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MODELING AND SIMULATION OF FUZZY BASED AUTOMATIC INSULIN DELIVERY SYSTEM

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ABSTRACT

The aim is to design a complete online, automatic, intelligent and independent insulin delivery system. The proposed system calculates the amount of insulin by formulation based upon two linguistic factors i.e. weight and blood glucose levels. These factors have been used to develop a rule based fuzzy system in LabVIEW. The fuzziness brings a better regulation into the regime than a non fuzzy system as small changes in quantities of insulin can bring about effective command on the glucose levels. A user friendly interactive webpage has been designed that inculcates the fuzzy system for providing online doctor consultation. The insulin delivery has been simulated in LabVIEW where the quantity of insulin delivered to the patient can be controlled automatically or by the doctor. The system has been verified by taking a random sample of hundred insulin dependent individuals to test the effectiveness of the system. The developed fuzzy system was found to be more accurate than a non fuzzy system. This study is modeled for soluble human insulin type. The implementation of this system in real time with insulin pump will enable those in inaccessible areas and intensive care units to control the glucose levels automatically in an efficient manner.

Keywords: Insulin, Fuzzy, Insulin Delivery, Simulation

1. INTRODUCTION

India has become the diabetic capital of the world with 4 crores Indians suffering from diabetes as of 2006 and the number is expected to rise to 7 crores by the year 2025 (Wild *et al*., 2004). Diabetes may result in significant morbidity, leading to conditions such as blindness, cardiovascular disease, kidney disease and premature death. Most of the diabetic patients are insulin dependent and effective monitoring is necessary for keeping the glucose levels under control (Dudde and Vering, 2003). Insulin is a "High Alert" Medication, due to complex individualized dosing and administration regimens; insulin is not a "one-size-fits-all" medication. Medication errors associated with insulin use have the potential to cause patient harm and are responsible for 80% of inpatient errors caused by glucose-lowering agents and 10% of all harmful drug errors. These human based insulin delivery systems can be replaced by an automatic insulin delivery systems, which are time efficient, convenient with no human errors and thus results in easier and better control of insulin for patients. Bed ridden patients require human assistance and these systems would eliminate the need for it if implemented in real time (Albisser *et al*., 1986). Diabetes is a lifelong disease and it is best to maintain proper control to suppress its negative impact on the quality of life.

1.1. Problems with Insulin Therapy

The type and amount of insulin to be given is decided by wide range of factors including type of diabetes, age, gender, body mass index and other diseases the patient may suffer from. The insulin therapy needs to be supplemented by lifestyle and diet changes so as to lead an active and healthy life. Insulin

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dosing is individualized and complex (Mirouze, 1983; Jayaraj *et al*., 2009). Administration of too much or not enough insulin causes dire consequences. The Institute for Safe Medication Practices (ISMP) placed insulin, subcutaneous and Intravenous (IV), on a list of “High-alert Medications” due to its potential to cause serious patient harm if given in error. Too much insulin intake may lead to hypoglycemia and then loss of consciousness and seizures. International diabetes care centre has recognised the numerous reports of serious errors associated with the misadministration of insulin. These errors involve human error and errors occurring in the prescribing of insulin amount. It should not be assumed that all healthcare practitioners are knowledgeable and skilled with measuring doses and recognizing doses that exceed safe limits. So these medication errors involving insulin are responsible for disproportionate number of serious adverse events.

1.2. Importance of Fuzzy System

The above complexities have contributed to a plethora of insulin errors at every step of the prescribing, dispensing and administration. A single solution for all the above insulin therapy problems can be given by a fuzzy based automatic insulin delivery system (Fabietti and Canonico, 2006; Yang *et al*., 2007; Goh *et al*., 2008; Xu *et al*., 2006; Zelin *et al*., 1975) Accurate amounts of insulin dosage can be calculated or prescribed from the fuzzy system. The fuzzy system is more accurate than the normal controller because instead of being either true or false, a partial true case can also be declared. Thus exact number of units of insulin can be delivered to the patient thus aiding efficient control of glucose level.

2. MATERIALS AND METHODS

2.1. Patients

The patients have been randomly selected from populations of southern states of Tamil Nadu and Andhra Pradesh. The analysis was performed by collecting data from hundred patients of varying ages and gender suffering from diabetes. The patients were informed about the specific use of the data collected from them. All patients provided their consent for usage and publication of the data obtained from them.

2.2. Instrumentation

The software used for the development and analysis is LabVIEW. The insulin quantity is calculated by a fuzzy system designed in fuzzy system designer in LabVIEW (Wild *et al*., 2004; Zelin *et al*., 1975). The linguistic variables are weight and blood glucose levels. The insulin quantity is the output of the system. The input and output variables are divided into membership functions according to their ranges.

2.3. Membership Functions

The variables are divided based on the range of values they can take. The blood glucose level is divided into six triangular membership functions ranging from 100 to 400. The weight is divided into twelve membership functions ranging from 0 to 120. The insulin level is divided into 53 membership functions ranging from 0 to 400. The membership functions of insulin are shown in **Fig. 1**.

2.4. Rules

The rules are formed using if then statements where a certain combination of each of the inputs’ membership functions give a particular insulin quantity. The number of rules depends upon the number of input variables and the total of membership functions for each input variable. All different possible combinations need to be added to the rules so as to obtain the exact insulin quantity for the mid values. The total number of rules built for insulin calculator is 66. Few examples of rules are: IF weight is ‘i’ and blood glucose is ‘F’ THEN Insulin is ‘i42’ IF weight is ‘a’ and blood glucose is ‘A’ THEN Insulin is ‘i1’, IF weight is ‘b’ and blood glucose is A’ THEN Insulin is ‘i3’. TTTT.

2.5. 3D Graph

The relationship between the input and output variables can be studied with help of 3D graphs between two input variables and the risk as shown in the **Fig. 2**. The defuzzification method used is centre of area. The input variables can be progressively varied to study the effect of each of the input variables on the risk.

2.6. User Interactive System

The interactive system physically consists of two computers connected to each other by internet protocol. The program developed is running on both ends of the system. One end is the patient or individual and the other end is the doctor. The program includes a display where the individual can enter the details using which the fuzzified insulin quantity to be delivered is calculated. The implementation of such a system is time efficient and thus makes control of diabetes hassle free to a large extent.

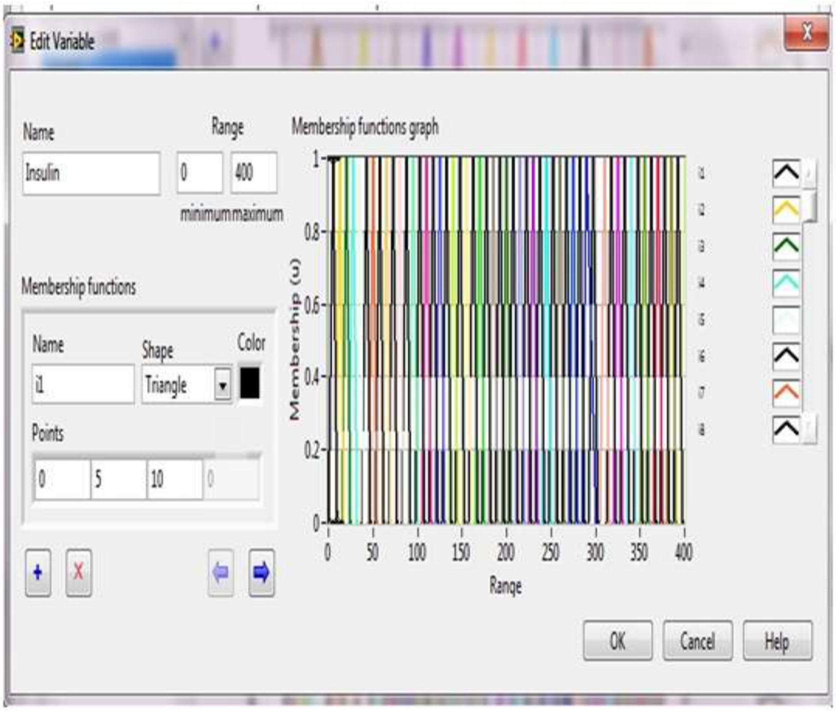

Fig. 1. Membership function of insulin therapy system

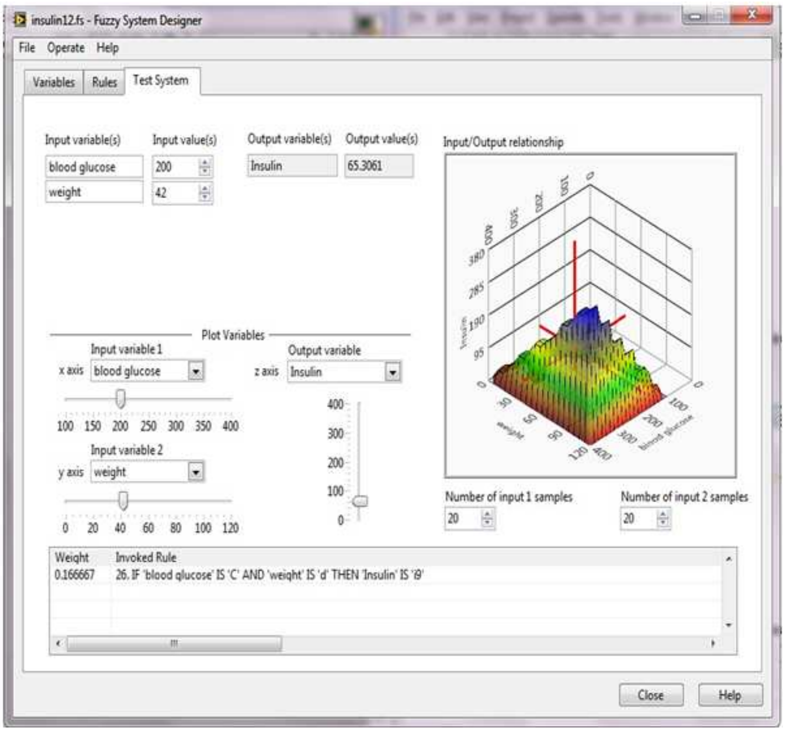

Fig. 2. 3D graph between input and output variables

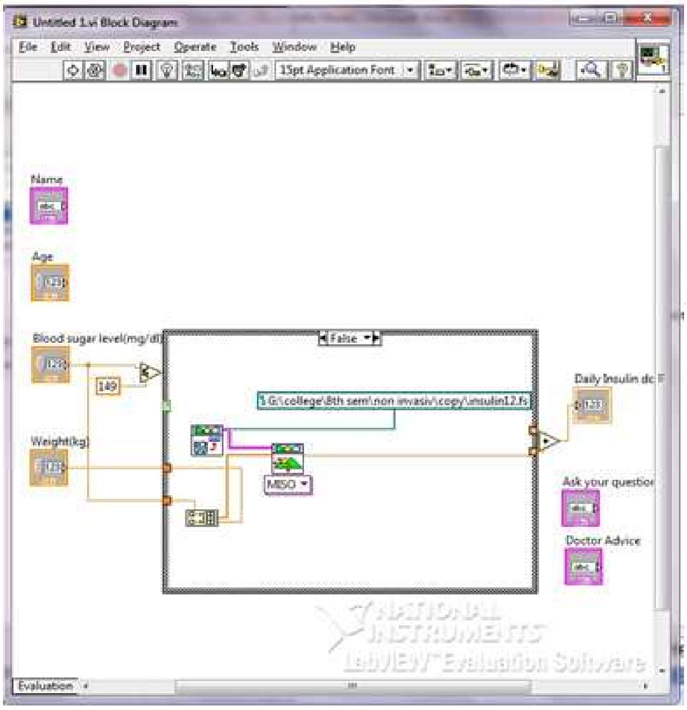

Fig. 3. Block diagram of developed system

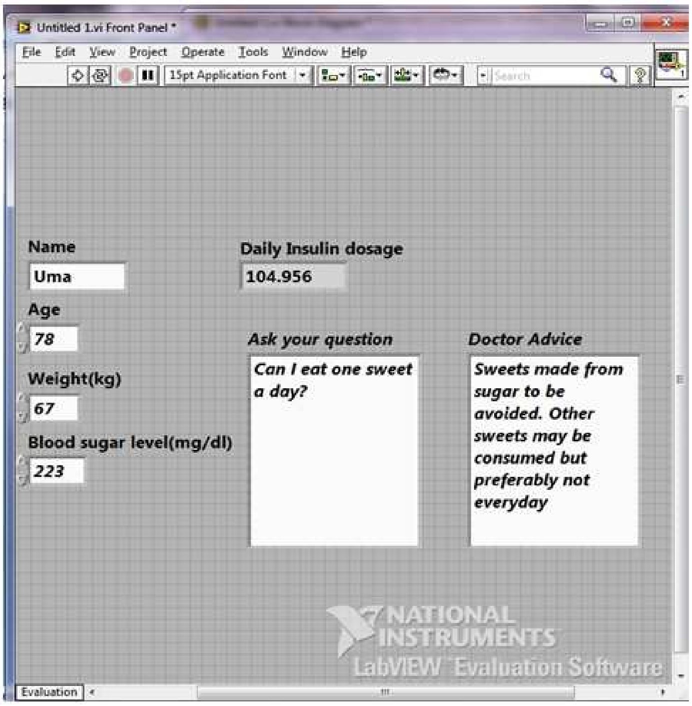

Fig. 4. Front panel of the developed system

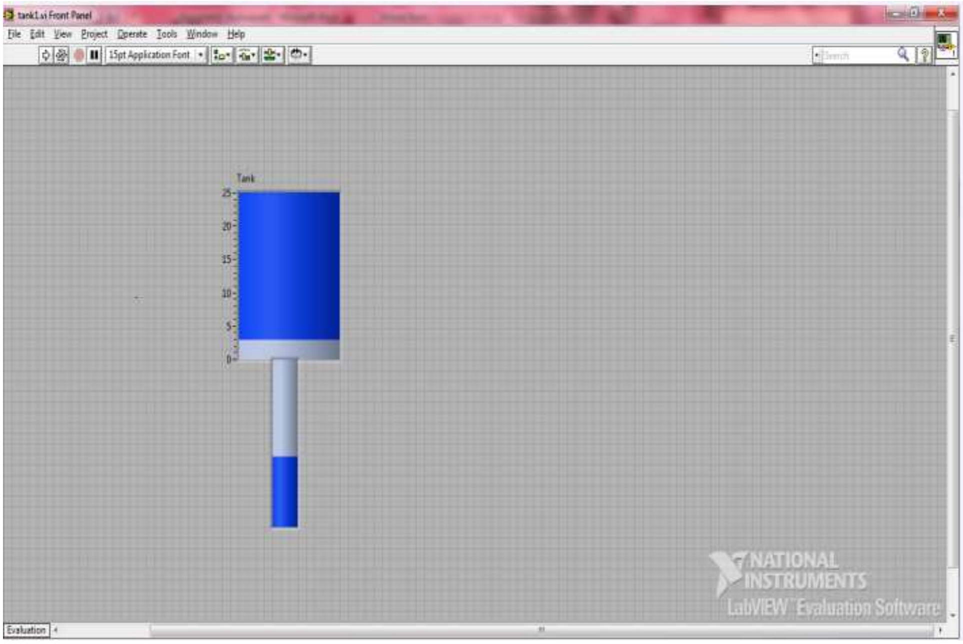

Fig. 5. Front panel of the pump

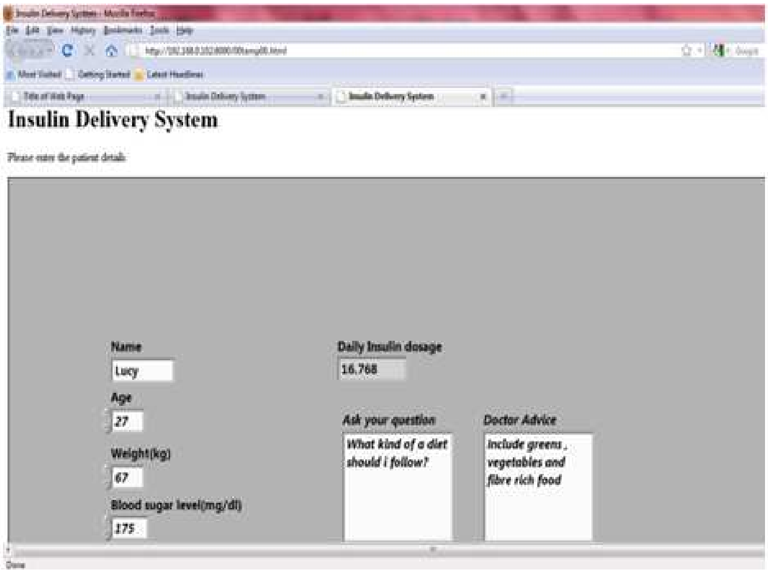

Fig. 6. On line web page for insulin therapy

2.7. Program

The program has been coded in LabVIEW and hence the user interface and logic behind the program are developed simultaneously. The program is coded to inherit the already designed fuzzy system. The doctor can suggest on the amount of insulin calculated by the system. The doctor can control the amount of insulin injected to the patient by automatic insulin pump. The patient at the user end will have to enter details like name, age, weight and blood glucose which upon execution displays the insulin quantity to be taken. After analyzing the results, the patient can choose to automatically inject oneself with insulin or ask for further clarifications from the doctor. The doctor can access the program from his end and step in when ever required to give is suggestions. The block diagram and front panel are shown in **Fig. 3 and 4**.

2.8. Simulation of Insulin Pump

The quantity of insulin from fuzzy analyzer is given as an input to the insulin pump (Albisser *et al*., 1986; Mirouze, 1983; Jayaraj *et al*., 2009; Fabietti and Canonico, 2006; Goh *et al*., 2008; Xu *et al*., 2006). The required quantity flows from the pump into the injector. The number of units can also be set by the doctor in case it is required. The system is simulated in front panel of LabVIEW in form of two interconnected tanks where the top one is the insulin pump and the bottom is the insulin injector. The front panel of pump is shown in **Fig. 5**.

2.9. Online Webpage

The real time implementation of the system would require computers with internet access at specific locations and insulin pump with required circuitry. The LabVIEW program can be converted to exe and run on any computer without the software installation procedure. The use of a webpage for data transmission inherently brings its own characteristics of less time consumption, faster access and lesser incidence of errors. The webpage display is shown in **Fig. 6**.

3. RESULTS

The data was obtained from a random population of individuals. The individuals mainly belonged to southern regions of India. The distribution of the individual records according to the factors is shown in **Table 1**.

The insulin obtained from normal system was compared with the fuzzy system and it was found to be giving more exact results. The number of units of insulin the patient was taking was found to be comparable to the results obtained from the fuzzy system. A random database illustrating the comparison is shown in **Table 2**.

The small change in number of units to be injected to the patient will cause long term effects in controlling the amount of glucose levels effectively. The various patient record samples collected were used to obtain insulin levels. One sample of 3D graph is shown in **Fig. 6**. The insulin obtained directly from the equation and fuzzified insulin levels are compared with each other. The fuzzified insulin levels were found to be more accurate. The results were also compared with the real time insulin data obtained from the patient. It was found to be compatible.

Table 1. Distribution of records

Factor	Category	Percentage	Total
Insulin units	30-Oct	24	100
	31-60	32	
	61-90	17	
	91-120	18	
	121-150	2	
	151-180	3	
	181-210	4	
Blood glucose	100-130	8	100
	131-160	9	
	161-190	5	
	191-210	10	
	211-240	14	
	241-270	22	
	271-300	16	
	301-330	3	
	331-360	4	
	361-390	9	
Weight	0-20	4	100
	21-40	38	
	41-60	33	
	61-80	23	
	81-100	2	

Table 2. Comparison between prescribed and calculated insulin dosage

Patient	Daily insulin dosage prescribed	Fuzzy system daily dosage
1	20	16.7
2	40	35.5
3	40	42.9
4	50	47.4
5	60	63.4

Thus by employing this system an online based insulin injector control is possible. It also enables the physician to be present at multiple locations virtually. This eases the problems caused by patients in rural and inaccessible areas.

4. DISCUSSION

The validity of the equation is verified by comparison with the actual amount of insulin that is being taken by the patient. The results of the system are transmitted online through a webpage and also insulin injection is controlled by the physician.

5. CONCLUSION

The fuzzy system was found to provide more accurate results as compared to normal system.

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