Kaunas University of Technology
Faculty of Mechanical Engineering and Design

Particle swarm optimisation based blood glucose control in type1 diabetes

Master's Final Degree Project

Salman Farcy Jamal Mohamed Malik
Project author

Prof.habil.dr. Arvydas Palevicius
Supervisor

Kaunas, 2018

Kaunas University of Technology
Faculty of Mechanical Engineering and Design

Particle swarm optimisation based blood glucose control in type1 diabetes

Master's Final Degree Project

Industrial Engineering and (621H77003 Management)

Salman Farcy Jamal Mohamed Malik
Project author

prof. habil. dr. Arvydas Palevicius
Supervisor

Assoc. prof. dr. Giedrius Janusas
Reviewer

Kaunas, 2018

Kaunas University of Technology
Faculty of Mechanical Engineering and Design
Salman Farcy Jamal Mohamed Malik

Particle swarm optimisation based blood glucose control in type1 diabetes

Declaration of Academic Integrity

I confirm that the final project of mine, Salman Farcy Jamal Mohamed Malik, on the topic “Particle swarm optimisation based glucose control in type1 diabetes“is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this project.

I fully and completely understand that any discovery of any manifestations/case/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology.

(name and surname filled in by hand) (signature)

KAUNAS UN IVERSITY OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Study programme INDUSTRIAL ENGINEERING AND MANAGEMENT 621H77003

TASK ASSIGNMENT FOR FINAL DEGREE PROJECT OF MASTER STUDIES

Given to the student: Salman Farcy Jamal Mohamed Malik

1. Title of the Project: Particle swarm optimisation based blood glucose control in type1 diabetes Gliukozės kiekio kraujyje 1 tipo diabeto atveju valdymas atsitiktinės paieškos optimizavimo algoritmu.Approved by the Dean Order No. V25-11-6, 12 April 2018

2. Aim and Tasks of the Project: The main aim of the thesis is the development of the control system and also to improve its performance to control the glucose level devoted for diabetes Type 1 patient. The thesis is to be executed in the follwing steps:To develop a closed loop system with ZN based PD controller for diabetic patients,To design a IMC controller for blood glucose level system,To design a PD controller and IMC using particle swarm optimization technique,Finally to compare the results of PD controller, IMC, IMC based PID, PSO-PD & PSO-IMC.

3. Initial Data:Diabetes glucose measurment data, bergmaans minimal model,

4. Main Requirements and Conditions:The matlab/simulink

5. Structure of the Text Part: Introduction, Modeling of blood glucose system, Design of PD and IMC controller,Design of PD and IMC controller using particle swarm optimization techmique

6. Structure of the Graphical Part:

7. Consultants of the Project:

Student ....

(Name, Surname, Signature, date)

Supervisor ....

(Name, Surname, Signature, date)

Programme Director of the Study field Assoc. Prof. Regita Bendikienė

(Name, Surname, Signature, date)

Table of contents

List of figures

List of tables

Salman farcy Jamal Mohamed Malik. Particle swarm optimisation based blood glucose control in type1 diabetes. Master's Final Degree Project / supervisor prof. habil. dr. Arvydas Palevicius; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.
Study field and area (study field group): Production and Manufacturing Engineering, Technological Sciences.
Keywords: glucose, diabetes, insulin, controller
Kaunas, 2018. 55 pages.

Summary

In this world everywhere, people are affected by diabetes millitus a disease which affects people of all ages. A report by the World Health organisation (WHO) shows that 180 million people are affected by diabetes mellitus, and this rate will increase upto 360 million people in 2030. The pancreas in the human body responsible formaintaining normoglycemia controls the range within 70-120 mg/dl. Beta cells produce the insulin in the pancreas when the blood glucose level is high. Insulin is a hormone that allows glucose to enter into the cells of the human body for providing energy. The conditon, Type 1 Diabetes Mellitus (T1DM) occurs because of the damage of pancreatic beta cells by the body's immune system. Hence, manually controlled insulin therapy is suggested by the physician where three or four times the blood glucose measurements to be taken by finger picking. Then, subcutaneous insulin injection is given based on the daily activities. The automatic blood glucose control is challenged by the disturbance of meal intake and internal system changes.

To avoid the manually injecting insulin and to limit the significant changes in blood glucose concentration, an artificial pancreas (using Closed Loop Approach) is developed. The components of the artificial pancreas are glucose monitor, insulin pump, and control algorithm. This controlled framework is called Automatic Blood Glucose- Insulin (ABGI) regulatory system.

This thesis proposesthree control strategies for closed loop artificial pancreas and has used three diabetic patient models for simulation that is designed to reduce the risks of hyperglycemia.

The proposed control algorithm is implemented for the Bergmann Minimal Model (BMM) as the diabetic patient model. The control algorithm is proposed to develop a closed loop artificial pancreas. The conventional Proportional and Derivative (PD) controller and Internal Model control (IMC) are designed for the BMM model. Then, the PD and IMC control problem is optimized based on control problem to improve the performance of controller. To get optimal controller for the bergmaan minimal model (pso) particle swarm optimization algorithm is used, which should minimize the Integral Square Error (ISE).This research focus on the development of control algorithm using PSO based PD and PSO-IMC. The control problems are studied explicitly and the results show the improved performance of the proposed system.

Salman Farcy Jamal Mohamed Malik. Gliukozės kiekio kraujyje 1 tipo diabeto atveju valdymas atsitiktinės paieškos optimizavimo algoritmu. Magistro baigiamasis projektas / vadovas prof. Arvydas Palevicius; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.
Studijų kryptis ir sritis (studijų krypčių grupė): Gamybos inžinerija, Technologijos mokslai.
Reikšminiai žodžiai:gliukozė, diabetas, valdytojas, insulinas
Kaunas, 2018. 55 p.

Santrauka

Kiekvienais metais šiame pasaulyje žmonės patiria diabetą. Tai yra liga, paveikianti visų amžiaus grupių žmones. Pasaulinės sveikatos organizacijos (PSO) ataskaita rodo, kad diabetu serga 180 milijonų žmonių, o šis skaičius iki 2030 m. padidės iki 360 milijonų žmonių. Kasa žmogaus kūne, atsakinga už gliukozės lygio palaikymą, 70-120 mg / dl. ribose. Beta ląstelės gamina insuliną kasoje, kai gliukozės koncentracija kraujyje yra didelė. Insulinas yra hormonas, leidžiantis gliukozei patenkti į žmogaus kūno ląsteles ir tiekti energiją. 1-o tipo cukrinis diabetas (T1DM) atsiranda dėl kasos beta ląstelių pažeidimų, kurią sukelia organizmo imuninė sistema. Taigi, gydytojo siūloma rankiniu būdu kontroliuojama insulino terapija, kurios metu trijų ar keturių kartų kraujo gliukozės matavimai atliekami rinkimo būdu. Tada poodinio insulino injekcija skiriama atsižvelgiant į kasdienes veiklas. Automatinio gliukozės kiekio kraujyje kontrolė yra susijusi su maisto vartojimo ir vidinių sistemos pokyčių sutrikimu. Siekiant išvengti rankiniu būdu švirkščiamo insulino ir riboti reikšmingus gliukozės koncentracijos kraujyje pokyčius, sukurta dirbtinė kasa (naudojant uždarojo ciklo metodą). Dirbtinės kasos komponentai yra gliukozės monitorius, insulino pompa ir valdymo algoritmas. Ši kontroliuojama sistema vadinama automatine gliukozės-insulino (ABGI) reguliavimo sistema.
Siekiant išvengti rankiniu būdu švirkščiamo insulino ir riboti reikšmingus gliukozės koncentracijos kraujyje pokyčius, sukurta dirbtinė kasa (naudojant uždarojo ciklo metodą). Dirbtinės kasos komponentai yra gliukozės monitorius, insulino pompa ir valdymo algoritmas. Ši kontroliuojama sistema vadinama automatine gliukozės-insulino (ABGI) reguliavimo sistema. Šiame baigiamajame darbe siūlomos trys uždaro komtūro dirbtinės kasos valdymo strategijos ir panaudoti trys diabetu sergančių ligonių modeliai, skirti sumažinti hiperglikemijos riziką. Siūlomame valdymo algoritme yra taikomas Bergmann Minimal Model (BMM) kaip diabetikos paciento modelis. Siūlomas valdymo algoritmas skirtas sukurti uždaro kontūro dirbtinę kasą. PD valdiklis ir vidinio modelio valdymas (IMC) yra sukurti BMM modeliui. Tada PD ir IMC valdymo problema optimizuojama remiantis valdymo problema, siekiant pagerinti valdiklio efektyvumą. Optimizuoto BMM parametro valdiklio parametrui naudojamas algoritmas " The Particle Swarm Optimization " (PSO), turėtų sumažinti kvadratinę paklaidą (ISE). Šiame tyrime daugiausia dėmesio skiriama valdymo algoritmo kūrimui, naudojant PSO grįstą PD ir PSO-IMC. Valdymo uždaviniai išsamiai tiriami, o rezultatai rodo geresnį siūlomos sistemos funkciškumą.

Introduction

In this world, people are facing many kinds of disease. According today census 131.4 million births per year, 55.3 million death per year 360,000 births per days, 151,600 people die daily. Each person dies for different reason like accident, suicide, disaster etc. but mainly they die in different form disease even though our medical is improved people are dying its natural calamity that no one can stop it [1]

According today diabetes is the main disease people are facing. Diabetes is caused due to pancreas fail to produce insulin or human body not responding insulin secret by pancreas.

Diabetes mellitus is wide spread disease. In 2011 nearly 346 million people have this problem source from world health organization (WHO). In 2030, it will expected to increase up to 552 million according to international diabetic based. china, japan, India have more number diabetic patient and it rank top three countries [1].

This disease is classified into type1 and type 2 .Patients with these types of diabetes require insulin for maintaining the blood glucose level . Although there are varieties of injection regimens used in insulin , The acceptable glucose reading which are accquired by the usage of single and multiple dose does‘nt reach the expected level.

These diabetic patient need to control glucose level manually using insulin on a regular basis. They need to measure their glucose level by test strip according to which insulin can be injected through insulin pen or pump .In order to avoid regular dose of insulin , and to reduce high variation in glucose concentration, the basic solution can be determined by simulating the insulin dose based on continuous glucose measurements using control algorithm, as it can be obtained by sensor technology rather than manual input. These appropriate insulin injections can be supported by mathematical patient model and then appropriate amount of insulin dose are examined by a controller which stimulates the delivery of insulin to the patients continuously

The Research study of Diabetes Control shows that frequent control in blood glucose level for diabetes patients shows minimal variations in glucose concentration . Decreasing rate of secondary diabetic disorders improve their heath.

Therefore automated development insulin pump of a closed-loop system have advantage control glucose level for both diabetic patients and the healthcare system [1].

Aim

The main aim of the thesis is the development of the control system and also to improve its performance to control the glucose level devoted for diabetes Type 1 patient.

Main task of this research work

- To develop a closed loop system with ZN based PD controller for diabetic patients
- To design a IMC controller for blood glucose level system.
- To design a PD controller and IMC using particle swarm optimization technique.
- Finally to compare the results of PD controller, IMC, IMC based PID, PSO-PD & PSO-IMC.

1. Literature survey

In this present scenario, human beign are facing lot many health issues all over the world wide and now the survey is been recorded by world health organization (WHO) that diabetes mellitus is a disease which is been affected by 180 million people all over the world. In future 2030, this disease will be affected by double the time of 360 million people and it is been guaranteed by them. In order to avoid this, we should maintain normoglycemia which is in the range of (70-120 mg/dl) by controlling blood glucose level which is been handled by pancreas . While, the glucose level goes high, insulin is secreted by the beta cells of pancreas. This insulin is a peptide hormone which gives energy to the human body when the glucose enters the human body. It also develops the intake of glucose into the human cells and glucose is been stored in liver as glycogen. While, the blood glucose level goes low the pancreases secretes glucagon. This glucagon has the negative effect as it is shown in the figure. 1.1. Also there exist different types of Diabetes mellitus, where Type 1 diabetes mellitus T1DM occurs due to the damage of pancreatic cells caused by the immune system [2] [3].

Later case studies by diabetes control is been generated by the research group, which shows there exist the slight variation of glucose concentration when the blood glucose level of the patient is frequently controlled. On the other hand when there is a decrease in secondary diabetic disorder, it gradually increases patient’s life and thereby reduces the cost of treatment. Also it is found that, global health care budget to take care of complications related to diabetes is been increased sufficiently within upcoming years, for instance it is approximately from 375 B$ to nearly 490 B$. The history related to the group of people with diabetes in countries like Asia, US, Europe, Africa, Brazil for the year 2010 and 2030 is graphically shown in the figure 2.2. T1DM (Type 1 Diabetes Mellitus) earlier known as insulin independent diabetes. The number people who is been affected by T1DM is found to around 30,000 in Denmark. Since these many people is been affected it is called as an autoimmune disease. So the people use exogenous insulin to survive their lives. While deciding on insulin dosage we need to too careful. Too little intake of insulin may lead to problems like blindness, problem in kidney, nerve related damage, etc.. or conversely over dosage of insulin may also leads to low sugar level which may even lead to death [2] [3].

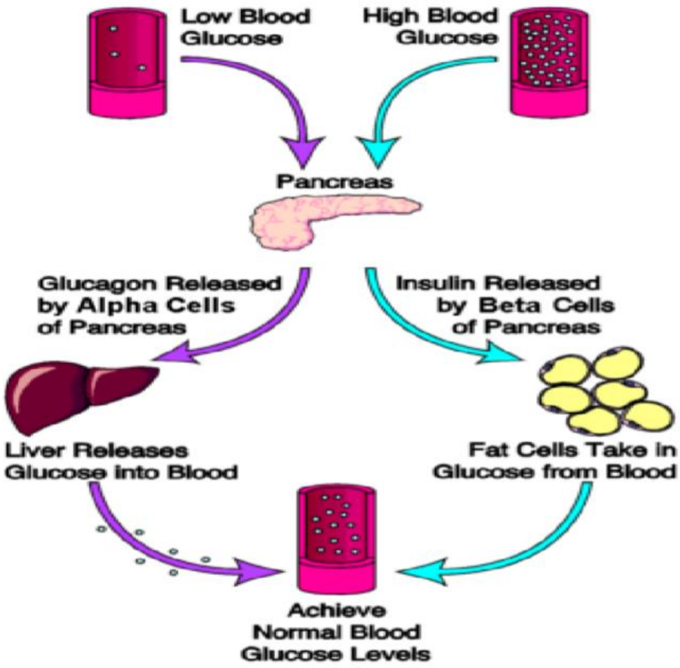

Figure 1.1. Blood glucose regulation in healthy people [3].

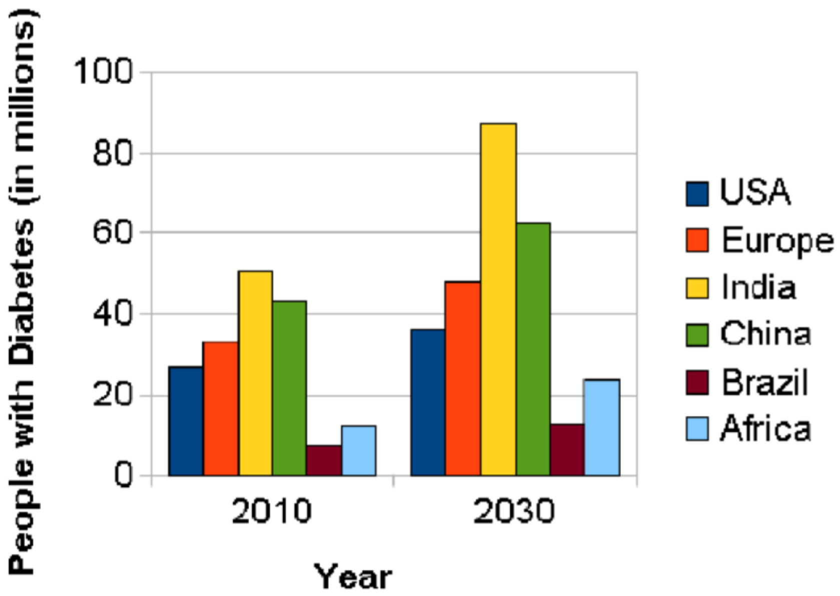

Figure 1.2 Estimation of the number of people with diabetes in the usa, europe, india, china, brazil and africa in 2010 and 2030 (boiroux et al 2012) [4].

1.1 Artificial pancreas

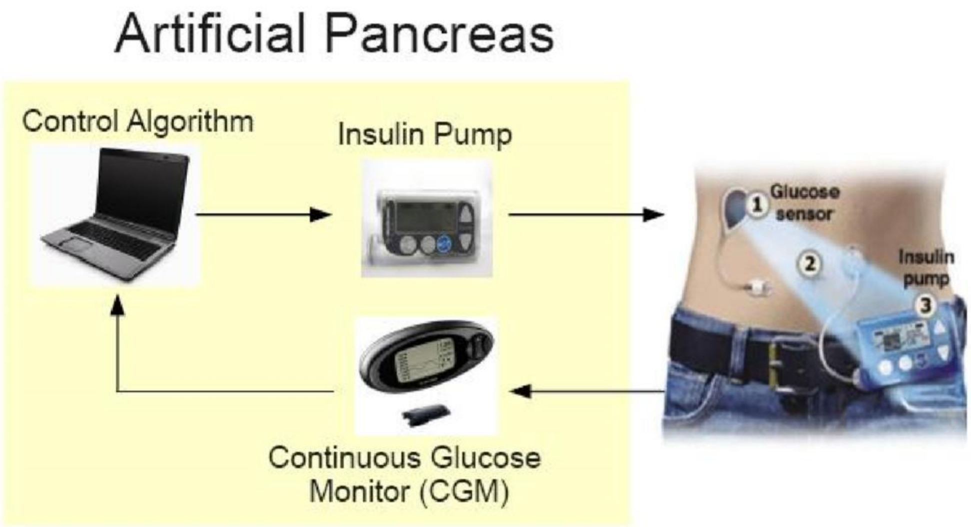

Figure 1.3. Design of an artificial pancreas (boiroux et al 2012) [5].

In order to keep track of glycemic control, it has been observed as the ideal resolution of developing an artificial pancreas. The artificial pancreas is a technology that automatically controls the glucose level of blood for the patients. The controlled glucose level of blood should be within the desired range and limits in order to minimize or eliminate the need for patient help.

For the fully developed man-made pancreas, it has been said that control of blood glucose after a meal is one of the important challenger. The important reason for the increase of glucose into the blood stream is caused by meals. The CGM sensor detects when there is increase in glucose level has occurred only after the controller reacts to it. Insulin overloading is caused due to elevated glucose level, which results in postprandial hypoglycemia.

For almost 5decades the artificial pancreas has been subject of interest. Intravenous glucose measurements and intravenous insulin and glucose injection uses bio-stator which are the early versions of AP. The blood glucose cannot be controlled in everyday life. Fully automated artificial pancreas has increased the potential due to the better improvements in CS11 pump technologies, insulin analogs and CGMs.

The three compartment minimal model was proposed by Bergman et al is used to test the disappearance of glucose in the blood and sensitivity of insulin which occurs during an intravenous glucose tolerance test. Overall there are three sections that explain about glucose insulin dynamics model. Plasma glucose level describes the first section. The action of insulin represents second section and at last the insulin concentration illustrates the third section. It is common among people with type1 diabetes. In literature it has been said that it is most popularly utilized model and dynamic response of a diabetic patient's blood glucose is analyzed. Original minimal model have undergone some modifications that includes the various physiological effects.

To separate the effect of glucose generation utilization, cobelli et al in 1986 proposed a revised version of minimal model. Another publication was done by cobelli et al in the year 1999, which illustrates the over evaluation of glucose effectiveness and underestimation of insulin, sensibly. The original model is been added to the second non accessible glucose section. Then the original minimal model is continued by hovorka et al by adding three glucose and insulin sub – section to capture absorption, distribution and dynamics.

Since 1970, the lengthy research process has been done for the artificial endocrine pancreas. The control approaches planned for the intravenous glucose sampling and intravenous insulin infusion. Initially, the work is been done by albisser et al and Pfeiffer et al, designed and developed the glucose controlled insulin infusion system (GCIIS) which leads to the management of bio stator. In respect to this algorithm, albisser et al, changes the rate of glucose which is been linked to it by insulin mixture. The advanced algorithm followed by the great scientist fischer et al, fischer and tio, ollerton, shichiri et al is been developed accordingly. Parker et l made an excellent review of algorithms based on intravenous insulin delivery [5].

In recent times, medical sciences place more emphasis on prevention and offers only general treatment for illness. Survey says that, in order to improve the diabetes treatment, biomedical engineering designs new instruments for the instance insulin pump. This is a medical device which is being used for the treatment of diabetes mellitus. This device has an application in both the type of diabetes, but one thing we need to monitor is about the designing of suitable controller for insulin pump.

The steps for the design of an appropriate controller are as follows.

1. The taken dosage of insulin should be minimized by the controller by chase et al.
2. The blood glucose level should be lowered by the controller in the shortest period of time within the allowed desired range, that is from 70 - 120 mg/dl before meals and below 180mg/dl after meals by koacs et al, li &hu, beyki et al.
3. It is to be known that the controller should be in order to perform the robust action, as it is to be used on all diabetic patients, Such parameter uncertainties that exist in diabetic model by acikgoz, diwekar, kovacs et al [5].

For closed-loop artificial pancreas system, the insulin therapy should believe the fact that hyperglycemia is not a naturally occurring episode in T1DM.

In general, these algorithms becoming popular among many control engineers, where they involve in the process of optimal tuning of PID, MPC, Fuzzy controllers, etc.., The reason is that these are the parameters which gives accurate evaluation in the process and thereby illustrates the engineers to work on it.

A fuzzy PI controller for glucose concentration using genetic algorithm has been proposed by al fandi et al. GA operators such as mutation, cross over, and selection operator has taken time and there by the parameter tuned by GA is delayed. This GA operator shows that convergence was guaranteed but it seems like time was uncertain and the parameter updation is not straightforward.

The optimal fuzzy PI controller based on mamdani type structure for the blood glucose in diabetic patient is proposed by abadi et al.It is been tested with three different parameters on three different patients in order to check the performance characteristics of the proposed controller. In relative to the existing insulin injection rate, this proposed controller reduces the insulin injection rate and time margin. Thus the convergence may occur in certain forms [5].

2. Modeling of blood glucose level system

2.1. Introduction

In this chapter, a detailed explanation of the blood glucose level system and its modeling has been discussed. This chapter deals with glucose monitoring system, insulin infusion system, automatic insulin pump and its parts are discussed. Also, the state space modeling of blood glucose level system is explained step by step.

Continuous Glucose Monitoring System

Electro enzymatic sensor which is small flexible probe that is placed just underneath the skin of patient which is surrounded by glucose concentration (i.e. blood),glucose oxidized by enzyme in the blood is present on the tip of the sensor to give hydrogen peroxide and other elements, this hydrogen peroxide then diffuses in the base metal layer of the sensor where it is oxidized to form hydrogen, oxygen and electrons which we measure as a current which is proportional to the concentration of glucose in the patient's body.

Insulin Infusion System

This system is used nowadays by allowing patients to inject insulin rapidly rather than periodically, transmitted signal from CGM is being monitored and processed by the infusion system and it is used to inject the insulin into patients body to maintain the level of insulin in the patients body, though there is a disturbance which can affect the CGM rate an approach is made by us to compensate the disturbance and process the system to inject precisely as required for the patient

Automatic insulin pump

An insulin pump is small electronic device look like a mobile phone is attached to our belt , or it can be placed inside pocket or even it can attached in bra so that it can hide from others.

Those pump is injected to your body24 hours is monitor. Whenever your body reduce or increase glucose level it will control by injecting insulin.

Basal rate

Every body has a insulin rate to maintain the glucose level. according to the rate of. pancreas will secrete the insulin. Due to malfunction of pancreas we programmed insulin rate made based on the health care professional according to your body. So that programmed insulin rate is called as basal rate.

The basal rate can be increased or decreased based on your needs. According to the basal rate the pump inject the insulin to your body

Bolus dose

Additional insulin also possible you can add according to your body you have eaten. So that you can correct your high blood sugar

The insulin pump consist of

- It has compartment and reservoir
- Compartment only holds the reservoirs
- Reservoir filled with the insulin
- Infusion set connects insulin reservoir to your body
- The infusion set is connected in our body through a tinny tube(cannal) it is placed under the skin
- Infusion set is connected to the reservoir with the small tube so that it can be connected and dis-connected easily

Figure 2. Automatic insulin pump [6].

Three main component of the insulin pump

- Insulin pump
- Reservoir
- Infusion set

Insulin pump

A small durable electronic device that consists of:

- Buttons for programming insulin navigation
- A LCD colour screen for visual
- Battery compartment
- A reservoir compartment

Reservoir

A plastic cartridge filled with insulin is locked to the pump. It comes with a transfer guard, the top piece is removed before inserting insulin pump. It can store upto300 units of insulin

Infusion set

It consist of thin tube from the reservoir to the infusion site in your body. a small needle is injected to the canal and removed, once it is located. It goes on the same place where the insulin injections are given. The infusion set is replaced over a period of two or three days [6].

Advantages of insulin pump:

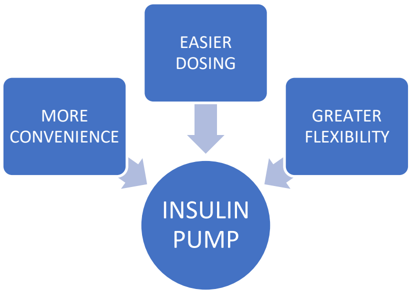

Figure 3. Advantage in insulin pump [6].

The above fig.3 shows the main three advantages of the insulin pump system

Main parts of automatic insulin pump system:

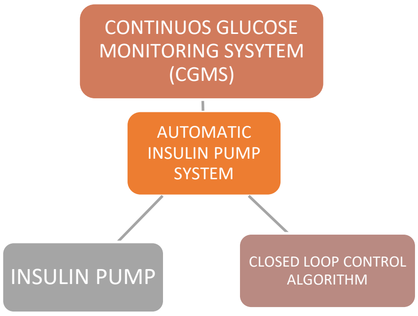

Figure 4. Main parts of insulin pump [6].

The above fig. 4. shows the main three part of automatic insulin pump system.

2.2. Evolution of insulin pump technology

Initially insulin pumps were only used for research purposes. It was then commercialized in the year 1970 for diabetic patients as they can calculate the amount of insulin for finding glucose reading and food coverage. Due to the advanced technology, the usage of pump has increased approximately up to 350,000 people in the U.S and also 30,000 people had type 2 diabetes. In addition advanced features were introduced such as self-monitoring of glucose level as they communicate wirelessly through infrared technology. This helps in eliminating errors which are occurred due to manual operation. For example: the technology of touch screens are incorporated in T-slim insulin pump and disposing pumps are also used. On estimated scale, the cost of insulin is around US $6000.[7], [8], [9]

Figure 5. Medtronic minimized insulin pump [10].

fig. 5. A Medtronic Minimized Insulin Pump with a blood glucose meter that communicates readings wirelessly [10].

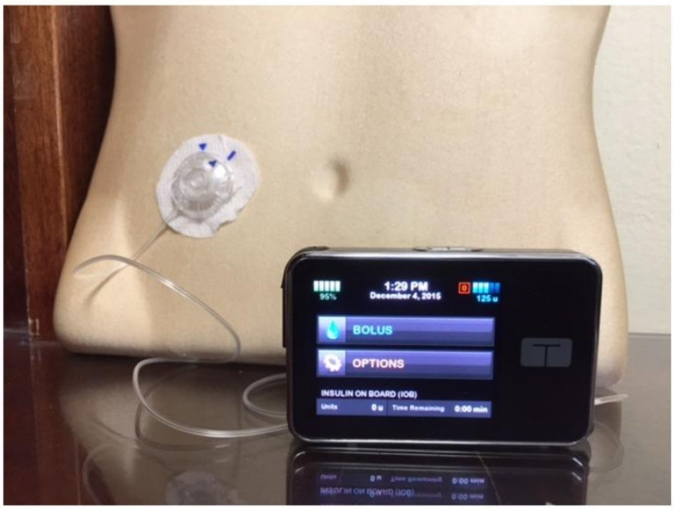

Figure 6. T slim insulin pump [10].

fig. 6. The T-slim Insulin Pump is trending among the young patients, beacuse of its innovative touchscreen [10].

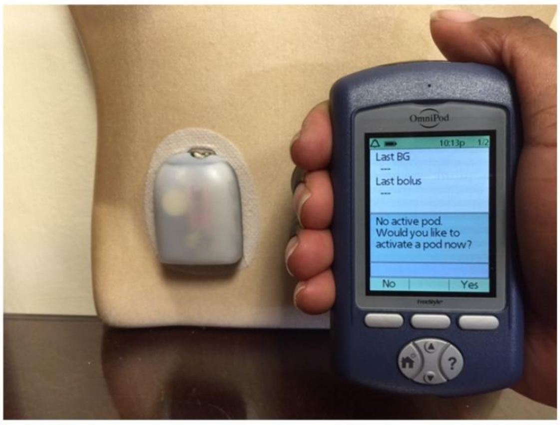

Figure 7. Omnipod tubeless insulin pump [10]

fig. 7. The OmniPod Tubeless Insulin Pump with a pod (**right**) and a handheld device that functions as a blood glucose meter and based on patient‘s settings it communicate‘s wirelessly [10].

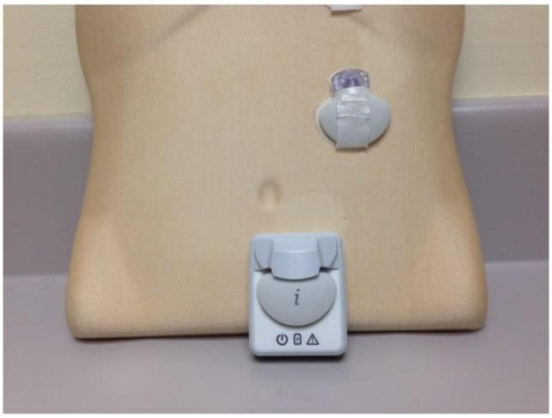

Figure 8. Medtronic ipro2 [10].

The Medtronic iPro2 Professional Continuous Glucose Monitor (Fig.8)with its charger, and a Downloaded Tracing showing daily color-coded readings (Fig. 9) given below [10].

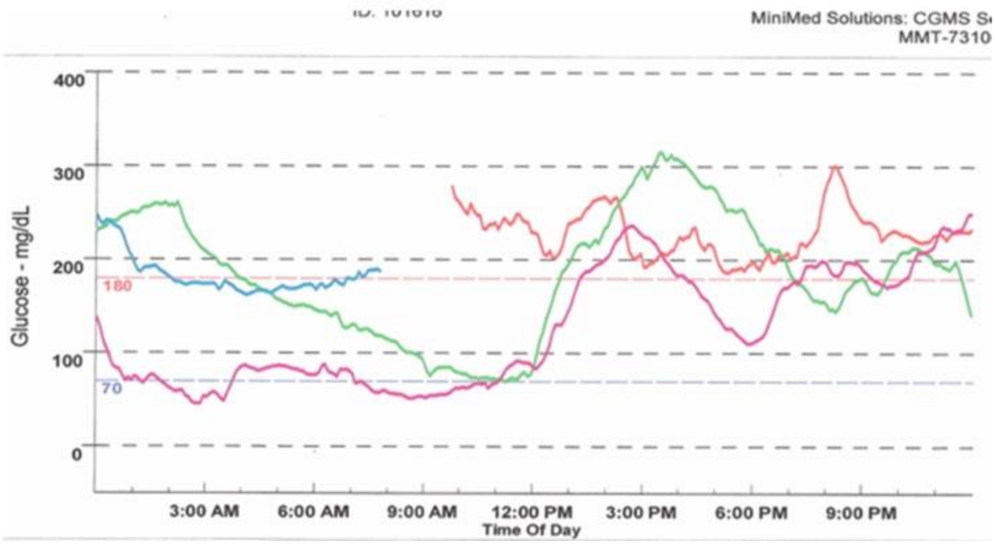

Figure 9. Tracing graph [10]

2.3 Selection of canditate for pump use

The diabetes can be treated by using insulin pump as they control essential needs such as self care and better glycemic control .These patients need to be aware of the advantages of changing into insulin pump and the amount of exertion required. In addition it must be clear that a pump is a concentrated device as programming and active communication is required. Features such as self-checking of blood glucose level, capacity required and active communication with the expert pump is essential for accomplishing the usage of pump successfully.[10]

Indication of insulin pump therapy

- Imperfect glycemic control regardless of endeavors different day by day insulin infusions
- Visit or erratic hypoglycemia and hypoglycemia ignorance
- "Day break" wonder with persevering early-morning hyperglycemia
- A dynamic way of life (exercise, strenuous physical action, athletic interests)
- Kids and youthful grown-ups who normally want less limitations and greater adaptability
- Development spurt of youthfulness
- Bias arranging and pregnancy
- Nearness of gastroparesis
- Frenzied way of life and regular travel
- Move work and sporadic every day plans
- Requirement for adaptability in sum and dinner schedules
- type2 diabetes with expanded insulin prerequisites [10].

2.4. Types of diabetes

Diabetes mellitus

The metabolic disorder known as Diabetes Mellitus is the most common form of diabetes which results due to the deficiencies and abnormalities in insulin. The major defect in secretion of insulin leading to hyperglycemia happens when pancreas produce excess insulin due to the force exerted by the insulin resistance. Other disease such as cardio vascular, nerve damage, retinal damage, chronic renal failure can be triggered by long term hyperglycemia

Hypoglycemia

Hypoglycemia is defined as low plasma glucose concentration which occurs when blood glucose level reaches below 70mg/dl which indicates symptoms such as nervousness, shakiness and metabolic changes. Most common type of hypoglycemia is called post granted hypoglycemia occurring after the intake of food [13].

Hyperglycemia

Hyperglycemia occurs when the blood glucose level is above 270 *mg/dL*. This can arise when diabetics eat large amount of meal or the insulin in the blood is low level. It is dangerous when hyperglycemia is not treated [13].

Benefit of the automatic insulin pump system

Diabetes:

Patients suffering from type1 and type2 diabetes can be benefitted.

Hyperglycemia patients

A person has hyperglycemia, when the blood glucose level is above 270 *mg dL*without appropriate treatment given to that patient hyperglycemia can be dangerous.it is predominant when diabetic patient eat large meal or insulin level get declined in the blood [13].

Hypoglycemia patients

A person has hypoglycemia when the blood glucose level is below 60 *mg dL*. This can happen ex. Over exercise, insulin dosage high, food contain small amount of carbohydrates or if the diabetic skips meals. Hypoglycemia canresult in loosing ofthe conscience. when insulin used as treatment issue in hypoglycemia can be avoided.This Kind of patients are highly beneficial by this project, as it test the blood glucose level time to time and insulin**is** being injected into the patients' blood to maintainthe glucose level in the blood automatically [13].

Bergmann's Minimal Model

Bergman's minimal model is described as the compartment including basal concentration of insulin. And glucose level in the body. It consist of two minimal models.

Glucose kinetics describes how the concentration of blood glucose reacts with blood insulin , wheras insulin kinetics describes how the concentration of blood insulin reacts with blood glucose by taking both the data's of insulin and glucose as input

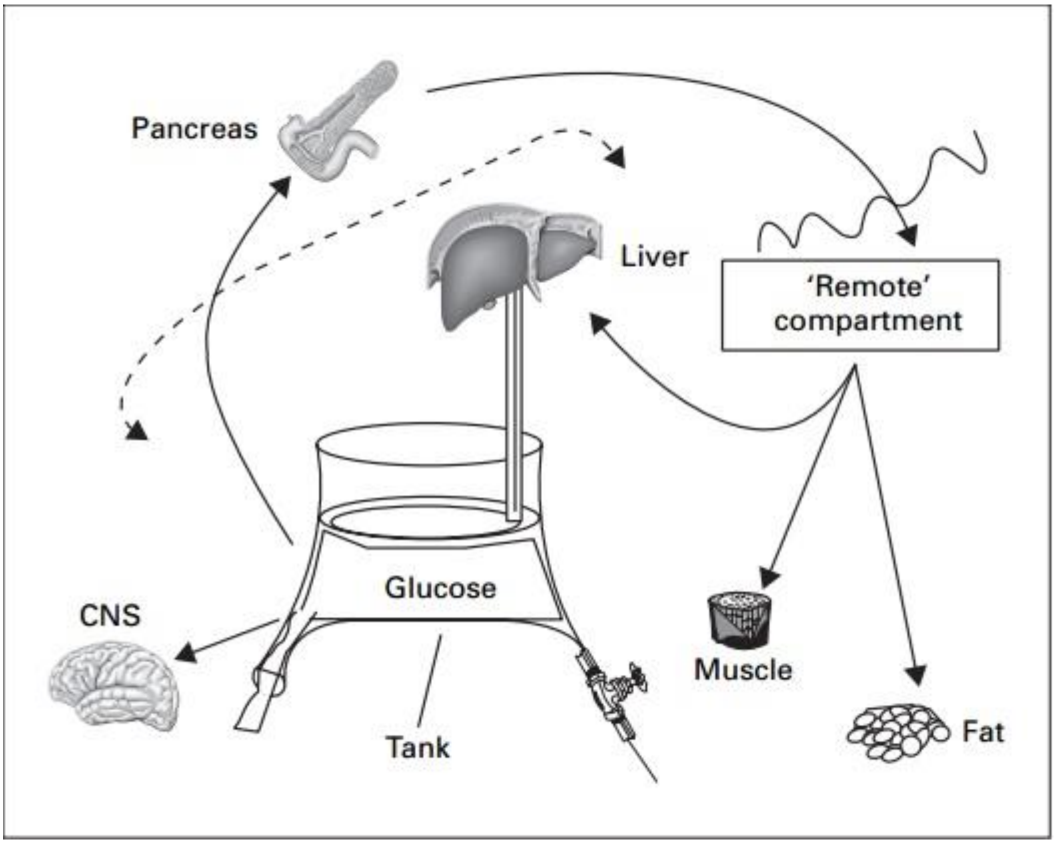

Figure 10. Bergmann's minimal model [14].

fig. 10. The figure elucidates tank containing glucose fluid by determining closed-loop relationship between , insulin secretion, glucose and insulin action.

The level of glucose is defined by balancing between the rate of utilization and the rate of production. After food intake , the glucose level increases as the hormones get suppressed from the fat . Due to which less glucose is produced in the liver. More specifically extra pancreatic tissues are represented including the overall glucose utilization and their effects in insulin [14].

2.5. Modeling of blood glucose level system

In human being body there are many feed back control loop for e.g.. We all know that pancreas secrete insulin. That insulin which regulate glucose. When we consume our food that food breakdown by the help of digestive system and glucose will rise and it help to produce insulin. The main role of cell which uses insulin to breakdown the glucose. the main problem of diabetic patient is they don't have capacity to produce insulin especially the type 1 diabetic patient they don't have capacity to produce insulin completely. So they have to monitor and inject several time in a day to help control their glucose level. A typical patient having this huge problem then they helping us a control system. there are few action which is free forward in nature. Like administration gives insulin shot which should be compensate with meal consumption and some other are feed back in nature, these patient will inject insulin based on their glucose level measured those measurement seen in "finger pricks" and they analysis glucose.

Long term, hyperglycemia patient can cause problem like blindness and also some cardio vascular problem

Short term, hyperglycemia patient cause problem like diabetic coma or fainting. Because of this problem our engineers came out with more advance technology in closed loop system now present technology has external pump along with reservoir contain insulin in it. That will inject insulin continuously. This technology especially for the patient who want to inject insulin several time a day. With external pump still the patient has to monitor their glucose level. And In future they have plan to develop implantable glucose sensor and insulin pump. This sensor will measure the glucose level and send this to wrist watch size controller. From the controller it send signal to the insulin injection pump. Here closed loop as a pancreas of type 1 diabetic patient [15] [16].

Mathematical modeling

Bergman minimal model is widely used model for the insulin injection and meal(glucose) input these are explained by three differential equation

$$\begin{aligned} dG/dt &= p1G - X(G+Gb) + Gmeal/V1 \\ dX/dt &= p2X + p3I \qquad \text{.....................................} \ (2.1) \\ dI/dt &= -n(I+Ib) + U/V1 \end{aligned}$$

Where,

G – blood glucose deviation

I – insulin concentration

X – is equivalent to the concentration of insulin within a remote area

Input are Gmeal and U

Gmeal – meal disturbance i/p of glucose

U – manipulated insulin injection rate

By using this value we can determine basal rate of infusion in insulin for maintaining a steady state [17].

Linearised state space model

This model helps to develop control system design the state, i/p, o/p variable (in deviation form) define as,

$$\begin{bmatrix} x1 \\ x2 \\ x3 \end{bmatrix} = \begin{bmatrix} G \\ X \\ I \end{bmatrix} \begin{bmatrix} u1 \\ u2 \end{bmatrix} = \begin{bmatrix} U - Ub \\ Gmeal - 0 \end{bmatrix} y = G \quad \text{...} \ (2.2)$$

From this matrix we got two input (first input, second input)

First input = manipulated(insulin injection)

Second input = meal glucose disturbance [18]

The state space model of the process is given as follows

$$A= \begin{bmatrix} -P1 & -G1 & 0 \\ 0 & -P2 & P3 \\ 0 & 0 & -n \end{bmatrix} \quad B= \begin{bmatrix} 0 & 1/V1 \\ 0 & 0 \\ 1/V1 & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \quad D = \begin{bmatrix} 0 & 0 \end{bmatrix} \text{...} \ (2.3)$$

Example set of parameter

Imagine a diabetic patient is modelled with the help of following parameters (lynch and bequette,2001)

G_b = 4.5mmol/liter

I_b = 4.5mU/liter

V_1 = 12 liters

P_1 = 0 min^{-1}

P_2 = 0.025 min^{-1}

P_3 = 0.000013mU/liter

n = 5/54 min^{-1}

notice that concentration is in mmol/liter unit and glucose disturbance in gram unit so it should be simply conversion factor 5.556 mmol/g to Gmeal

from steady state solution we came to know the basal rate should ne UB= 16.667mu/min. the below resulting state space model is take by using this value parameter [19]

$$A= \begin{bmatrix} 0 & -4.5 & 0 \\ 0 & -0.025 & 0.000013 \\ 0 & 0 & -5/54 \end{bmatrix} \quad B= \begin{bmatrix} 0 & 0.04630 \\ 0 & 0 \\ 1/12 & 0 \end{bmatrix} \text{...............................} \ (2.4)$$

It is common to work with glucose concentration unit "mg/deciliter" instead of "mmol/liter "since molecular weight of glucose = "180g/mol". We have to multiply our obtained glucose rate "mmol/liter" by 18 to get the measured glucose o/p "mg/deciliter" this leads to below state-output relation. [19]

$$\mathbf{C}= \begin{bmatrix} 18 & 0 & 0 \end{bmatrix} \quad \mathbf{D}= \begin{bmatrix} 0 & 0 \end{bmatrix} \text{...} \ \mathbf{(2.5)}$$

The process transfer function is

$g_p(s) = -3.79/(40_s+1)(10.8_s+1)$ .... (2.6)

Because of the cancellation of pole/zero. And the following disturbance transfer function is.

$G_d(s) = 8.334/s$ .... (2.7)

A meal disturbance is best model as pulse among various chemical process disturbances, imagine that in 15min period 50g glucose meal is consumed, then obtain magnitude of 3.333g/min for the pulse during 15min period. [10] [20]

$g_d(s) = 8.334/s(20s+1)$ .... (2.8)

Likewise, numerous chemical process disturbance, a pulse imagine containing 50 g glucose meal is consumed on a 15-minute interval ;then the pulse has a greatness of 3.333 g/minute for a length of 15 minutes. [19][20]

2.6. Simulation results

The model of the blood glucose level system is developed using Matlab/Simulink as shown in fig. 11.

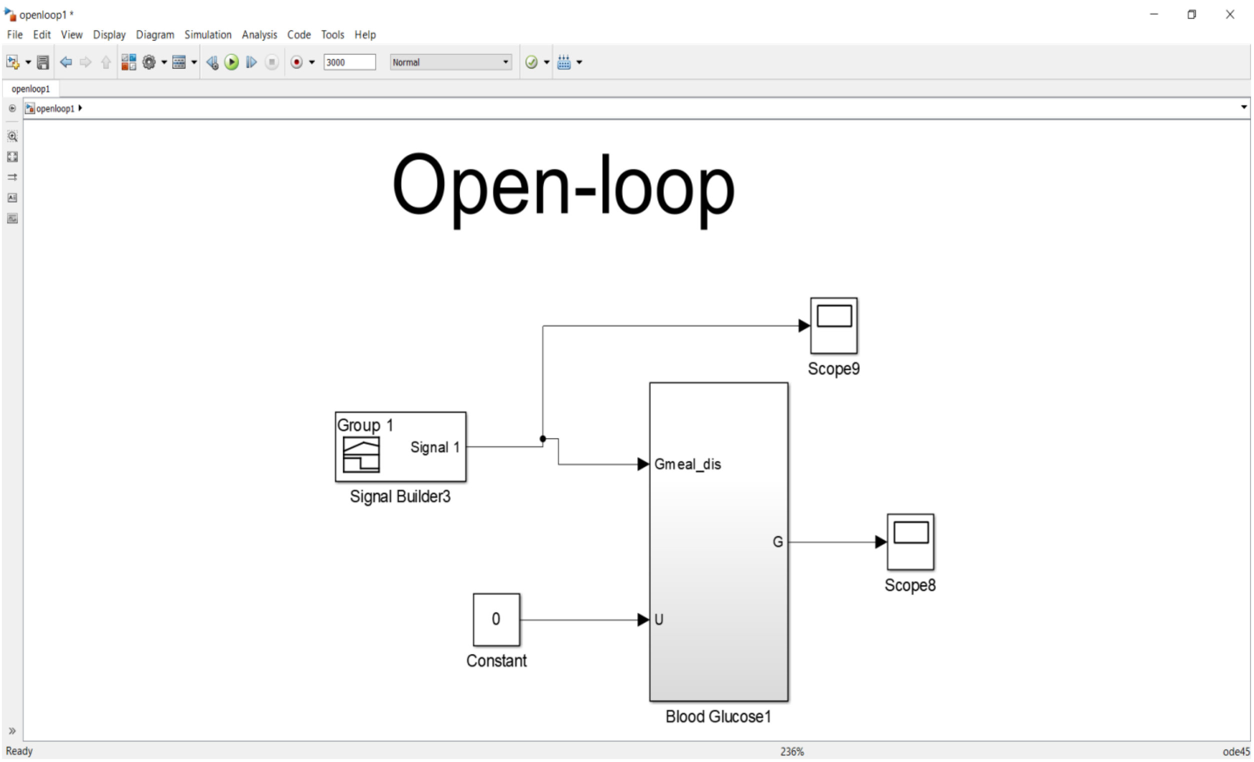

Figure 11. Mathematical model of blood glucose level system

The open loop response of the blood glucose level system is shown in fig. 12.

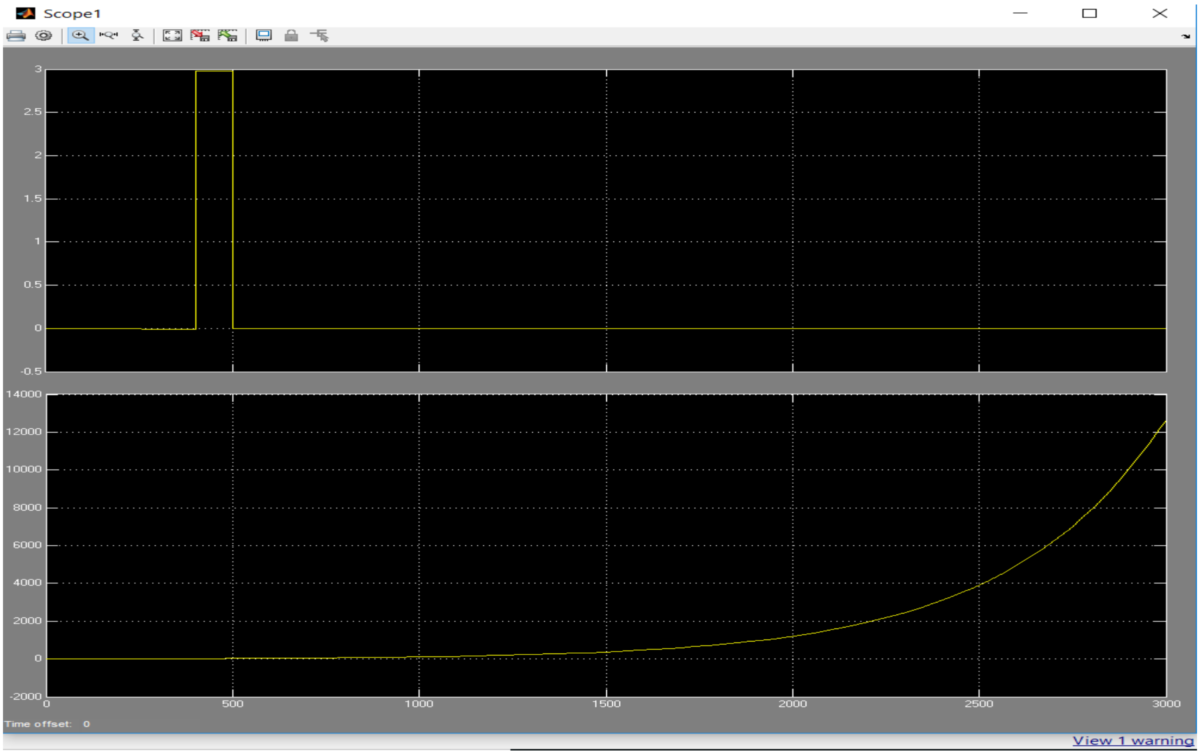

Figure 12. Open loop response of blood glucose level system

2.7. Conclusion

Thus the mathematical model and the linearized state space model of the process taken is presented in this chapter. The state space model obtained is based on the states considered and the modeling is the first step in designing a controller.

3.Design of pd and imc controller

3.1. Introduction

In industries each process is automated, so it is vital to maintain the varying parameters like flow,level,temperatue,pressure, etc. of the concerned operation at the rquired value for effective, economic and safe operation. The difference between the set point and the measured controlled variable (i.e error) is sent to the controller. When the error arises, then according to the set point the controller adjusts the actuator. Such control system are known as closed loop control system. It mainly consists of a controller, actuator and a measuring device. Either Pneumatic or Electronic controller can be used to perform the control action. The operation whatever, carried out by the pneumatic principles are preffered the most, because those system are safe. In the explosive environments such as refinery and industries where the application of electronics systems might cause dangerous issues. Pneumatic systems which uses air, are widely used. Hence , due to its safety consideration pneumatic signals are used mostly for operating valves.[21] [22]

3.2. PD controller design

Proportional-Derivative or PD control combines proportional control action and derivative control action. It improves the overall transient response of the system, it could handle any operation with time delay and it also reduces the settling time by modifying damping and reducing the peak overshoot.

PD controllers are employed for sluggish and integrating process. PD controller mode is mainly used, in order to predict future error. So by using this, effect of extra or additional dead time could be reduced. Due to the instant change in the desired value of process variable will end with a maximum overshoot in PI control, hence in PD control, effect of integrating action will be reduced by summing up the Proportional action term along with derivative action term .

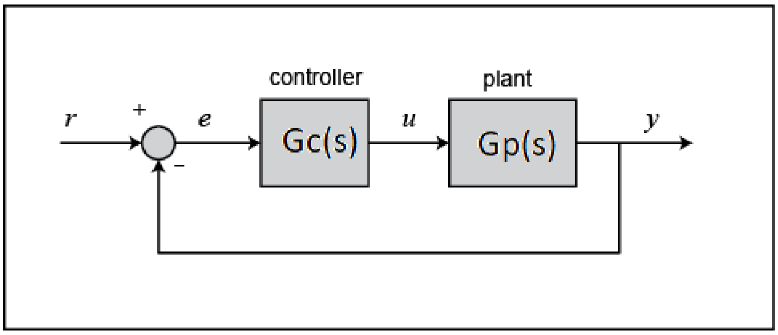

Figure 13.1. Feedback controller Scheme (PD) [23].

Where the ‘r’ is the setpoint of the closed loop system, Gc(s) is the PD controller and Gp(s) is the begmern

The equation is represented as,

$$P = K_p e_p(t) + K_p K_D \frac{de_p(t)}{dt} + P(0)$$ ------(3.1)

Where,

C(s) = PD controller’s output

K_P = Proportional Gain

K_D = Derivative Gain

e_p (t)= Desired Value of controlled variable – Measured Value

P(0) = the output of controller (if error = zero)

From the equation, we can say that this mode cannot eliminate the steady state error of proportional controller. However, it can handle fast process load changes as long as the load change steady state error is acceptable.The parameter of a PD controller is tuned using Ziegler–Nichols closed loop tuning method [21][22].

Zn method (zingler – Nicholas) uses a closed loop controller. And it require some following step

- first step is to be bring the system in steady state condition
- By using the p control, changing the set point and differ gain until the system oscillating continues. This frequency is ω_{co} and M is amplitude ratio
- Compute following:

  Ultimate Gain = K_u = 1/M
  Ultimate Period =P_u = $2\pi/\omega_{co}$

Table.1 Ziegler–Nichols closed loop tuning method

Ziegler–Nichols	
Kp	0.8 Ku
Kd	Pu/1.2

3.3. Internal model control

The Internal Model Control (IMC) depends upon the Internal Model Principle, which defines that control perfect control is theoretically possible, if exact model of the process is available. fig. 13.2. represent the open loop control system.

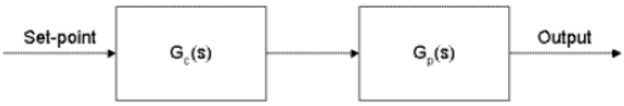

Figure 13.2. Open loop control system.[23].

A controller, $Gc\ (s)$, is used to control the process, $G_p(s)$. Suppose $\tilde{G}_p(s)$ is a model of $G_p(s)$. By setting $G_c(s)$ to be the inverse of the model of the process,

$G_c(s) = \tilde{G}_p(s)^{-1}$, -----(3.2)

and if $G_p(s) = \tilde{G}_p(s)$ ------(3.3)

then it is clear that the output will always be equal to the setpoint. From this, it is concluded that complete knowledge about the process being controlled is well known, we can achieve perfect control through open loop itself.

In practice, however, process-model mismatch is common; As the process model is not invertible and the unknown disturbances affects the system. To maintain the set point, the above open loop cannot be used. it forms the basis for the developing a control strategy which has the potential to achieve perfect control. This Internal Model Control (IMC) stratergy has the general structure depicted in fig. 14 [23].

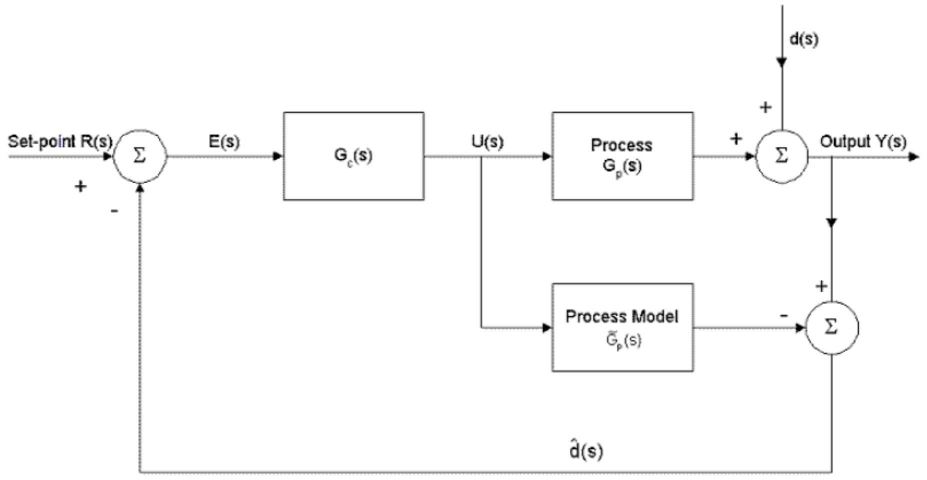

Figure 14. IMC general structure [27].

From the above diagram, *d(s)* is considerd as an unknown disturbance, which affects the process of this system. A input

U(s) is given to the process and process model ,which is known as manipulated input. Finally, the concerned output of the process, *Y(s),* and the output of the model are compared, which is results in a signal $\hat{d}$(s). That is,

$\hat{d}$(s) = [$G_p(s)$ - $\tilde{G}_p(s)$]U(s) + d(s) ----(3.4)

for example, the measure of difference in behaviour between the process and process model would be $\hat{d}$(s), if *d(s)* is equal to zero. But , if $G_p(s)$ = $\tilde{G}_p(s)$, then obviously $\hat{d}$(s) will be equal to the value of unknown disturbance. So ,$\hat{d}$(s) may be the information that is absent in the model, $\tilde{G}_p(s)$, and it could be used further to improve the control action. This could be done by considering the differnce between $\hat{d}$(s) and setpoint *R(s),* which is actually a similar method to effecting a setpoint trim. Then, the final control signal is represented by,

U (s) = [R(s) – d(s)]G_c (s) = { R (s) – [G_p (s) – G_p (s)] U (s) – d(s)} G_c(s) ----(3.5)

Thus,

$$U(s) = \frac{[R\ (s) - d\ (s)\ ]Gc\ (s)}{1 + [Gp\ (s) - Gp\ (s)]Gc\ (s)} \quad \text{------(3.6)}$$

$$Y(s) = G_P\ (s)U(s) + d(s) \quad \text{-----(3.7)}$$

Thus,the transfer function for the IMC is .,

$$Y(s) = \frac{[R\ (s) - d\ (s)\ ]Gc\ (s)\ Gp(s)}{1 + [Gp\ (s) - Gp\ (s)]Gc\ (s)} + d\ (s) \quad \text{-----(3.8)}$$

Or, $Y(s) = \frac{Ge\ (s)Gp\ (s)R\ (s)+\ [1-Ge\ (s)Gp\ (s)]d\ (s)}{1+[Gp\ (s)-Gp\ (s)]Ge\ (s)}$ ------(3.9)

The above mentioned expression of a closed loop system, states clearly, if $G_c(s) = \tilde{G}_p(s)^{-1}$ and if $G_p(s) = \tilde{G}_p(s)$, then precise setpoint tracking of setpoint and even elimination of disturbance could be done, even if theoretically $G_p(s) \neq \tilde{G}_p(s)$, so disturbance elimination could still be made perfectly with $G_c(s) = \tilde{G}_p(s)^{-1}$. By minimising the effects of process model missmatch, robustness could be improved. A filter $G_f(s)$, which has the characteristics of low pass is made in series with inverse of process model $G_{imc}(s) = G_c(s)G_f(s)$,which is basically the design of controller. It is designed in order to reduce the effects of process missmatch, which occurs at the high frequency end of frequency reponse. For applying low pass filter, the order of the filter should be chosen such that $G_c(s)G_f(s)$ is appropriate, to safeguard the extra differential control action. Thus, the final closed loop then becomes

$Y(s) = \frac{GIMC\ (s)\ Gp\ (s)R\ (s)+[1-GIMC\ (s)Gp\ (s)]d\ (s)}{1+[Gp\ (s)-Gp\ (s)]GIMC\ (S)}$ -----(3.10)

IMC design procedure

The transfer function model is given below:

$G_p\,(s) = \frac{-3.79}{(40s+1)(10.8s+1)s}$ .... (3.11)

Internal model controller was designed

block diagram of IMC controller for blood glucose system is likely shown in the figure.

The transfer function model of diabetic patients is considered (Lynch and Bequette 2001),

The model transfer function is,

Gp=-3.79/(40s+1)(10.8s+1) .... (3.12)

The controller parameters for PD and IMC are analytically tuned using the formulas. The obtained controller parameters settings are given below,

Kp=-0.516, Kd=0.1010 .... (3.13)

The IMC controller parameter **λ is 0.15.** The closed loop simulation study was conducted to analyze the performance of PD and IMC controller for blood glucose system [11][12][23][24].

Table.2 The Controller parameter of PD and IMC

Controller	Controller parameter	
PD Controller	Kp	Kd
	-0.00948	28.53
IMC Controller	Λ	
	0.15	

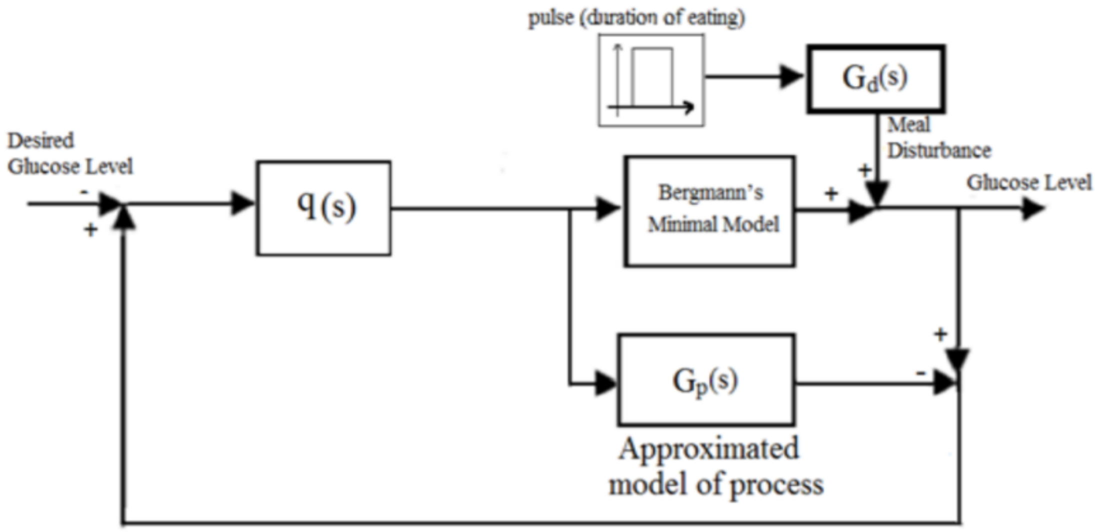

Figure 15. IMC based controller for blood glucose system [24].

The level of blood glucose, has to maintain a particular level while it increases, naturally pancreas inject the insulin to our body to maintain the glucose level whereas for type-1 diabetic patients pancreas doesn't inject the insulin so insulin pump injects the insulin The glucose sensor continuously monitoring the blood glucose level after a meal the glucose level is increases drastically it has refers to input disturbances to the process. The Process is first order with dead time process. The single loop PID controller is used for control the blood glucose system. Insulin pump there is a stepper motor it coupled with a injection needle shaft. If the glucose level increases the PID controller produces a control signal in terms of voltage to drive a stepper motor. The displacement of shaft is equivalent to injection of insulin into human body.

The PD controller tuned using GA to achieve minimum ISE. The PD control signal affects the insulin system due to its oscillatory response; the time take to regulate the blood glucose is high. To overcome this complexity IMC controller is used. In practice, the glucose level does not enter the blood stream immediately. Meals take some time to reach it into blood stream. Assume, the patient is taking 50g meal over 15 minutes. Hence 3.3g/minutes pulse is applied in simulation for 15 minutes. The glucose level increases suddenly due to the meal, and it is gradually reduced by applying insulin. Figure 13 shows the Comparison of PD response, IMC response to meal disturbance

The simulation starts with time t=0, the setpoint for the closed loop control is set as 80 mg/deciliter , then meal disturbance is given to closed loop system at 400 seconds . The both controller tries to track the glucose in the desired level.[11][12]

3.4. Conclusion

Thus the closed loop controller design using PD and IMC for the blood glucose level system have been designed and discussed broadly in this chapter. In the next chapter, the design of controller i.e, PD and IMC using optimization technique has been discussed.

4. Design of pd and imc controller using particle swarm optimization technique

4.1 Introduction

This chapter describes the design of fuzzy gain organized Particle Swarm Optimization (PSO) based PID controller design for the control of CSTR, with highly nonlinear characteristics. The GA and DE techniques involve many operations like crossover, mutation and selection making the process computationally tedious. An alternate method, PSO is investigated in this chapter. PSO requires position and velocity updation making it computationally simpler. In the present work, a try has been given to tune the PID controller parameters using the techniques of PSO. Fuzzy gain scheduler is attempted for the gain selection to accommodate the entire range.[25]

4.2 PSO principles

PSO algorithm is a type of optimization and a process change (evolution) computation technique. This mode is really effective in the application of problem solving, multiple optima, indication of nonlinearity, non-differentiability and it has high measure in one direction via adaptation derived from the theory of social psychologic . The fundamental PSO is built from swarm techniques like, flocking and fish schooling. Thus, the postulate made through the observstion, it is clear that the data (information) sharing happens in bird flocking. From, the observation of human groups behaviour it is clear that each individual has its own behaviour depends on the behaviour patterns which is recognised by customs and other more behaviour patterns based on the individual experience. This postulate is the fundamental idea of PSO. In this algorithm, when a d-variabled optimization problem is considered, a group of particles are located into the d-dimensional search space with random positions and velocities by knowing it‘s best values, Pbest and the position in the d-dimensional space. By self the flying experience of other particle, velocity of each particle could be altered. Thus ,The ith particle is presented as ϰi =(ϰi1, ϰi2,…..,ϰid) in the d dimensional space. The previous best positions of the ith particle is coded again and presented as

Pbesti = (Pbesti1 ,Pbesti2,….., Pbestid) .... (4.1)

Best particle which outstands among all of the particle is gbestd. The velocity of particle i is presented as ʋi = (ʋi1, ʋi2,….., ʋid).

By applying the current velocity and distance from Pbesti d to gbesti d. The position and modified velocity of the particles could be determined, which is presented in the following formulae ʋi,m(t+1) = w.ʋi,m(t) +c1* rand( )* (pbesti,m - ϰi,m(t)) +c2* rand( )* (gbesti,m - ϰi,m(t))....... (4.2)

ϰi,m(t+1) = ϰi,m(t)+ ʋi,m(t+1).......... (4.3)

where

i = 1,2,….,n

m = 1,2,….,d

where

t - Number of iteration

n - Number of particles in group 91

d - Dimension

i - Pointer of iterations (generations)

m - Population $\upsilon_{i,m}(t+1)$ - particle I velocity at iteration (t+1) $\upsilon_{i,m}(t)$ - particle I velocity at iteration (t) $V_{dmin} \leq \upsilon_{i,d}(t) \leq V_{dmax}$

w - Inertia weight factor

c1,c2 - Acceleration constant

rand( ) - Random number from 0 to 1 $\varkappa_{i,m}(t)$ - particle I curent position at iteration (t) $\varkappa_{i,m}(t+1)$ - particle I current position at iterations (t+1) pbesti m - previous best, position of the ith particle

gbesti m - Best particle in the population.[25]

4.3 pso based pd tuning and minimizing the performance index

fig. 16 shows the flowchart of PSO based Tuning of PD control. PSO based design of controller gives a try to reduce the error that occurs in the system due to some inputs, system error could be the difference between the desired and the actual response of a particular system. The measure of system error depends on performance criteria. The method of PD controller design minimizing IAE, ISE and ITAE using PSO are proposed. The Swarm Optimizations techniques is used for auto tunning PD controller. In this techniquethe tuning of PD parameters are done by using PSO techniques. The same is used in online for minimum performance index and for each region individually.

.

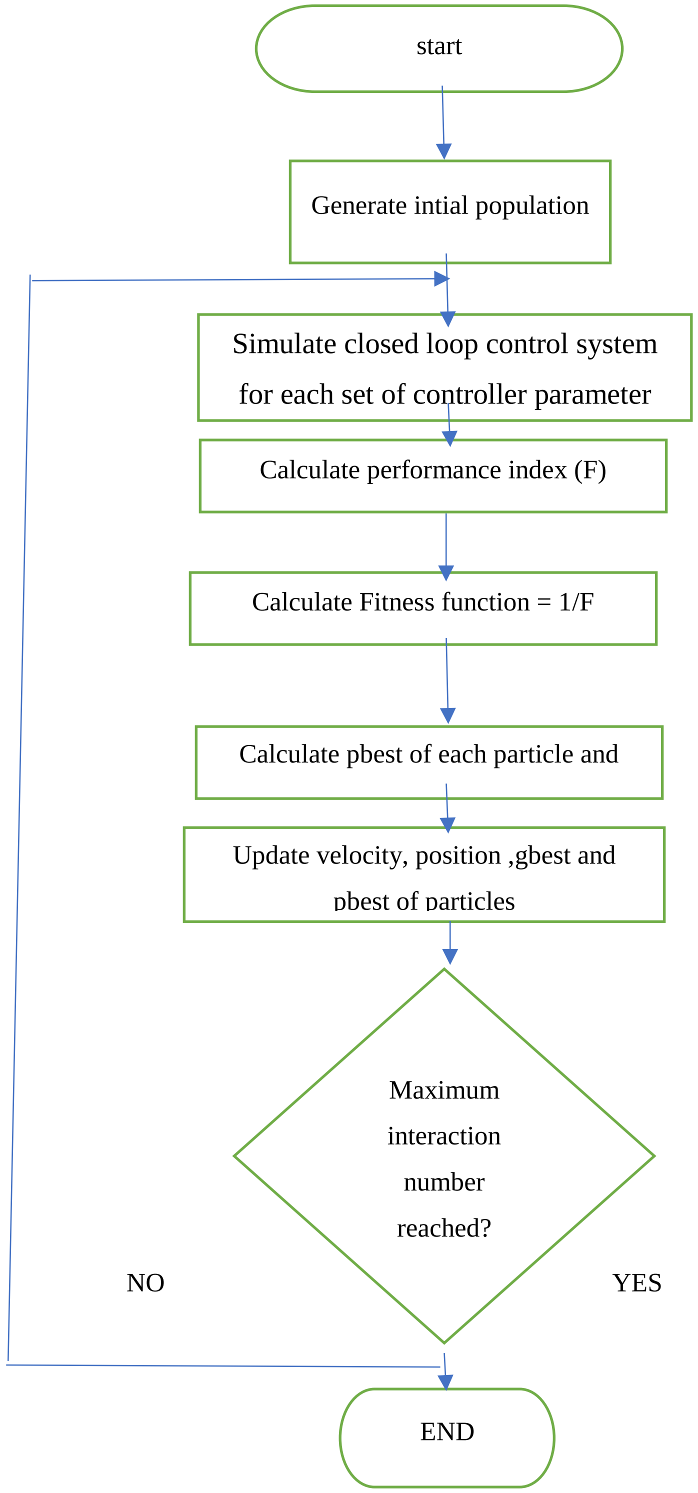

Figure 16. Flowchart of PSO based tuning of Pdcontrol [25].

For PSO, PID parameters are the particles fig. 17 represents the block diagramfor PSO based tunning of PID parameters using PSO minimizing IAE. Initially, the position of particles are initialized randomly. Then, by using the fitness function which is based on the error inverse form, gbest and pbest are found. Fitness function is denoted as 1/IAE. A better performance could be achieved in system‘s response by making larger value of the fitness function. Computation of particle‘s next movement coud be done,by updating the position and velocity vectors. Fitness functions of the optimized PID parmeters with larger values are decided by repeating required number of iterations.The number of iterations carried for the simulation of process is 30 with an inertia of 1. The correction factor c1 , the cognitive acceleration is considered as 2.0 and c2 the social acceleration is considered as 3.0 with 25 of swarm size for lower region. The correction factor c1 is chosen as 2.0 and c2 as 20.0 with a swarm size of 40 for the middle region. The correction factor c1 is taken as 2.0 and c2 as 2.0 with 20 of swarm size for higher region. Trail and error methods are used to select the accleration factors. For the three different operating regions, simlation results are reported.[25] [11] [12].

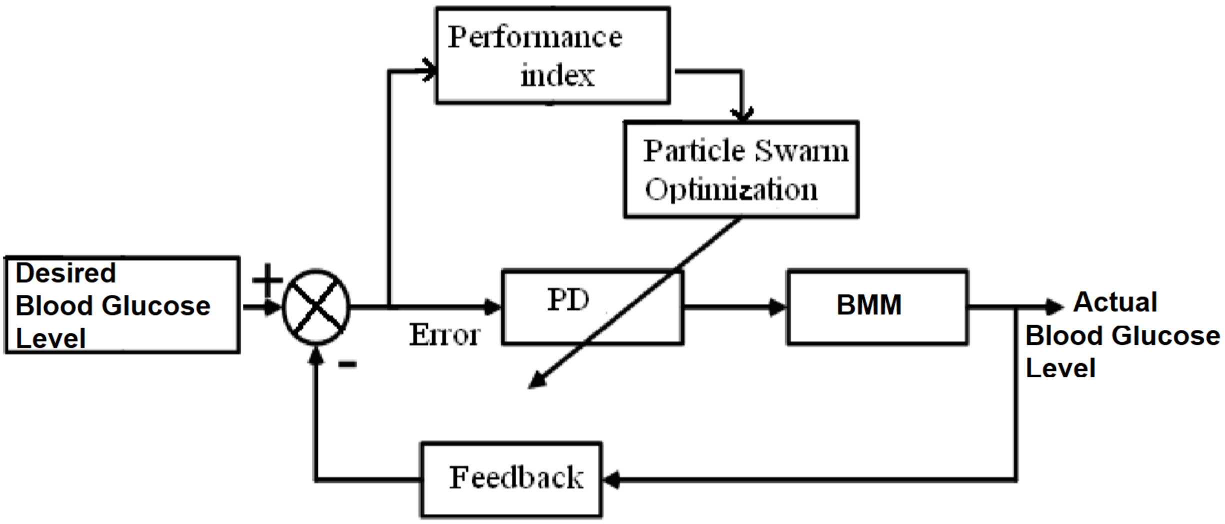

Fig 17. Closed loop block diagram for online tuning of PD [25].

Table.3 The Controller parameter obtained by PSO algorithm

Controller	Controller parameter	
PSO-PD Controller	Kp	Kd
	-0.01459	-0.5102
PSO-IMC Controller	Λ	
	0.1041	

4.4. Simulation study

The closed loop response of CSTR is studied separately in each linear region with the optimized PID controllers. It is evident that the output response follows the set point without overshoot or undershoots. Even in unstable region the set point is tracked with zero steady state error using the optimum controller parameters with some oscillations in the initial response

4.4.1. PSO Based PD Controller

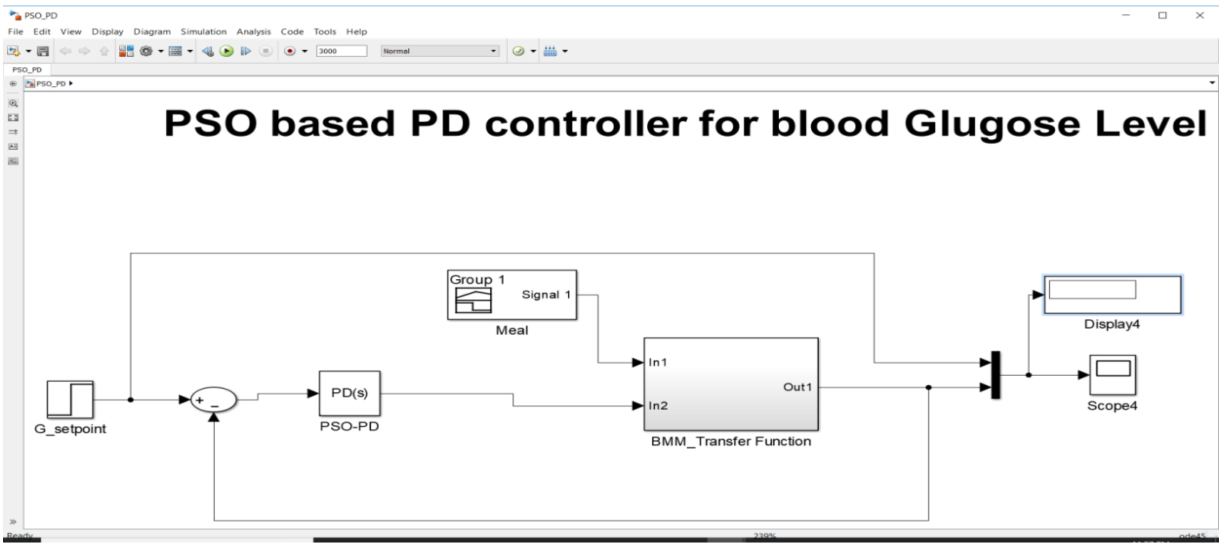

figure 18. Matlab/simulink model of the PSO based PD controller for blood glucose level

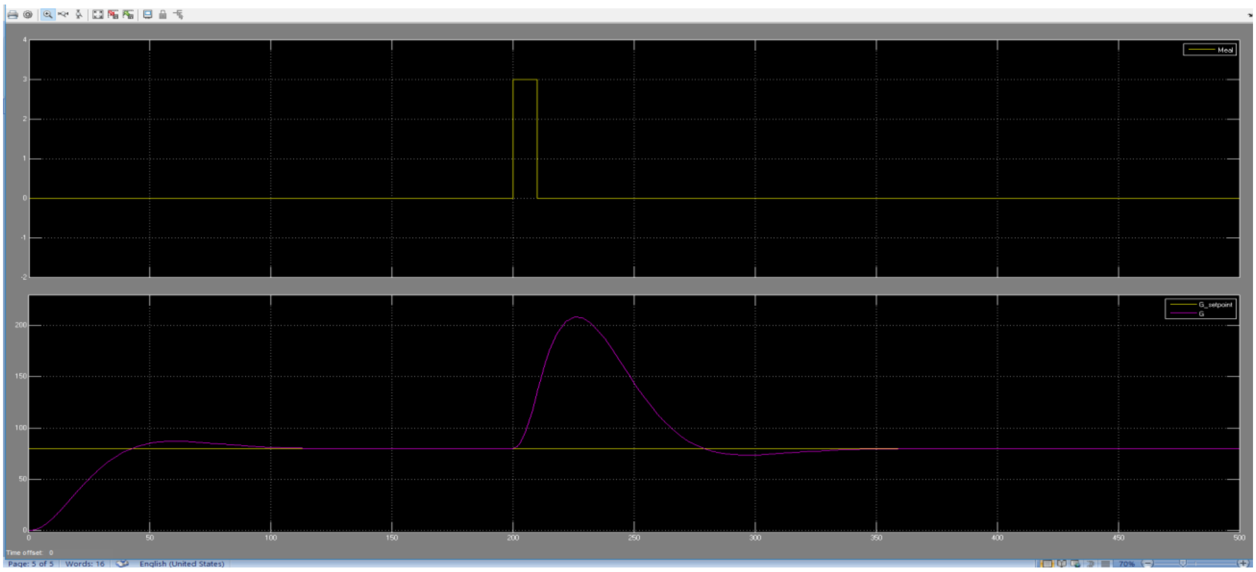

Figure 19. Closed loop response of PSO based PD controller in the blood glucose level control

fig. 19. shows the servo and regulatory response of the BLC. Initially the set point is fixed as 5 kgmol/m3 and at 100th sampling instant the feed concentration is changed by 5%. At 200th sampling instant, the set point is set to 1 kgmol/m3 and at 300th sampling instant 5% change is given to the feed temperature and at 400th sampling instant the set point is given as 8 kgmol/m3 and the feed concentration is varied at 500th sampling instant. The response reveals that the controller scheme provides good tracking and regulatory control of the BLC.

4.4.2 PSO Based IMC Controller

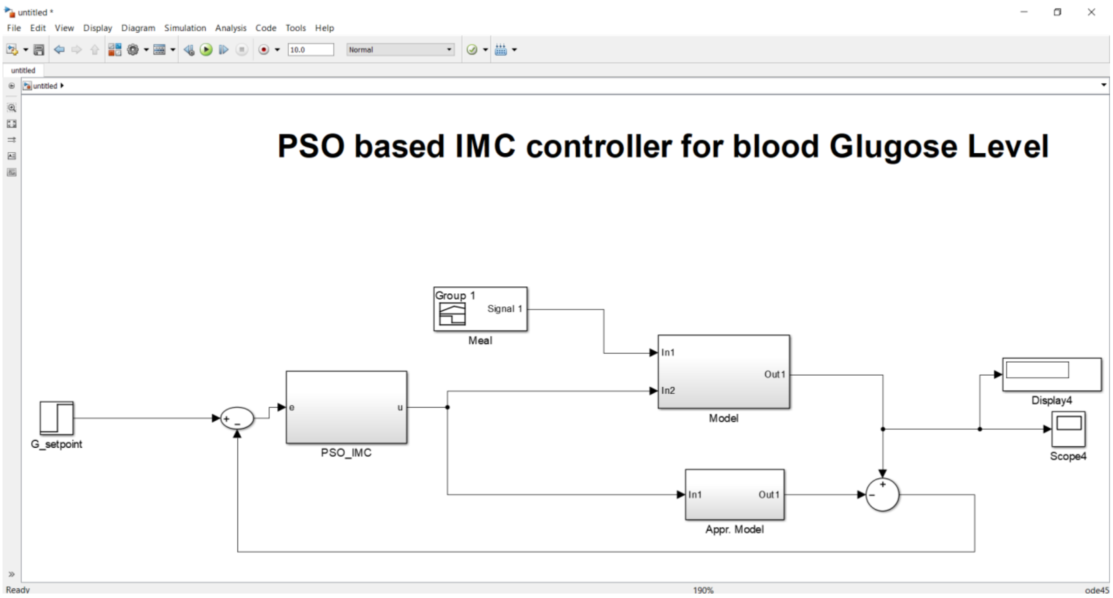

Figure 20.Matlab/simulink model of the PSO based IMC for blood glucose level

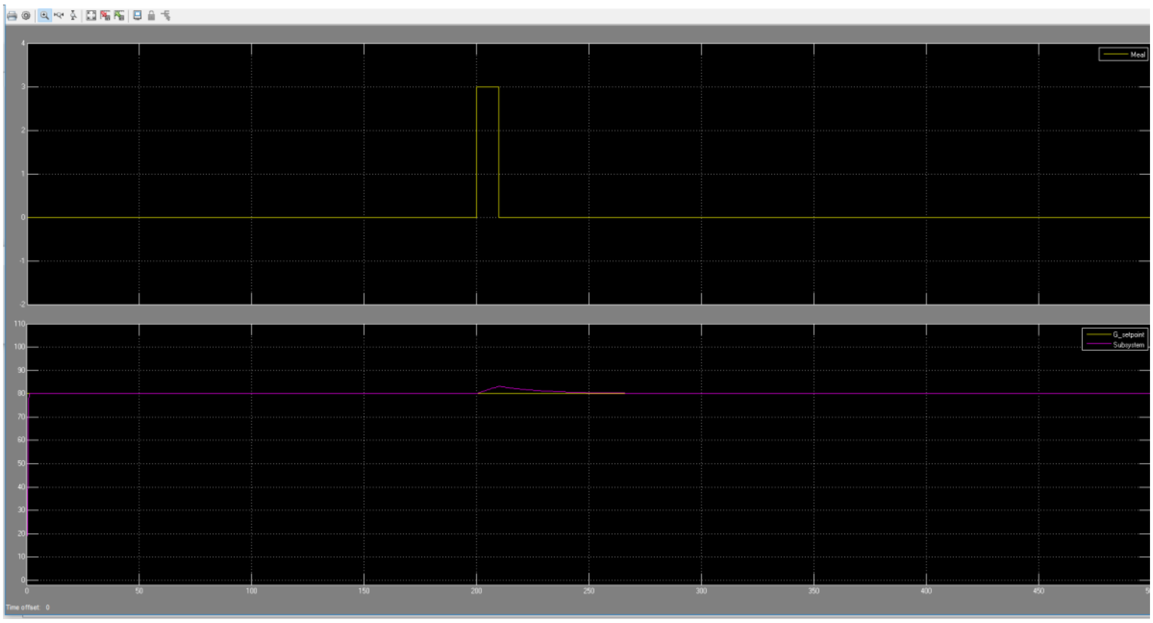

Figure 21. Closed loop response of PSO based PD controller in the blood glucose level control

fig. 21. shows the colosed loop Pso Based PD controller response. Simulation results are reported for the Servo tracking of PSO based PD and PSO based IMC controller.

Performance index

A measure know as performance indices. Performance index are shown below in three express error signal.

1. **Integral square error (ISE)**

   ISE = $\int_0^{\infty} e^2\,(t)\;\,dt$

2. **Integral absolute error (IAE)**

   IAE = $\int_0^{\infty} |e\,(t)|\;\,dt$

3. **Integral time absolute error (ITAE)**

   IATE = $\int_0^{\infty} t|e\,(t)|\;\,dt$

Table.4 Comparison of performance measures of servo and regulatory response of controllers

Controller	IAE	ISE	ITAE
PSO-PD	1176	2066	$1.219*10^4$
PSO-IMC	865	921	$0.2947*10^4$

The performance indices for the PSO based PD and PSO based IMC minimizing IAE, ISE and ITAE are tabulated in Table. 4. The IAE and ISE criteria results in a response with small overshoot and weighs, where all the errors are equally independent of time. The ITAE does not discourage against initial error which is large in the response following the step demand, but penalize errors which are smaller at a time later.

4.5. Conclusion

In this chapter, PSO based PD and PSO based IMC controller minimizing the performance indices are applied for the control of Blood Glucose Level process. PSO based IMC concentrates on the minimization of the performance indices, IAE, ISE and ITAE. The PSO based IMC techniques have been proven to be more efficient in controlling the blood Glucose level with faster settling time and minimum integral value.

5. RESULTS AND DISCUSSION

5.1. Introduction

To achieve the controller performance goals by designing the different controllers to control the blood glucose level system and their response are compared effectively with the common controller. The PD and IMC controller schemes are used in the research work to control the level of blood glucose. The PD and IMC controller are tuned using the conventional rules and trial & error method. The PSO algorithm is applied to obtain the parameter of controller for minimum value of integral square error. The research work is carried out to check the capability of controller in the regulating the blood glucose level of human body. The BMM is considered as human body for implementing the controllers in the simulation environment.

5.2. Performance Analysis of PD controller

The PD controller performance for the control of blood glucose level is investigated for the desired setpoint of glucose level 140mg/dL. In order to evaluate the regulatory performance of the PD controller, the meal disturbance is applied as a pulse at 400 sec as shown in figure. 22 The PD controller trying to regulate the meal disturbance as well as to maintain the desired glucose level 140mg/dL.

figure. 23 show the closed loop simulation response of PD controller. It can been seen from the figure. 23 is that the controller rejects the meal disturbance faster, but there are huge overshoot with oscillation in the control of glucose level. It is found that PD controller provides large settling time with larger integral indices.

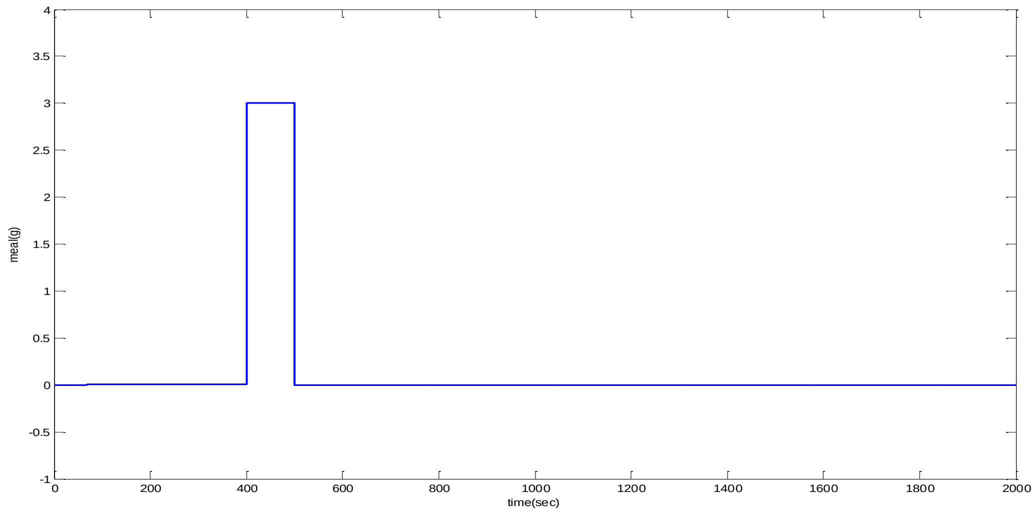

Figure 22. The input meal disturbance signal

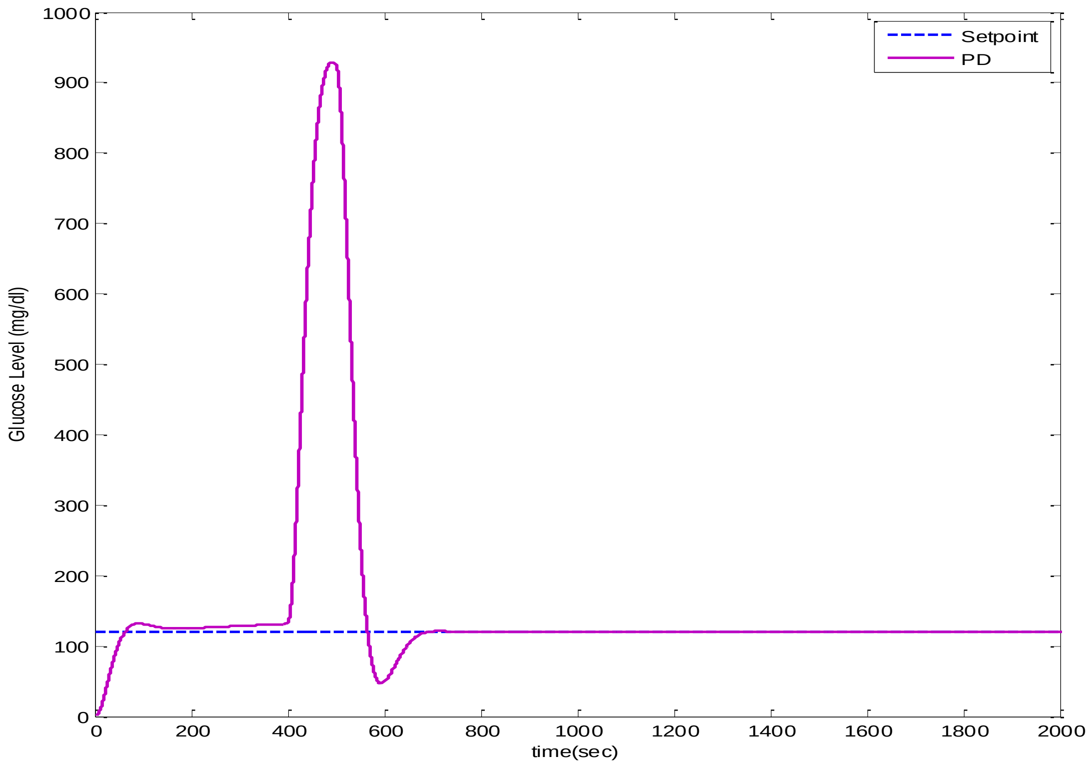

Figure 23. Closed loop response of PD controller in the blood glucose level control

5.3 Performance Analysis of IMC controller

The PD controller performance for the blood glucose level control is investigated for the desired setpoint of glucose level 140mg/dL. For evaluating the regulatory performance action of the IMC controller, the meal disturbance is applied as a pulse at 400^{th} minute with 3.3g as shown in figure. 24 There is lack of analytical rules in the literature for the tuning the filter time constant in the IMC controller . Hence, The IMC controller parameter was fixed trial and error. The IMC controller regulate the meal disturbance as well as to maintain the desired glucose level 140mg/dL faster than the PD controller.

fig. 25. show the closed loop simulation response of IMC controller. It can be seen from the fig .26. is that the controller rejects the meal disturbance faster than PD controller. It is found that IMC controller provides large settling time with larger integral indices.

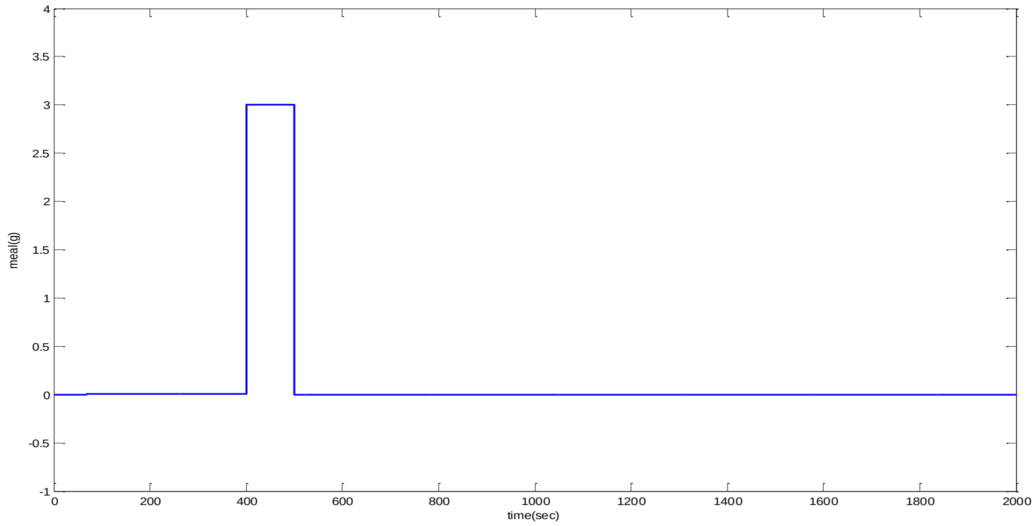

Figure 24. The input meal disturbance signal

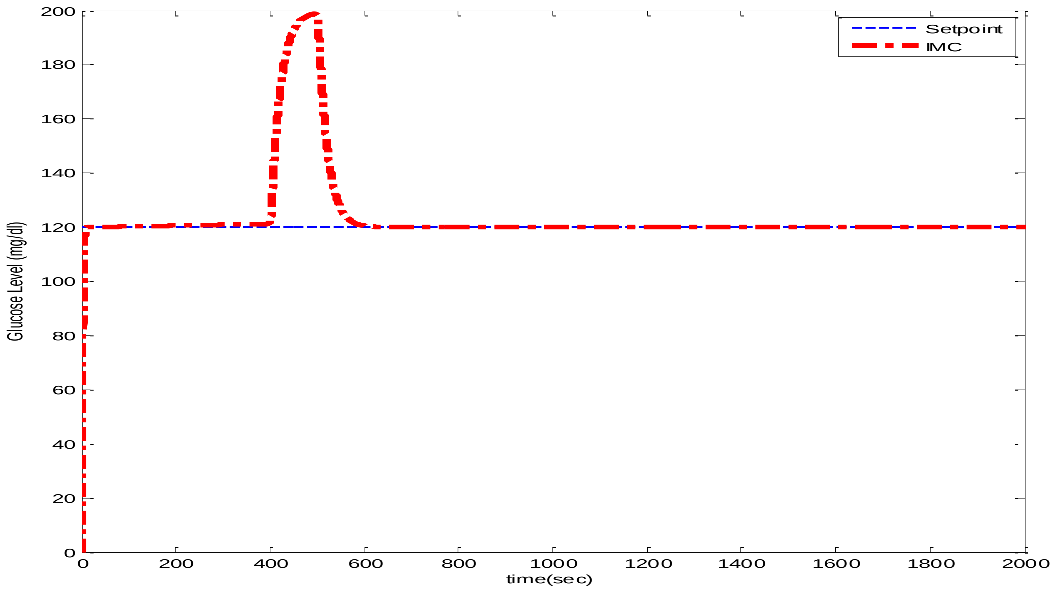

Figure 25. Closed loop response of imc controller in the blood glucose level control

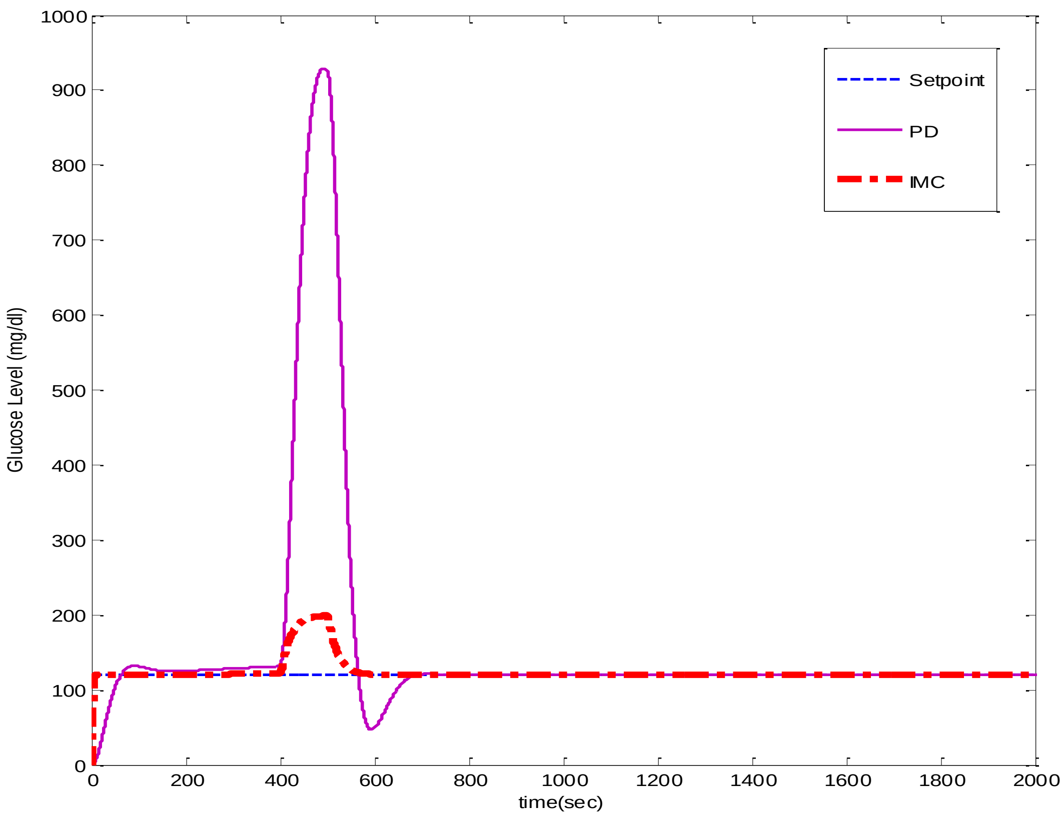

Figure 26. Comparision of PD and IMC control response

5.4 Performance analysis of PSO based PD and PSO-IMC controller.

The researchers started applying the optimization algorithm in the design of controller tuning. As discussed in the chapter 4, the PD and IMC controllers are tuned using PSO for minimum values of ISE. The simulation study is carried to compare the performance of proposed controller. The following simulation results show that the desired objectives of achieving minimum ISE are achieved. The simulation started with time t=0 , without any disturbance. The controller tracking the set point of 120 mg/decilitre level and then the meal disturbance with magnitude of 3.33g/minute is applied at 400th minute as a pulse which raises the glucose level of patient. The PSO-IMC based controller rejects the meal disturbance effectively than PSO-PD control. The PSO-IMC regulates the glucose level within 40 minutes after having meal whereas PSO-PD takes longer time to regulate the glucose level.

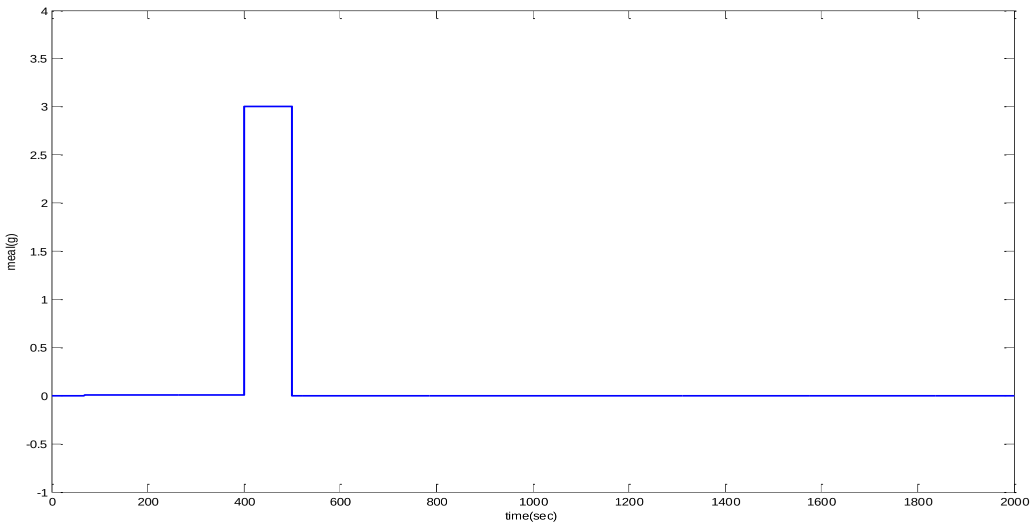

Figure 27. the input meal disturbance signal

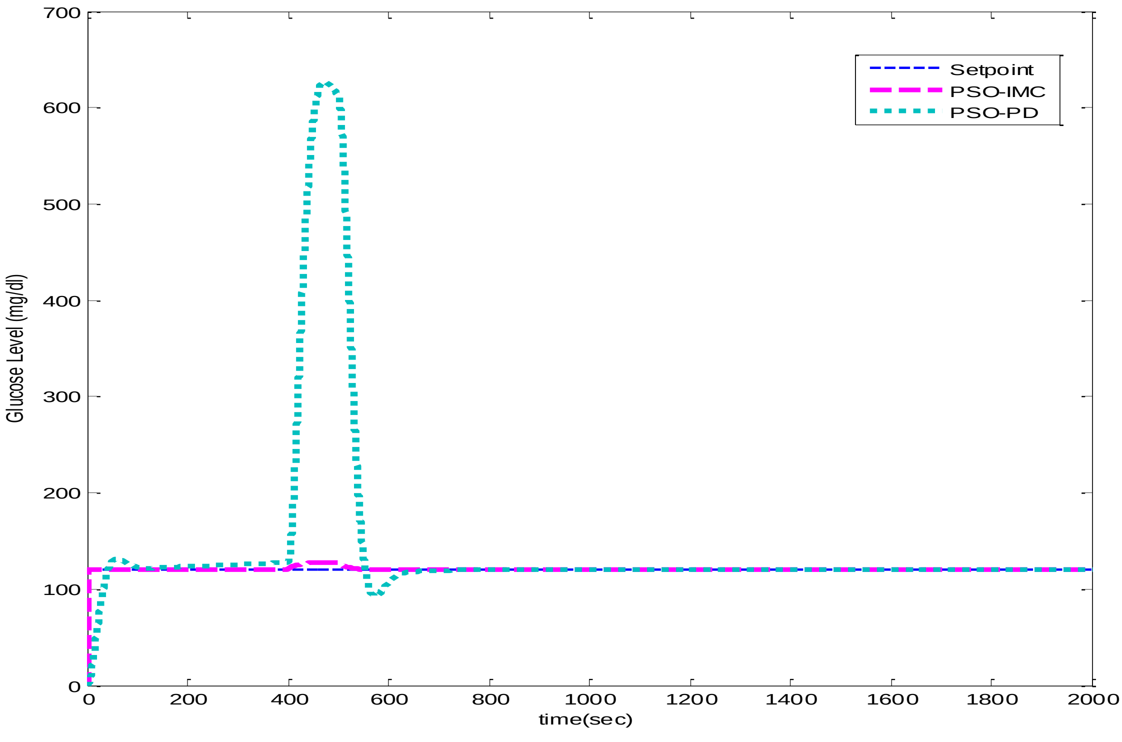

Figure 28. closed loop response of pso-pd and pso-imc controller in the blood glucose level control

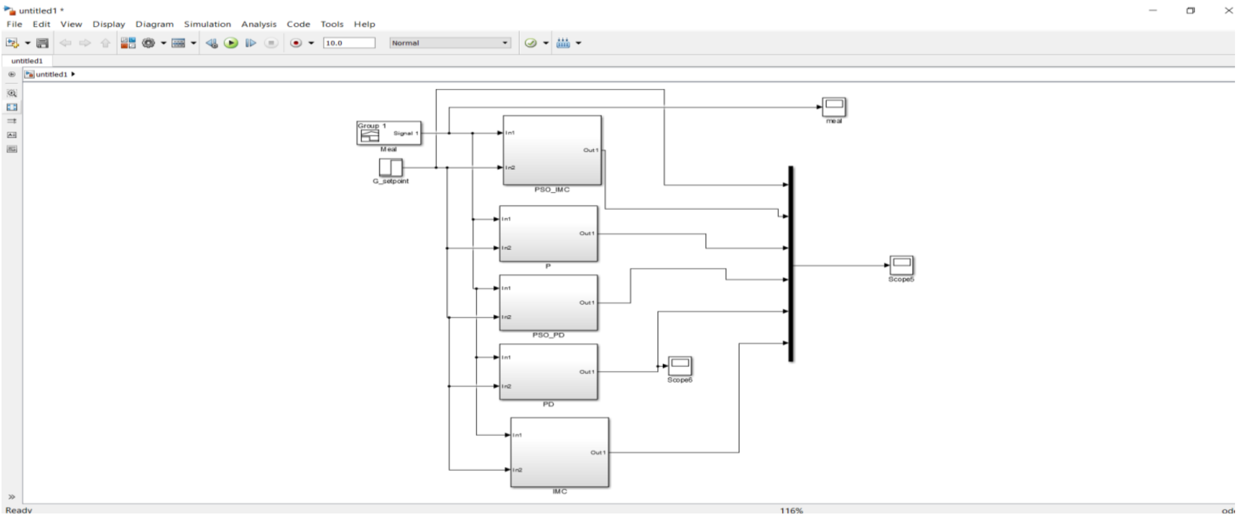

Figure 29. Matlab/simulink model of all the control schemes

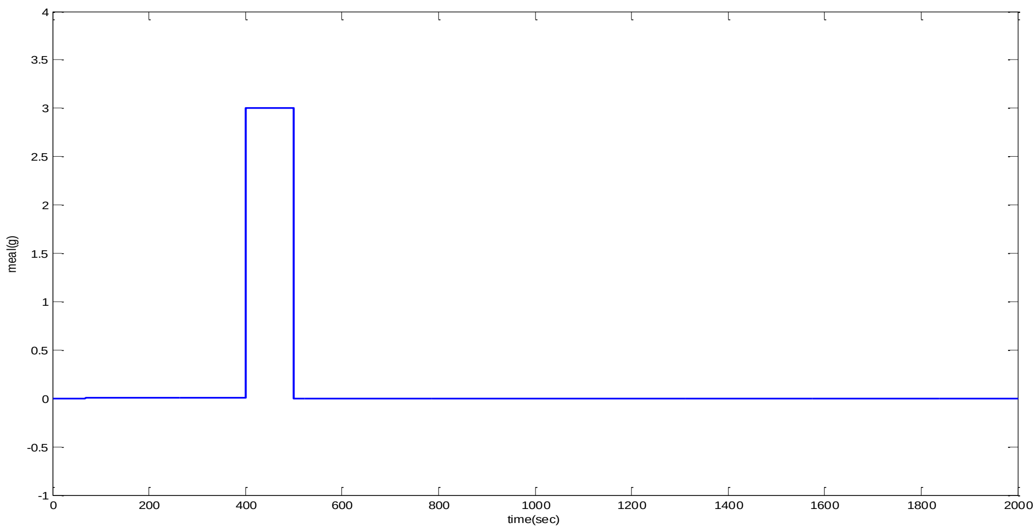

Figure 30. The input meal disturbance signal

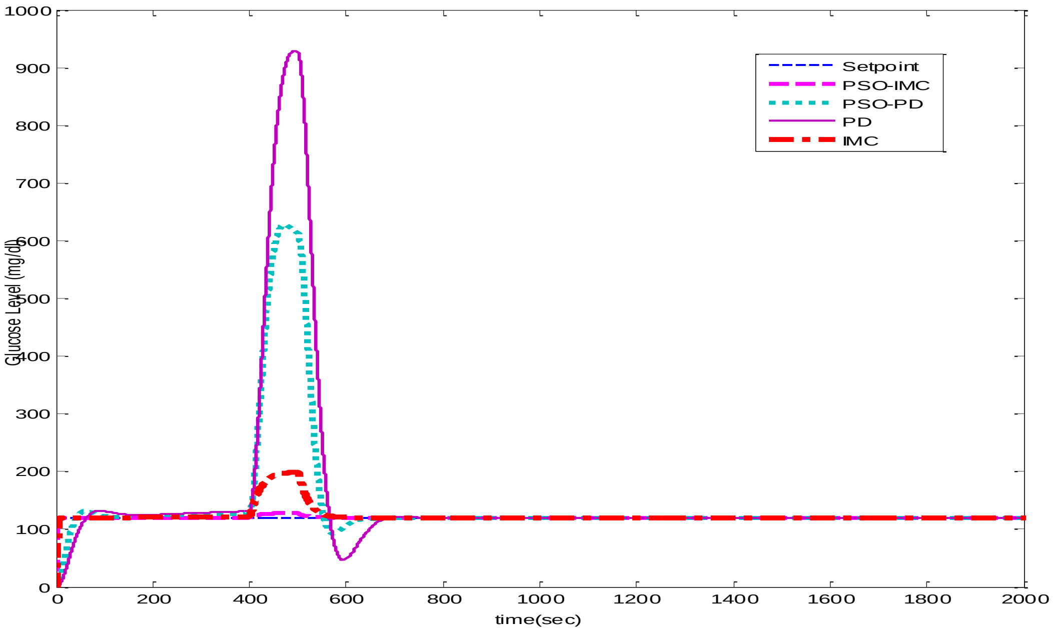

Figure 31. closed loop response of PD, IMC, PSO-PD, PSO-IMC controller in the blood glucose level control

The quantitative comparison of closed loop performance action of the controllers based on performance indices are listed in Table. 5.

Table.5 Comparison of performance measures of servo and regulatory response of controllers

Controller	IAE	ISE	ITAE
PD	1130	2867	$1.154*10^4$
IMC	972	1253	$0.998*10^4$
PSO-PD	1176	2066	$1.219*10^4$
PSO-IMC	865	921	$0.2947*10^4$

Comparison of responses on this basis of error indices values reveals that the performance action of the proposed PSO-IMC controller shows good performance. The PD controller is tuned by PSO algorithm to overcome drawbacks of conventional PD controller and its performance is examined.

The quantitative comparison of closed loop performance action of the controllers based on performance indices are listed in Table 5. From the table, the absolute error of PSO-IMC is 865 less than PSO-PD, PD, IMC controller and the integral squared error is also 921 which is lesser than other controllers. Comparison of responses on this basis of error indices values reveals that the performance action of the proposed PSO-IMC controller shows better performance.

5.5 Conclusion

The project work focus on the design of closed loop controller for diabetic typ 1 patients. The injection which contains insulin is altered to keep the glucose level of blood in normal range at each time, by acquiring the difference between blood glucose level measured and reference level . Based on the optimal value of glucose, the presented PSO- IMC control system regulates the glucose levels by injecting the insulin effectively than PD, IMC, PSO based PD control system.

Conclusions

This thesis proposed control strategies for the closed loop artificial pancreas and used three diabetic patient models for simulation that is designed to reduce the risks of hyperglycemia.

- In this work, the conventional PD and IMC controller are designed to investigate the performance characteristics of controller in the blood glucose level control. The proposed control algorithm is implemented for the Bergmann Minimal Model (BMM) as the diabetic patient model. The control algorithm is proposed to develop a closed loop artificial pancreas.
- Then, the optimization algorithm is applied to in this work to optimally tune the PD and IMC controller. The simulation results are analyzed and reported. It is inferred that the PSO based IMC controller control the glucose level in the desired setpoint by applying the optimal insulin to patient to regulate the meal disturbance faster. The settling time of IMC based PD is 218.6 sec which lesser than the IMC (271 sec) , PD (310.7 sec) and PSO based PD (297.4 sec).
- The optimally tuned IMC controller using PSO algorithm has yielded much better results than the PSO based PD, IMC and PD controller. This work focus on the development of control algorithm to control the blood glucose level of patient. The PSO based IMC controller provides closed loop control response with minimum values of IAE as 865 , ISE as 921 and ITAE as 2947 comapred to PSO based PD, IMC and PD.
- The closed loop simulations are carried out for all the control algorithm. The PSO-IMC controller provides improved performance such as faster meal disturbance rejection, faster settling time.

List of references

1. Katrin Lunze, Tarunraj Sing, Marian Walter, Mathias D.Brendel, Steffen Leonhardt. Blood glucose control Algorithm for type 1 diabetics patient: A methodological review, 3p,2012
2. Abu-Rmileh, A & Garcia-Gabin,A gain-scheduling model predictive controller for blood glucose control in type 1 diabetes‘, Biomedical Engineering, IEEE Transactions on, vol. 57, no. 10, pp. 2478-2484, 2010
3. Abu-Rmileh, A & Garcia-Gabin, ‗Hypoglycemia Prevention in Closed-Loop Artificial Pancreas for Patients with Type 1 Diabetes‘, INTECH Open Access Publisher, 2010
4. Eren-Oruklu, M, Cinar, A, Quinn, L & Smith, D , ‗Adaptive control strategy for regulation of blood glucose levels in patients with type 1 diabetes‘, Journal of Process Control, vol. 19, no,pp. 1333-1346, 2010
5. El-Khatib, FH, Russell, SJ, Nathan, DM, Sutherlin, RG & Damiano, ER , ‗A bihormonal closed-loop artificial pancreas for type 1 diabetes‘, Science translational medicine, vol. 2, pp. 27, 2010
6.Diabetes.com.au/pump-therapy/what-is-insulin-pump-therapy, Availabe from https://www.medtronic visited on 1.06.2017.
7. Riley W.J., Silverstein J.H., Rosenbloom A.L., Spillar R., McCallum M.H. Ambulatory diabetes management with pulsed subcutaneous insulin using a portable pump. Clin. Pediatrics (Phila), 609–614p.1980
8. Diabetes Self Management Insulin Pumps [(accessed on 3 November 2017)]. Available online: http://www.diabetesselfmanagement.com/diabetes-resources/tools-tech/insulin-pumps/.
9. David G., Gill M., Gunnarsson C., Shafiroff J., Edelman S. Switching from multiple daily injections to CSII pump therapy: Insulin expenditures in type 2 diabetes. Am. J. Manag. Care,490-497p,2014
10. Brooke H. McAdams and Ali A.Rizvi, An Overview of Insulin Pumps and Glucose Sensorsfor the Generalist,Available online: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4730130/,2016
11. Bequette B , ‗A critical assessment of algorithms and challenges in the development of a closed-loop artificial pancreas‘, Diabetes Technology and Therapeutics, vol.7 , no.1, pp.28–46,2005
12. Bequette BW, Analysis of algorithms for intensive care unit blood glucose control‘, Journal of diabetes science and technology, vol. 1, no. 6, p. 813-824,2007
13. Friis-Jensen, Esben. "Modeling and simulation of glucose-insulin metabolism." In Congress Lyngby. 2007.
14. Bergman, Richard N. "Minimal model: perspective from 2005." Hormone Research in Paediatrics 64, no. Suppl. 3 , p. 8-15,2005

15. Ahmed Y. Ben Sasi , Mahmud A. Elmalki " A Fuzzy Controller for Blood Glucose-Insulin System" Journal of Signal and Information Processing, 4, pp no:111-117,2013
16. Van den Berghe, G., How does blood glucose control with insulin save lives in intensive care?. Journal of Clinical Investigation, 114(9), p.1187,2004
17. Parker, R.S., Doyle, F.J. and Peppas, N.A. A model-based algorithm for blood glucose control in type I diabetic patients. IEEE Transactions on biomedical engineering, 46(2), p.148-157,1999
18. ebook777.com, Blood glucose in diabetic patient. Available from:process control modelling, design and simulation by wayne baquette ,2003
19. Ahmed Y. Ben Sasi , Mahmud A. Elmalki " A Fuzzy Controller for Blood Glucose-Insulin System" Journal of Signal and Information Processing, 2013
20. Bequtte, B. wayne. Process control: modeling, design and simulation. Prentice hall PTR,2010.
21. Gantt, JA, Rochelle, KA & Gatzke, EP , Type 1 diabetic patient insulin delivery using asymmetric PI control', Chemical Engineering Communications, vol. 194, no. 5, p. 586-602,2007
22. Kishnani, M, Pareek, S & Gupta, R, Optimal Tuning of PID controller by Cuckoo Search via Lévy flights', in Advances in Engineering and Technology Research (ICAETR), International Conference on, pp. 1-5,2014
23. Chee, F & Fernando, T , Closed-loop control of blood glucose, vol. 368, Springer Science & Business Media,2007.
24. Abu-Rmileh, Amjad, Winston Garcia-Gabin, and Darine Zambrano. "Internal model sliding mode control approach for glucose regulation in type 1 diabetes." Biomedical Signal Processing and Control 5, no. 2 : 94-102,2010.
25. GirirajKumar, S. M., Deepak Jayaraj, and Anoop R. Kishan. "PSO based tuning of a PID controller for a high performance drilling machine." International Journal of Computer Applications 1, no. 19 12-18,2010.