Fuzzy Logic with ISF Based Controller for Intravenous Insulin Delivery System

S. Harini, Dr. S. Nirmala Devi

Abstract— This paper aims at design of a fuzzy logic with Insulin Sensitivity Factor (ISF) based controller to maintain blood glucose level in type 1 diabetic patient. Special emphasis is on maintaining blood glucose level for bed side patients where insulin is injected intravenously. Two major challenges common during diabetic treatment: 1. Hypoglycemia 2. Patient dependent insulin sensitivity, are addressed. This consists of a non invasive optical sensor that measures the patient blood glucose concentration. The insulin sensitivity factor that depends on patient's internal condition is determined which helps in estimating the amount of insulin to be infused. A control algorithm based on mamdani-type fuzzy logic is used to determine the rate of infusion. Fuzzy logic controller is less sensitive to patient parameters. The controller determines the amount of insulin to be infused. The controller also maintains constant flow irrespective of changes in volume of insulin to be infused. The system has mixed implementation of hardware and software. Since the amount of insulin to be infused is predetermined, this system eliminates the need for waiting to find the patient's post injection response for insulin and then tuning the controller accordingly, thus making it more reliable. This active step towards artificial pancreas will help diabetic patients to have better glycated hemoglobin levels and lower hypoglycemia.

Index Terms— Diabetes, Fuzzification, Hypoglycemia, IVICS System, Insulin Sensitivity Factor, mamdani-type fuzzy,Total Daily Dosage.

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1 INTRODUCTION

Diabetes is a chronic occurs when our body is not able to produce enough insulin or unable to make use of available insulin. It is reported that more than 382 million people have diabetes and the count will increase up to 592 million by 2035.Diabetes caused 5.1 million deaths in 2013.More than 79,000 children developed type1 diabetes in 2013 [1]. Type 1 diabetes is caused by an autoimmune reaction, where the body's defense system attacks the insulin-producing cells in the pancreas. As a result, the body can no longer produce the insulin it needs. Complications of diabetes may cause cardio vascular diseases, blindness, kidney failure, diabetic neuropathy and lower limb amputation [2]. Tight glycemic monitoring and control is the main goal in successful diabetes management to avoid its complications. In a typical diabetic treatment, patient measures blood glucose level 3 or 4 times in a day and attempts to maintain it in a normal range by injecting appropriate rate of insulin. In [2] the author also discussed about different insulin delivery techniques available and the problems with insulin therapy.

Intravenous infusion therapy is preferred under indications listed below

1. Diabetic Ketoacidosis,
2. Before, during and after surgery
3. Uncontrolled Diabetes
4. Blood glucose levels that are difficult to control
5. After heart attack or open heart surgery
6. Patient with severe infection
7. Insulin resistance / Glucose toxicity
8. Fluid restricted patients
9. Pregnancy(during delivery)
10. IV nutrition or tube feedings

Regular insulin is the common type of insulin that can be given intravenously. Design of an automatic controller for insulin delivery through IV is attempted here.

Over the past two decades widespread researches have been taken to develop a non invasive sensor to measure the patient blood glucose. In [3] authors discuss about the design of a novel NIR optical bio-implant for accurate measurement of blood glucose level. A logical system which is more close to spirit of human thinking and natural language has been developed to deal with the complex human system rather than traditional controllers like PID, MPC etc. Caner TAN *et al.*[4] and D.U. Campos-Delgado in [5] describes the design of fuzzy based optimal controller that controls the patient blood glucose level via an infusion device. In [6] mathematical model is developed for insulin glucose dynamics and a fuzzy logic controller is used which is optimized using genetic algorithm. The performance of fuzzy logic controller is compared with the performance of PID controllers in [7]. Mohammed Al- Fandi in [8] intro-

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duces an automated insulin delivery system based on a parallel PID- FLC structure tuned with genetic algorithm and found the results to be more promising. Also PID-FLC saved the amount of daily delivered insulin. R.Harikumar in [9] measures blood glucose using a non invasive technique based on Photo Plethysmography of pulse oximeter and designed automated controller using fuzzy (PD and PID) controller. In this process, patient's insulin sensitivity factor is determined beforehand designing the controller and the amount of insulin to be infused to bring patient blood glucose to normal is determined. Mamdani- type fuzzy controller is designed to automate the insulin infusion process. Thus a controller which is insensitive to patient parameters and reduces the possibility of hypoglycemia is developed. An IVICS system is used to control the intravenous infusion flow. The IVICS system is a closed loop control system which measures the number of drops falling through the drip feed unit and correct the flow by actuating a stepper motor which compresses or decompresses the drip feed hose. Use of fuzzy logic along with this IVICS system helps in more precise control of insulin delivery which in turn precisely controls the glucose level of type 1 diabetic patients.

2 System Flow

The overall system flow diagram is shown in Fig 1. The steps involved in the system design is as follows

1. Measuring the glucose value using non invasive sensor
2. Determining the insulin sensitivity factor
3. Applying fuzzy logic to determine the flow rate of insulin infusion
4. Design of IVICS system to regulate the flow
    a. Flow measurement
    b. Algorithm to control the flow

All the above mentioned steps are linked with the controller which ultimately controls the insulin delivery.

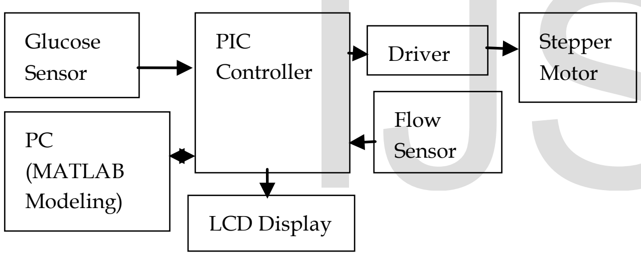

Fig 1. Overall System Flow Diagram

2.1 Non Invasive Glucose Sensor

A major setback in diabetes treatment is invasive measurement of glucose done many times in a day where patients are subjected to pain and it troubles continuous measurement. To develop an effective treatment strategy, a non invasive method to measure blood glucose is designed. An optical technique which uses red and infra- red radiation is used. It is promising to use these two wavelengths because the wavelength range between 600 nm and 1000 nm are least absorbed by other body tissues (tissue and pigmentation absorb blue green and yellow light and water absorbs longer infra-red wavelength). The block diagram of optical glucose sensor is as shown in Fig 2.

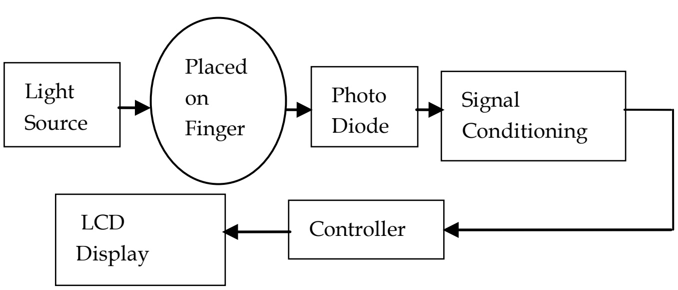

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Fig 2. Block Diagram of Non Invasive Glucometer

The light from the source is made to incident on the finger. A portion of light is absorbed and a portion is reflected and transmitted. The transmitted radiation is detected using the photodiode. The detected signal is amplified and is matched with the glucose values based on the result obtained from the invasive glucometer. However this invasive glucometer has to be calibrated for individual patient with an initial reading from invasive glucometer. The result is displayed using LCD display. The result obtained from non invasive sensor is as shown in table 1.

Table 1. Output Levels of Non Invasive Glucometer

S.No	**Name**	**Amplifier output(v)**	**Glucose level(mg/dl)**
1	Subject 1	2.88	90
2	Subject 2	2.52	89
3	Subject 3	2.23	92
4	Subject 4	2.2	94
5	Subject 5	2.52	89
6	Subject 6	3.3	86

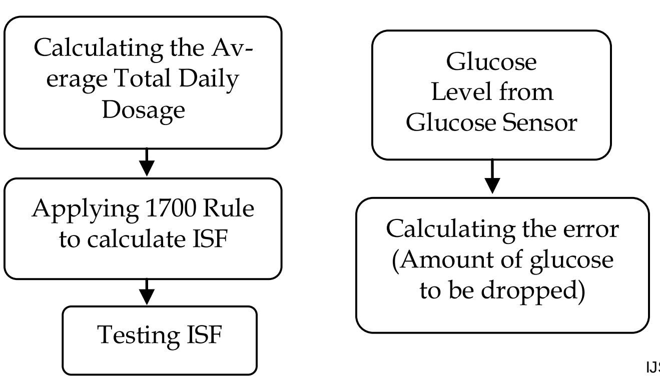
2.2 Insulin Sensitivity Factor

For more precise regulation of glucose level, patient's insulin sensitivity factor (ISF) is determined. The ISF refers to the correction factor, which is the mg/dL drop in glucose caused by one unit of insulin. In conventional methods insulin will be infused at some fixed rate and the response will be determined after one hour of infusion by measuring the glucose concentration. The glucose level is expected to reduce by 10% of its initial reading. Two cases that may arise and the action to be performed are listed in table 2.

Table 2. Conventional Control Strategy

Case	**Condition**	**Action to be performed**
1	Reduction < 10%	Rate of infusion will be doubled
2	Reduction ≥10%	Same rate will be stabilized

Either of the two actions will be performed as per the condition. This procedure will be repeated every one hour of infusion till the glucose level returns to the targeted value. Also the amount of insulin to be infused remains unknown. To avoid these uncertainties insulin sensitivity factor is determined. The steps involved in determining the sensitivity factor are shown in Fig 3



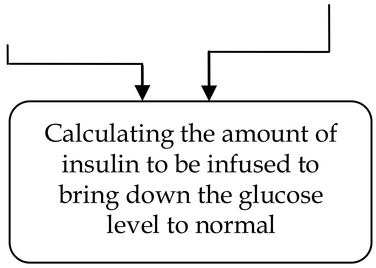


Fig 3. Calculation of ISF

The Total Daily Dosage is the amount of insulin taken by the patient per day. The total daily dosage includes both basal insulin and bolus insulin. An average of 3 days dosage is considered. This factor varies from patient to patient based on their body's response to insulin. Applying the 1700 rule insulin sensitivity factor is found. The error value, excess glucose level above the target is calculated. Using the sensitivity factor and the error value, the amount of insulin to be infused to bring the glucose level to normal is found and the results are shown in table 3.

Table 3. Calculation of ISF for varying TDDs

S.No	Total Daily Dosage (units)	Insulin Sensitivity Factor	Blood Glucose Level (mg/dL)	Amount of Insulin to be infused (units)
1	60	28.33	350	7
2	45	37.78	310	4.25
3	60	28.33	390	8.333
4	50	34	280	3.89
5	40	42.5	410	6.353

2.3 Fuzzy Logic Controller

Fuzzy control systems allow extremely precise control of insulin injection. The three main parts in fuzzy design are fuzzification, fuzzy rule base and defuzzification. The difference between the measured blood glucose level and the target level (error) and derivative of error are used as two inputs to the fuzzy system. The target value is assumed to be 140 mg/dL which is little above the normal value to avoid hyperglycemic conditions. The rate of infusion of insulin is the output of the fuzzy system. The linguistic variables chosen for membership functions are listed in table 4.

Table 4. Linguistic Variables

Type	Linguistic Variable	Meaning
Input 1	nE	Error Negative
	zE	Error Zero
	pE	Error Positive
Input 2	nR	Rate Negative
	zR	Rate Zero
	pR	Rate positive
Output	nO	Output Negative
	zO	Output Zero
	pO	Output Positive

Mamdani-type fuzzy inference system is used. The membership functions chosen for both the inputs and the output are as shown in Fig 4.a, 4.b and 4.c. The rules of simulated fuzzy system are as shown in Fig 5.a and 5.b. the surface view of the system is shown in Fig 6. Centroid procedure is used for defuzzification.

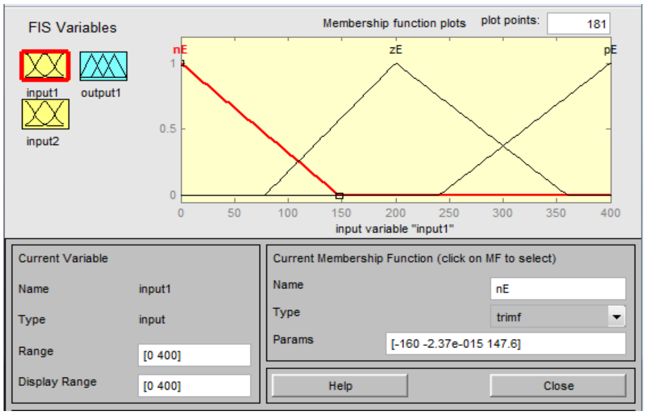


Fig 4.a. Membership Functions for
Error (Input 1)

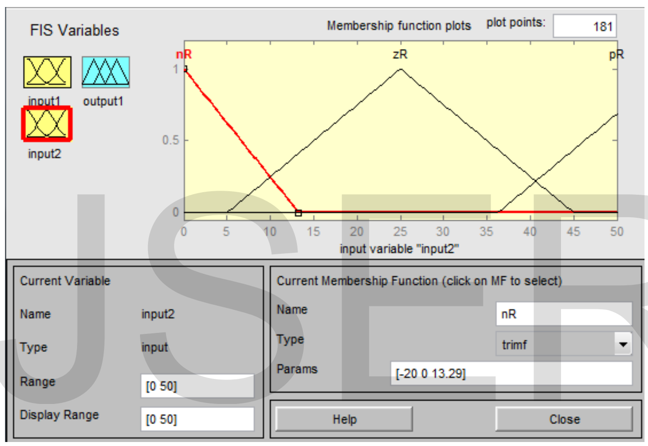


Fig 4.b. Membership Functions for Rate of
Change of error (Input 2)

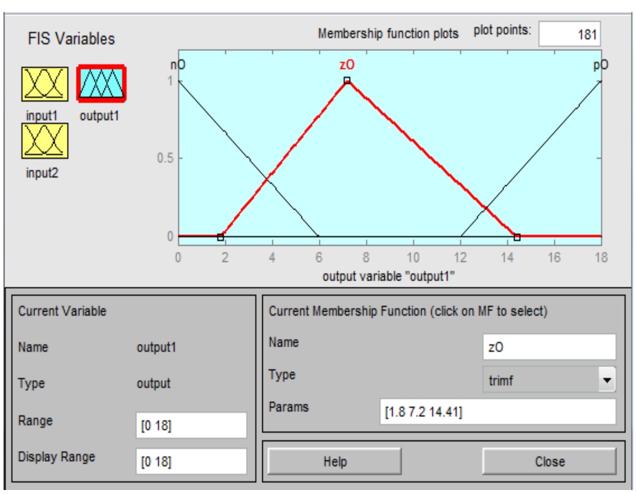


Fig 4.c. Membership Functions for Rate
of Insulin Infusion

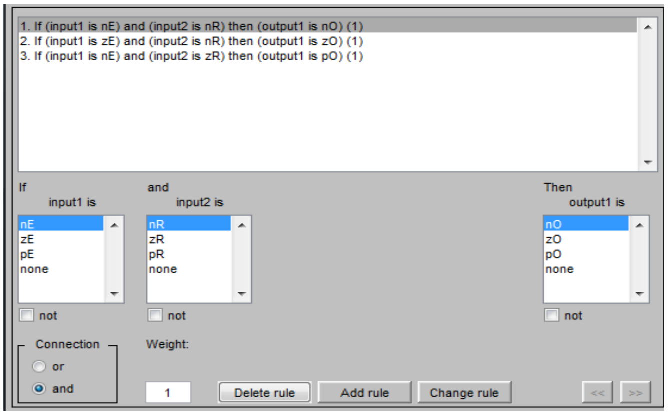


Fig 5.a. Rule Editor

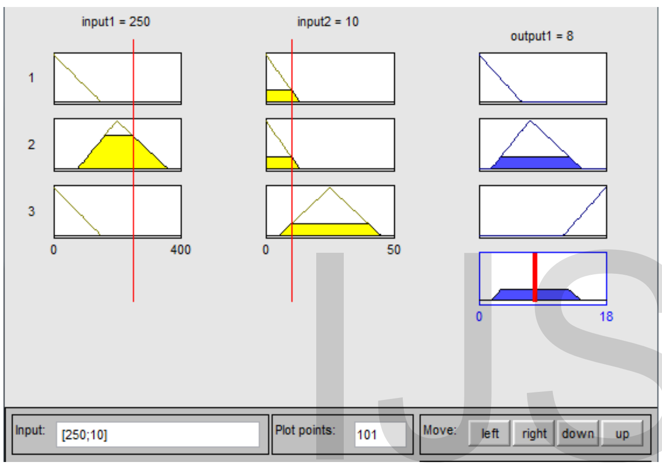


Fig 5.b. Rule Viewer

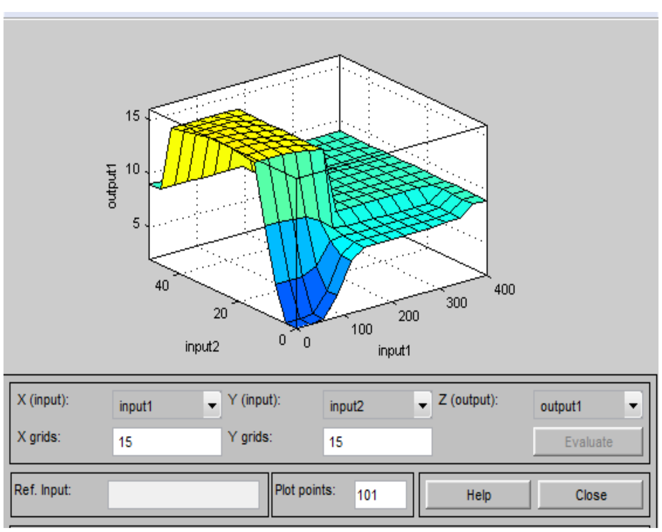


Fig 6. Surface Viewer

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The output obtained from the system is as shown in the table 5. Also the output obtained from the conventional system without fuzzy is listed in the table. It is found that fuzzy controller yields more accurate results than the conventional system.

Table 5. Results obtained with and without fuzzy

S.No	Blood Glucose Level (mg/dL)	Output using fuzzy-Rate of Infusion (mg/dL/hr)	Output without fuzzy-Rate of Infusion (mg/dL/hr)
1	300	7.9994	6
2	450	8.852	12
3	350	8.167	10
4	200	0.8078	2

IVICS System

The Intra Venous Infusion Controller System (IVICS) is a single patient control system which controls the intravenous infusion flow (in drops/min) and the infused volume (ml). The system aims to keep the flow at the required rate as determined by the fuzzy system with a maximum error of ± 1 drop per minute.

This closed loop control system measures the time interval between successive drops falling through the drip-feed unit and correct the flow by actuating a stepper motor, which compress or decompress the drip feed hose. The block diagram of IVICS system is as shown in Fig 7

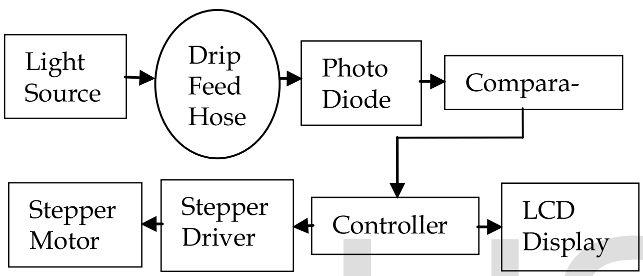

Fig 7. IVICS System Block Diagram

An optical sensor is used to detect the drops. The sensor consists of an infra red LED and a photodiode which sends 1 (drop) or 0 (no drop) to the controller. The controller counts the drop for 10 sec, calculates the error and the direction in which stepper motor has to be rotated is determined as shown in table 6 and the corresponding pulses are given to the stepper motor.

Table 6. IVICS System

S.No	Error Value	Position of the Stepper Motor
1	Drop Value = Set Value±1	No Action
2	Drop Value > Set Value-1	Forward Action
3	Drop Value < Set Value+1	Reverse Action

The IVICS system has fault tolerance capability for the case when the patient makes abrupt movements causing a pseudo changing of the flow rate. The system waits for three subsequent drops and returns to the normal operation mode. This system also gives indications of conditions like End of Infusion.

Conclusion

In this work, a precise controller for blood glucose control was designed. This controller was implemented using fuzzy logic which clears the uncertainties that may arise otherwise. The simulation results show that fuzzy controller is a better option for handling non linear systems. The system is tested for patients with different Insulin Sensitivity Factor and Total Daily Dosage. The output of the fuzzy system is compared with that of without fuzzy. The result is found to be more precise using fuzzy controller. In this work patient glucose level is monitored at an interval of one hour and the controllers adapts to the new condition. Optimization of the fuzzy controller using genetic algorithm and validation of the result with physician are the works yet to be done. Future work can be including other parameters like type of insulin to be used for injection, controlling the combined use

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of different types of insulin at different stages of treatment.

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