain the blood glucose level as [1], [6] 90-130 mg/dl. Also, this control problem has been designed based on the physiological dynamics along with distinct factors like diet, stress etc., and the doses given by the physicians vary from patient to patient. Therefore the suggested cascade control structure for this proposal is based on two independent loop architecture as shown in Fig.2, where the outer loop is supervising the inner loop with the attained time scale.

A. SECONDARY–LOOP CHARACTERISTICS

In conventional feedback system the process has been controlled with the variable feedback but the disturbance corrective action will not be initiated until the change in setpoint variable deviates and the action happens after the aberration of the control system. To overcome these variances and develop the efficiency of the system, secondary parameter estimation is implemented as a second process and this secondary controller is denoted as [$G_{c(P)}(s)$]. The inner loop computes the insulin doses with short and long term insulin

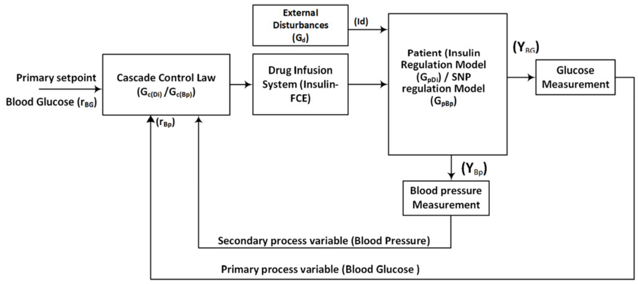

FIGURE 2. Cascade control law scheme.

doses given to the patient with the meal disturbance and this is continued with all three types of meals. The input variables of the inner loop controller are as follows.

- Blood pressure process measurement and stability considered as (G_{pP})
- The controller strategy of the secondary process considered as $G_{c(P)}(s)$

To make effectiveness to tune the controller enactment.

$$Y_P(s) = \frac{G_{c(P)}(s)\,G_{pP)}(s)}{1 + G_{c(P)}(s)\,G_{pP}(s)} r_{Bp}(s) + \frac{G_d(s)}{1 + G_{c(P)}(s)\,G_{pP}(s)} I_d \quad (7)$$

The transfer function of the secondary loop (inner loop) can be derived as

$$G_{c(P)Cl}(s) = \frac{G_{c(P)}(s)\,G_{pP}(s)}{1 + G_{c(P)}(s)\,G_{pP}(s)} \quad (8)$$

This modification generates the improvement of the combined system [Equation (7 & 8)] along with the rejection of its disturbance. The projected cascade scheme generates the combination of cascade laws and smith predictor advantages, also these schemes provide its excellence and the primary controller proposal generates the parameter identification in better perspective with the help of simple algebraic approach. The main objective is to control the blood glucose level in an optimal manner as a primary system and the secondary system measures blood pressure and this value has taken as an additional parameter to regulate the insulin infusion to the human body.

B. PRIMARY–LOOP CHARACTERISTICS

The cascade controller tuning is an intricate scheme and it has two different stages on its construction. To obtain the optimal performance the controller tuning starts with an inner loop controller [$G_{c(p)}(s)$] and the data should be analyzed and the tuning performed depends on the outer loop process (Blood pressure), the transfer function of the outer loop as defined in [Equation (9)] and the transfer function considered in [Equation (10)] for primary controller tuning [$G_{c(I)}(s)$]. Based on the primary loop the process prediction and the controller design implemented based on Fuzzy controller and the tuning has been attained using normalized tuning methods. Once the inner loop tuning is obtained and based on the parameters outer (primary) control loop tuning is performed based on its effectiveness to tune the controller enactment.

- Glucose stability of the patient (G_{pGl}) consider as Primary process
- The fluctuations in the diabetic level consider denoted as (G_{di})
- Time of the cycle (t) determines the expected meal in next
- r_{BG} and r_{Bp} are considered as the primary and secondary set levels for the insulin dose (I_d) Inner loop disturbances - fluctuations in glucose variation

$$Y_{Gl}(s) = \frac{G_{c(P)}(s)\,G_{pP}(s)}{1 + G_{c(P)}(s)\,G_{pI}(s)} r_{Bp}(s) + \frac{G_d(s)\,G_{pI}(s)}{1 + G_{c(P)}(s)\,G_{pP}(s)} I(s) \quad (9)$$

$$G_{pGl(eff)}(s) = \frac{G_{c(P)}(s)\,G_{pI}(s)\,G_{pP}(s)}{1 + G_{c(P)}(s)\,G_{pP}(s)} = G_{c(P)}(s)\,G_{pP}(s) \quad (10)$$

Also, the proposed cascade structure designed and tested with Fuzzy controller to identify the better performances of the proposed control loop based on its process function time constants along with its unstable ends of an integrator [23]–[29], the same approach is applied for outer loop design and further variation has derived as follows

$$Y_{Gl}(s) = \frac{G_{c(I)}(s)\,G_{pI(eff)}(s)}{1 + G_{c(I)}(s)\,G_{pI(eff)}(s)} r_{Gl}(s) = \frac{G_{c(I)}(s)\,G_{c(P)Cl}(s)\,G_{pI}(s)}{1 + G_{c(I)}(s)\,G_{c(P)Cl}(s)\,G_{pI}(s)} r_{Gl}(s) \quad (11)$$

The obtained equation clearly shows the secondary control loop transfer function affects the primary control loop which creates the disturbance to the primary transfer function and it is clearly affected. Based on the observations the secondary control loop measures the BP and this action is much faster then the primary measurement BG and primary controller response is comparatively lagging with inner control, so the secondary control parameter to be consider a $G_{c(P)Cl} = 1$ (on a virtual time scale on the main loop) and the primary control closed loop transfer derived as follows:

$$Y_{Gl}(s) \approx \frac{G_{c(I)}(s)\,G_{pI}(s)}{1 + G_{c(I)}(s)\,G_{pI}(s)} r_{Gl}(s) \quad (12)$$

IV. SYNTHESIS OF CASCADE CONTROL STRATEGY

This chapter confides the cascade control synthesis along with primary (Outer) and Secondary (Inner) loops as designated by fuzzy logic structure [26], [27]. The controller design has varied out with the help of Fuzzy toolbox in *MatLab*. The fuzzy guidelines were implemented based on the prescribed diet routine along with the adjustment guidelines. The cascade controller tuning is an intricate scheme and it has two different stages on its characteristics and the controller

TABLE 3. Secondary loop (inner) input characteristics.

Input	*Interval*	*Membership Function*		
Time (t)	[0,24]h	Breakfast (SMF)	Lunch (GBMF)	Dinner (SMF)
Blood Pressure(G_{bp})	[65,180] mm Hg	Normal	High	Very High
Blood Glucose (G_b)	[60 , 300]mg/dl	Low	Normal	Medium
Insulin (I_d)	[0,1] U	Very Low	Medium	High

A. SECONDARY (INNER) LOOP CONTROLLER

The objective of the Secondary controller is to minimize the disturbance occurred based on the BP and to control the BG level as shown in Fig. 2. The design provides the adjustment of the insulin level in a comprehensive way on a daily basis with an average of three times. The rules of the controller are structured with the help of MATALB fuzzy toolbox (Mamdani type) and the details of the characteristics as shown in Table 3. For assigning the membership function design, three types of function are used: 1) TMF; 2) SMF; 3) GBMF [32]. The output I_d is associated with the variation of normalized function [0, 1], and the fuzzy sets assigned as none, *normal, high, very high* as per the condition. The fuzzy membership function and shapes were identified based on the blood pressure variation and the variables quality has to be inferred in certain. Hence, the secondary controller and the membership functions rely on the primary controller data and the available input details having the interval of [1.0] or with equal value. Meanwhile to prevent the uncounted errors the input functions and functions were chosen based on the variables.

To obtain the desired outputs the definition of the input fuzzy set is defined with the multiple numbers of IF-THEN rules. These rules are generated based on predecessors of AND type with minimum values. The *centroid method is used to calculate the* outputs (defuzzification) of the inner loop. The following rules are used to observe the control trend of the secondary controller.

- If the Blood glucose is not stable due to the change in blood pressure variation
- The Rapid insulin doses increase based on the rapid increase in Blood glucose
- If there is a tendency to increase or decrease the blood pressure, then try to modify the scaling factors

Some sample proposed rules (2, 10 and 15) used in the inner controller are shown below:

2# IF Time = MORNING and Blood pressure = NORMAL and Blood Glucose = NORMAL and I_d = ZERO

10# IF Time = LUNCH and Blood pressure = MEDIUM and Blood Glucose = NORMAL and I_d = LOW

15# IF Time = DINNER and Blood pressure = HIGH and Blood Glucose = HIGH and I_d = SMALL and I_r = LARGE

B. OUTER (PRIMARY) LOOP CONTROLLER

The purpose of the outer loop controller is to supervise and control the blood glucose level as desired in the presence of blood pressure variation as a disturbance as shown in Fig.2. To obtain this purpose, the control scheme adjusts the Insulin dosage (I_P and I_{RA}) scaling factors similar to the inner-loop controller. Mamdani-type structure is used to design the structure of the fuzzy sets with the assigned characteristics of input and output variables as shown in Table 5 and 6. The qualities of the outer-loop controller input variables were assigned as Negative, Zero, or Positive. The membership function is assigned similar to inner loop controller with the help of triangular membership functions. Meanwhile, the same kind of approach was applied for the output variables of the control loop. In the course of the scheme, the prime insulin was specified that it would infuse the maximum doses, in the case of emergency the rapid insulin was infused in larger doses to control the sudden or emergency variation of blood glucose, and based on the daily prime insulin doses were higher in scale for confined rapid insulin doses.

According to Table 4, a substantial number of IF-THEN rules are assigned. These rules are generated based on predecessors of AND type with minimum values. The *centroid method is used to calculate the* outputs (defuzzification) of the outer loop again. The following rules are used to observe the control trend of the Primary controller.

- If the observed glucose is varied and not in control within the desired level, then reduce the scaling factor to attain a prescribed level.
- The prime insulin dose skipped while breakfast/lunch/dinner
- If the Blood glucose is above normal because of prime insulin infusion shortage
- If there is an inclination in the glucose deviation in the target TGL, then modify the scaling factors to achieve.
- If TGL declines the below target level, then adjust the scaling factors.

Some sample proposed rules (5, 26 and 34) used in an inner controller are shown below:

5# IF Time = MORNING and Glucose Deviation ($G_{d)}$ = NORMAL and Blood Glucose (G_b) = NORMAL and I_d = ZERO and I_{rd} = ZERO

26# IF Time = LUNCH and Glucose Deviation ($G_{d)}$ = LOW and Blood Glucose (G_b) = LOW and I_d = HIGH and I_{rd} = ZERO

34# IF Time = DINNER and Glucose Deviation ($G_{d)}$ = HIGH and Blood Glucose (G_b) = HIGH and I_d = ZERO and I_{rd} = HIGH

V. CASCADE LOOP SIMULATION RESULTS

The cascade advisory/control structure is analyzed and simulated using the nonlinear model of the Diabetic and Blood pressure (SNP) patient models. The proposed cascade control scheme observed that it will preserve and treat both diabetes, hypertension and its control of measurements. The proposed methodology (cascade) will reduce the disturbance in the

TABLE 4. Simulation scenario conditions analysis with meal intake comparison.

	Time	Breakfast in gcho	Glucose plasma	Blood Pressure mm/Hg	Time	Midday meal in gcho	Glucose plasma	Blood Pressure mm/Hg	Time	Night meal in gcho	Plasma Glucose	BP
Diabetic Patient Diabetic +	8AM	50	140	130/80	1 PM	65	134	120/90	8 PM	54	123	130/80
Hypertension patient	8 AM	50	160	145/90	1 PM	55	146	150/90	8 PM	52	136	140/90

TABLE 5. Primary loop (outer) input characteristics.

Input	*Interval*	*Membership Function*		
Time (t)	[0,24]h	Breakfast (SMF)	Lunch(GBMF)	Dinner (SMF)
Glucose Deviation (G_d)	[-20, 20] mg/dl	Low	Zero	High
Blood Glucose (G_b)	[60 , 300]mg/dl	Low	Zero	High
Increment in prime Insulin Dose(ΔI)	[-1,1] U	Low	Zero	High
Increment in rapid Action Insulin(ΔI_{RA})	[-3,3] U	Low	Zero	High
Variation of Plasma Glucose (Jd)	[-20, 20] mg/dl	Low	Zero	High

TABLE 6. Output characteristics for proposed control scheme.

Output	*Interval*	*Membership Function*				
Increment in prime Insulin Dose(ΔI)	[-1,1] U	Very Low	Low	Zero	High	Very High
Increment in rapid Action Insulin(ΔI_{RA})	[-3,3] U	Very Low	Low	Zero	High	Very High

process and will maintain the proper glycaemic index levels and this infusion achieved with fuzzy controllers. The numerical simulation was attained with the help of MATLAB/ Simulink©using the Fuzzy Logic Toolbox. The simulation was carried out on two categories of patients with three meals per day: breakfast: 8- 9 AM lunch: 1-1.30 -2 PM, and dinner: 7.30 – 8.30 PM.

The simulation starts at 8:00 A.M. An initial capillary blood concentration of 80 mg/dl [19] was assumed as reference input. The simulation clock l_{sim} turns in minutes of time-scale, based on the conditions the control strategy applied for [1], [25] Hours' time scale to measure the blood glucose and blood pressure. The insulin infusion programmed three boluses and the boluses are calculated according to the cascade control algorithm for rapid and prime insulin algorithm as per the calculations. The inner-loop controller supervises the blood pressure intensively adjust the insulin infusion scaling factors. Meanwhile, the simulation has been tested with fuzzy based cascade control and attained the proper and optimal insulin infusion rate. Also the proposed systems consider the average intake the rate of change of BP along with the intake food concentrations in the stage of stress, the observed values are taken as average for simulating the control strategies shown in Table 4.

The considered patient profile believes that 60% of the calories were consumed from carbohydrates and reaming from other disturbances. Also, the meal intake distribution was considered for 3 meals per day as follows: breakfast: 99 g CH, lunch: 128 g CH, and dinner: 57 g CH, assuming breakfast and afternoon meal as heaviest meal of the day for simulation. The simulation has been considered for a day (24Hrs) during which the amount of carbohydrate will vary randomly based on $+/-5\%$ (uniform distribution) to the observed nominal values of previous meal calculation. Similarly, the sensitive patient needs the insulin dose with minimal scaling for both prime and rapid infusion. The small amount of insulin doses were produced based on the low and high glucose levels, because of the patient characteristics. The proposed algorithm determines and adjusts the insulin dosages based on plasma glucose and as a reference for blood pressure for the patient to achieve the target blood glucose.

A. SIMULATION SCENARIOS

The following two different types of simulation scenarios are simulated and tested for cascade control system

Case 1: Sensitive Patient:

Target Level: 85- 130

The average intake of calories per day: 1700 kcal/day.

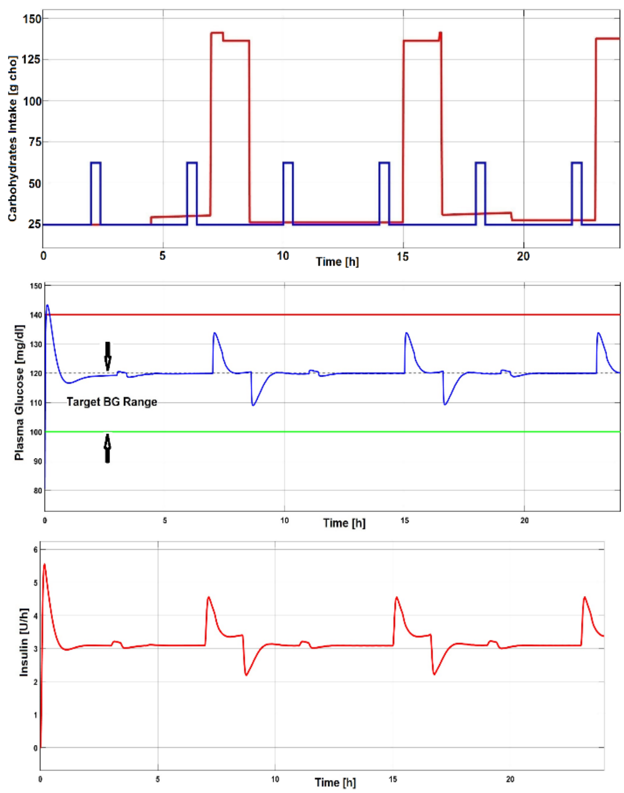

FIGURE 3. **Cascade simulation (24 hrs.) for sensitive patient.**

The sensitive patient needs the insulin dose with minimal scaling for both prime and rapid infusion. The small amount of insulin doses were produced based on the low and high glucose levels, because of the patient characteristics. The proposed algorithm determines and adjusts the insulin dosages based on plasma glucose and as a reference to blood pressure for the patient to achieve the target blood glucose as shown in Fig.3. For this sensitive scenario, the assumed error is to be considered as +/− 10 % in each glucose measurement. Also, the advisory controller rules are continuously updated to achieve the desired output for a longer period in spite of errors in sensor measurements.

Case 2: Hyper Sensitive Patient:

Target Level: 85- 130

The average intake of calories per day: 1700 kcal/day.

In the hypersensitive patient scenario, the insulin dose varies with high variation to achieve the stabilization of plasma glucose. As per the research condition, the variation of prime and rapid infusion is attained depending on the target blood glucose maintenance. The intake of carbohydrate varies and is considered to be within +/− 5% from the nominal ones. Hence the total intake is adjusted in the proposed algorithm to determine and adjust the insulin dosages based on plasma glucose rapid variation and blood pressure also. This analysis has considered 25 patients' records and these data were concerned with 10% of these parametric details to achieve the maximum sensitivity of blood glucose level based on continuous glucose and continuous blood pressure monitoring to achieve accurate control

The hypersensitive patient scenario the insulin dose varies with heavy variation to achieve the stabilization of plasma glucose. As per the research condition, the variation of prime and rapid infusion is attained depends on the target blood glucose maintenance. The intake of carbohydrate is varying and consider +/− 5% from the nominal ones. Hence the total intake is adjusted in the proposed algorithm to determine and adjusts the insulin dosages based on plasma glucose rapid variation and blood pressure also. This analysis has been considered 25 patients records and these data ware concerned with 10% of these parametric details to achieve the maximum sensitivity of blood glucose level based on continuous glucose and continuous blood pressure monitoring to achieve accurate control. The proposed cascade procedure adopts two types of patient parameters like sensitive and hypersensitive, the main intention is to control the perioperative patients hypo and hyper glycaemic levels. The proposed cascade law delivers the optimal infusion rate with the blood pressure variation as correction factor and the feed rate to control with the help of desired target values of both glycaemic and blood pressure targets. This adopted control is control the higher infusion of insulin to the human body because of a secondary input and the control action speed is far better to compare then the feedback system and the insulin rate comparatively maintained +/− 10% to the traditional methods. In the critical condition the plasma glucose rapidly varies in the higher limit (> 190 mol /L) the cascade law verify the blood pressure level simultaneously and it provides the instantaneous input to the drug delivery and controls the glycaemic level along with the indication of variation in blood pressure. Due to this action both the parameters are continuously monitored and the insulin infusion volume to be controlled based in parameter variation estimation. The prosed fuzzy based cascade law indicates the noticeable distinction of the insulin infusion rate of the hypersensitive patients is shown Fig.4. Nevertheless, no findings for hyperglycaemic were detected in the cascade advisory control and this algorithm is able to regulate the glucose level in the presence of hypertension as a disturbance.

These results have limitations in the real time implementation because the plasma glucose and blood pressure data keep on varying depending on the circumstance and need proper inputs to get good insulin regulation to attain the glycaemic stability. In the results of simulations Fig,5 Shows the combined response for sensitive and hypersensitive patients and the results show better glycaemic regulation and it indicates that the inulin infusion level is minimum and in control, as shown in Table 7. Also, the cascade algorithm clearly works in that wherever the disturbance occurred, it was immediately responded to and it maintained the glucose level in control and the same applied to insulin infusion also. It is very important that the details compared bet week blood glucose and hypertension based on limited available information

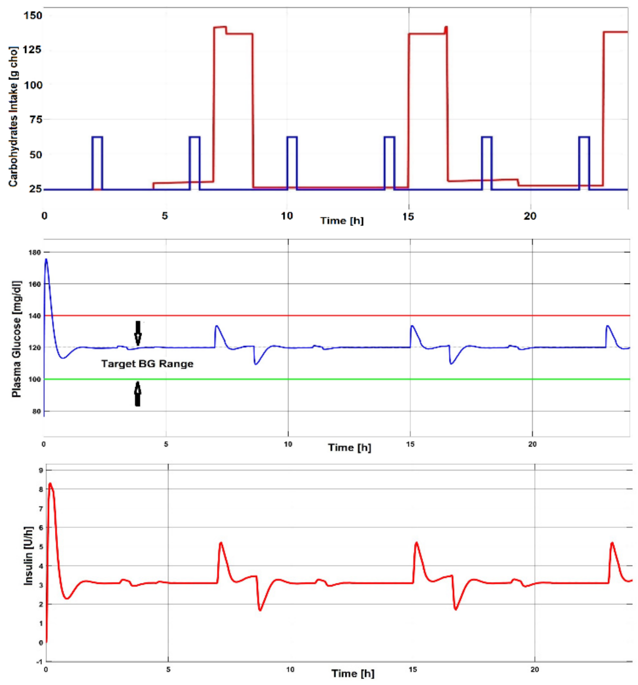

FIGURE 4. Cascade simulation (24 hrs.) for hypersensitive patient.

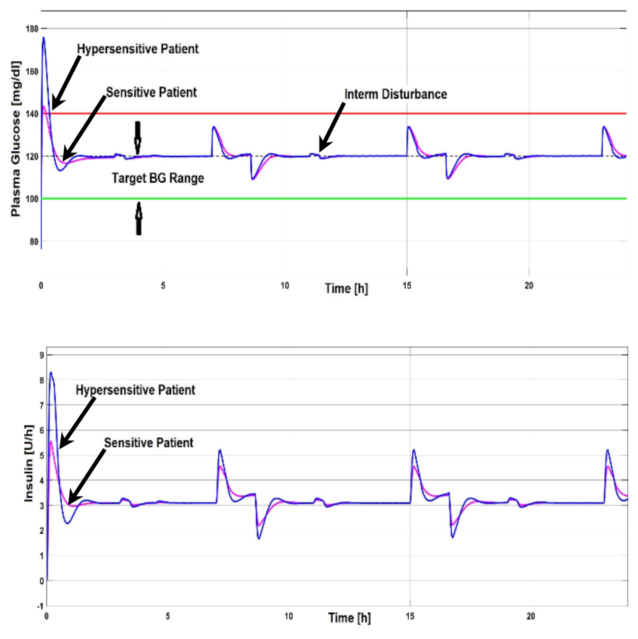

FIGURE 5. Combined cascade simulation (24 hrs.) for sensitive and hypersensitive patients.

since this scenario will be changed while using continuous monitoring of Hypertension for regulating the Insulin.

Henceforth the target the range is obviously relevant to the required numbers and avoiding the hyperglycaemic levels and maintain the target in 80-120 in most of the time for both the cases and the insulin infusion also relatively meet the target values. As an outcome, the cascade control algorithm has been properly modified and adjusted to active the proper glycaemic levels.

TABLE 7. Summary of simulation results for hypertensive and sensitive patients for 50 samples.

Parameters	Hypersensitive Patient	Sensitive Patient
Average BG [mg/dl]	142	135
Maximum BG [mg/dl]	178	157
Minimum BG [mg/dl]	84	78
% [70-180] mg/dl reaching time	73.2	70.4
Mean Insulin [U/h]	0.83 - 4.49	0.8 – 4.1
Maximum Insulin [U/h]	6.1	5.5

VI. CONCLUSION

In this work, the cascade control scheme is designed and adapted for nonlinear intravenous diabetic and Hypertension patient. To obtain the stability of the system hypertension inherent is considered as parametric disturbance compensation and the same maintain the uncertainty in the framework. The regulation of glucose stabilization and insulin infusion characterized and meal disturbance are attained for two types of patients like sensitive and hypersensitive scenarios based on random parametric calculations and simulations. The results are depicted after a number of simulations were represented in the combination of BG with BP invariance. The obtained output clearly indicates the control strategy reliability and maintaining the glucose level as described. Also, the system protects the hypo and hyperglycaemic events in the existence of BP fluctuation also it shows a significant role of insulin control performance.

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A. ALAVUDEEN BASHA received the B.E. degree in instrumentation engineering from Bharathidasan University, in 2002, and the M.E. degree in process control and instrumentation from Annamalai University, in 2005. He is currently pursuing the Ph.D. degree with the School of Electrical Engineering, Vellore Institute of Technology (VIT), Vellore, India. His research interests include diabetes and hypertension control, biomedical instrumentation, multivariable control, and advanced complex control systems.

S. VIVEKANANDAN is currently the Head and an Associate Professor with the School of Electrical Engineering, Vellore Institute of Technology (VIT), Vellore. He has been an Associate Professor with the School of Electrical Engineering, VIT, since 2015. His research interests include diabetics and hypertension, biomedical control, biomedical instrumentation, and multivariable control. He is the Faculty Advisor and a Mentor of the International Society of Automation (ISA), India. He has published over 20 research papers in reputed international journals and conferences. He has received the Best ISA Student Section Performance Award, from 2014 to 2015, from ISA District 14 (Asia–Pacific) and the ISA Bangalore Section, the Best Faculty Advisor, from 2015 to 2016, from the ISA Bangalore Section and ISA District 14 (Asia-Pacific), and the Best Mentor Award, from 2016 to 2017, from the ISA Head Quarter, USA. He has launched a product with TMI systems entitled InDiaTel diabetes for telemedicine, the outcome of DST/IDP Project on 8/12/17 by the Chancellor of VIT in the presence of UGC and AICTE expert committee members.