Asian Journal of Information Technology 13 (3): 131-137, 2014
ISSN: 1682-3915

Automatic Diabetic Control System Based on Multi-Variant Fuzzy Rule Sets

[1]R. Arangasamy, [2]J. Sundararajan, [3]Ila Vennila and [4]G. Shankar
[1]Department of ECE, Paavai Engineering College, Namakkal, India
[2]Paavai College of Technology, Namakkal, India
[3]Department of EEE, PSG College of Technology, Coimbatore, India
[4]Department of Physics, Government College of Engineering, Salem, India

Abstract: Unstable nature in blood sugar of diabetic patients influences more innovative techniques to come for regular usage. Researcher proposes a new approach to control the glucose level of diabetic patients using various biological metrics of the patients. The proposed system is a fuzzy one which uses various rule sets to control the glucose level. Researcher uses the following biological metrics like body temperature, pressure, glucose, red blood cell count, white blood cell count and plasma cells. All the biological features are monitored periodically based on which the proposed system comes to a decision of injecting insulin and rate of medicine. Researcher used various control circuits and regulators and monitors to track the biological features dynamically. The proposed systems have more impact on society for the better control of diabetics.

Key words: Thermal control, diabetics, multi-varient fuzzy systems, fuzzy rule sets, proposed system

INTRODUCTION

About 68.27 million people in this world suffer from diabetes which has many complications such as heart disease and stroke, high blood pressure, kidney disease, eye disease, nervous system disease and amputations. The hormone insulin has many functions in the body; most importantly it influences the entry of glucose into cells. The lack of insulin prevents glucose from entering the cells and being utilized and leads to excess blood sugar and excretion of large volumes of urine, dehydration and thirst. The current treatment method for insulin-dependent diabetes includes sub-cutaneous insulin injection or continuous infusion of insulin via an insulin pump. The former treatment requires patients to inject insulin four to five times a day. The amount of injection is usually determined by a glucose measurement, an approximation of the glucose content of the upcoming meal and estimated insulin release kinetics. The continuous insulin infusion pump allows for more predictable delivery due to its constant infusion rate into a subcutaneous delivery site. Keeping the blood glucose levels as close to normal as possible is essential for preventing diabetes related complications. Ideally this level is between 90 and 130 mg dL^{-1} before meal and <180 2 h after starting a meal. The ideal treatment for controlling blood glucose levels in insulin dependent diabetic patients would be the use of an artificial pancreas which would have the following components:

- A glucose sensor to monitor the blood glucose continuously with sufficient reliability and precision
- An insulin infusion pumps to supply the required amount of insulin into the blood

Safe delivery of insulin in this way requires glucose sensors. Two types of sensors have been developed during the last 30 years, minimal invasive and non-invasive (Koschinsky and Heinemann, 2001). The non-invasive approaches are carried out using optical glucose sensors. These sensors work by directing a light beam through intact skin and measuring the properties of the reflected light that are altered either as a result of direct interaction with glucose or due to the indirect effects of glucose by inducing changes in the physical properties of skin. These optical sensors are not able to measure glucose with sufficient precision. On the other hand, minimally invasive sensors measure the glucose concentration in the interstitial fluid of the skin or in the sub-cutis. There is a free and rapid exchange of glucose molecules and interstitial fluid. Therefore, changes in blood glucose are correlated. However, there is a time delay between these changes varying from a few seconds to 1 h which complicates the interpretation of measurement results (Roe and Smoller, 1998). The magnitude of this delay depends on factors such as the absolute glucose concentrations and direction of change. The Type-1 Diabetes Mellitus (T1DM) is a metabolic disease caused by the auto-immune destruction of

Corresponding Author: R. Arangasamy, Department of ECE, Paavai Engineering College, Namakkal, India

pancreatic beta cells, resulting in an insignificant release of insulin into the blood stream. The developed treatments around T1DM have been addressed to satisfy the insulin requirements, mainly through the re-establishment of insulin delivery function as pancreatic islet transportation (Morath and Zeier, 2009; Shapiro *et al*., 2000) or by the substitution of the secretary function by means of an external mechanism, like insulin infusion (Lenhard and Reeves, 2001). In both options, the aim is to ensure insulin to metabolize blood glucose (Molitch and Korenman, 2000).

Since, insulin was synthesized, daily insulin injections have become the most accessible and popular treatment of T1DM; nevertheless, the successful substitution of the pancreatic insulin release has required extensive work regarding the solution of its essential problem: supplying the required insulin amount to compensate blood glucose variations. Many advances have been addressed to develop suitable technology for insulin infusion and glucose measurement (Lenhard and Reeves, 2001; Mastrototaro, 2000; Bequette, 2005).

Background: There are various micro control system has been designed in the past to support various analysis of biological system.

Fuzzy Logic Based Water Bath Temperature Control System (Verma and Gupta, 2012), proposed a design to control the water bath which is most widely used in the process industry. Water bath conventional controllers are derived from control theory techniques to be controlled. The purpose of the feedback controller is to guarantee a desired response of the output y. The study devoted to control design method using Fuzzy Logic Controller (FLC) based non-linear control for water bath temperature to obtain the desired output water temperature of water bath and to implement them in a FLC for a temperature controller system.

Tuan *et al*. (2001) proposes Fuzzy Control System which uses parameterized inequality techniques to control the systems where as an predictive control for fuzzy system is proposed by Huang *et al*. (2000) to control the fuzzy systems based on nonlinear process. In this approach a fuzzy convolve model with different fuzzy implications are used. Fuzzy system based scrap conveyor has been proposed by Li *et al*. (2011) to get automatic control over tail frame of the conveyor. In this they have applied fuzzy logic on the hydraulic system to control the hydraulic cylinder which controls the electromagnetic valves.

In Fuzzy Logic Based Paper Feeding Control System using Self-Adaptive PID for Fruit-Bag Machine (Zhang *et al*., 2008), researchers presents a control system of feeding paper in fruit-bag machine based on fuzzy parameter self-adaptive PID. First, it put forward the mathematical model of control system according to the design characters. Then, it analyzed the structure and rules of controller and estimated the fuzzy parameters of PID by evaluating fuzzy relations equation. The theoretical analysis and system experimental test show that fruit-bag machine can automatically adjust deviator location according to roll size while feeding paper (Lee, 1990). It could solve the problem of paper wrinkling caused by drifting or deviation, incorrect congruence of internal and external bag. It apparently strengthens the stability of the whole producing process and improved the quality of fruit-bag.

Researchers discussed various methodologies described for various purposes, all are working with single valued fuzzy logics (Sandhu *et al*., 1996) and the researchers have the problem of controlling sugar level of human biological system using multi variant features and multiple rule sets (Zadeh, 1965; Mamdani and Assilian, 1975).

MATERIALS AND METHODS

Embedded model system: Embedded model system is shown in Fig. 1. Glucose level sensor, pressure sensor, temperature sensor are the sensors used in this system. The sensors will be of analog format and so, the researcher will use analog to digital converter to convert analog to digital values. Whenever the patient enters the lab he/she need to be monitored and provided with exact solution with the help of database. Whenever the patient's glucose level goes beyond the normal level, automatically insulin will be injected with the help of controller section. If the person enters the hospital, the lab test has to be conducted for him/her. Researcher will conduct only one test based on glucose level. This could be called lab as report. Next, check the glucose, temperature, pressure of the person will be checked and a database will be maintained with all the details based on time, from the details, researcher will compare the test result with the original values. In this there are three

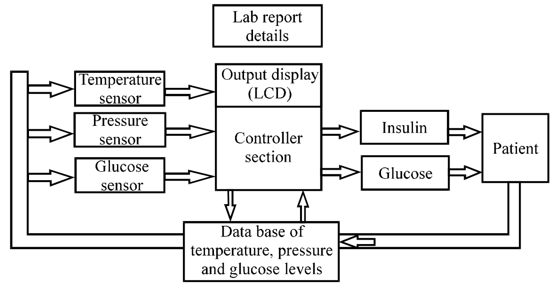

Fig. 1: Embedded model system

Table 1: Blood glucose levels

BGL 70-89 mg dL^{-1}	BGL 90-119 mg dL^{-1}	BGL 120-179 mg dL^{-1}	BGL≥180 mg dL^{-1}	Altering in infusion rate
-	-	BGL↑ by >40 mg/dL/h	BGL↑	↑Infusion by "2Δ"
-	BGL↑ by >20 mg/dL/h	BGL↑ by 1-40 mg/dL/h	BGL↓ by 1-40 mg/dL/h	↑Infusion by "Δ"
BGL↑	BGL↑ by 1-20 mg/dL/h	BGL↓ by 1-40 mg/dL/h	BGL↓ by 41-80 mg/dL/h	No infusion change
BGL↓ by 1-20 mg/dL/h	BGL↓ by 21-40 mg/dL/h	BGL↓ by 41-80 mg/dL/h	BGL↓ by 81-120 mg/dL/h	↓Infusion by "Δ"
BGL↓ by >20 mg/dL/h	BGL↓ by >40 mg/dL/h	BGL↓ by >80 mg/dL/h	BGL↓ by >120 mg/dL/h	↓Infusion by "2Δ"

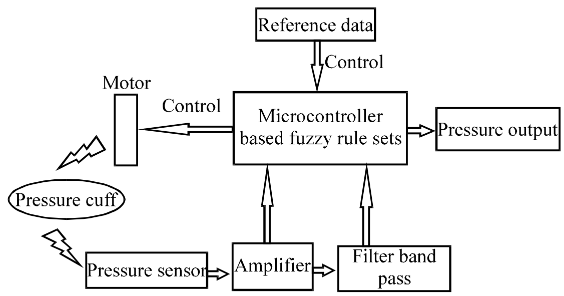

Fig. 2: Pressure monitor

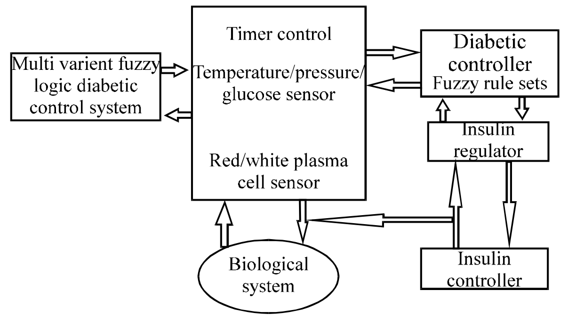

Fig. 3: Block diagram of Fuzzy Logic Diabetic Control system

conditions to be compared and monitored. The first one is normal level of glucose. From this comparison, researchers will come to know how much of insulin we need to inject to the person and this will be sent as a feedback to the controller again for maintaining the glucose level in the blood, the data's shown in Table 1. The process will be repeated for a certain period of time to maintain a database because whenever we need we will check the database with the help of time calculations and it will be easy for maintaining a patient detail in a database manner.

The entry of the person is based on sensors and whenever the person enters the lab test has to be conducted for the patient and the details will be stored in EEPROM and displayed in LCD. Then with the help of sensors, researcher will measure the information of the sensors and lab test value with the help of EEPROM. With the comparison, researchers will provide suitable level of insulin to the patient. The process with the help of controller has to be repeated.

Fuzzy logic based model system: Figure 2 shows the flow temperature sensing operation and the operation can be controlled through different mechanical interfaces as buttons. The Microcontroller Unit (MCU) acts as the main component which controls most of the operations performed by the system like analog to digital conversion and controlling the motor and valves. The resultant values produced by the system can be seen through the light emitting diodes attached.

The pressure monitor has an analog circuit to amplify the signals AC/DC components in order to process the signal through MCU to get valid and effective useful information's about the biological object.

The Fuzzy Logic Systems works through the rule set provided and the set of values which are logically analyzed and has values between 0 and 1 whereas digital systems uses only discrete values either 1 or 0. For decision making the rule set has to be prepared with more explore and has to consider each condition to get a rule and come up with more rules. The fuzzy system could be adapted for medical solutions and here researcher focus on implementing the fuzzy systems to monitor the sugar level of the biological system and control the blood sugar based on the values get from the sensors. The blood sugar reading of the patient will be varying at all the times in different time frames and we design a tool to monitor that and try to control based on different rules.

Like these monitors any biological feature can be monitored in nature. There are many inventions for the monitoring and controlling the biological features of the human. Researcher discusses few of them here and analyzes the results produced by them.

Fuzzy Logic Diabetic Control System: This proposed system contains the following micro controllers namely timer controller, diabetic controller attached to the system. The proposed system controls the injection of insulin into the human biological system based on the result of fuzzy system with the help of the reading of the sensors and few other factors (Fig. 3).

Timer controller: This controls the sensors attached to the body of the human. The timer is an automatic circuit used to trigger the sensors attached to the body of a human. It triggers the sensors periodically in certain intervals. It receives the analog data from the sensors and converts to digital form and hand over to the diabetic controller. Here, KP is an input set of temperature:

$$P = \{96,98,100,102,104\}$$

Q is an input set of pressure:

$$Q = \{90, 100, 110, 120, 130, 140, 150, 160, 170\}$$

R is an input set of glucose:

$$R = \begin{Bmatrix} 120, 140, 160, 180, 200, 220, 240, 260, \\ 280, 300, 350, 400, 450, 500 \end{Bmatrix}$$

T is an input set of time:

$$T = \{2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24\}$$

Rb is an input set of red block cells:

$$Rb = \{2, 4, 6, 8, 10, 12, 14, 16\}$$

Wb is an input set of white block cells:

$$Wb = \{2, 4, 6, 8, 10, 12, 14, 16\}$$

Pl is an input set of plasma cells:

$$Pl = \{2, 4, 6, 8, 10, 12, 14, 16\}$$

Algorithm:

```
Step 1: start
Step 2: Initialize time slot ts = ct. //ct-current time
Step 3: Trigger temp/pressure/glucose sensor
        Φ = ${t/p/g}
        μ = Ω (Φ (P, R, T))
        Ω- mapping operation to find the values in Φ
        towards  P, R, T
        Ω-will return three different values-normal,
        moderate, ubnormal
        Handover Ω to diabetic controller
        Wait for next time slot ts_i
Step 4: end
```

Temperature/pressure/glucose sensor: These sensors are triggered by the timer controller periodically. Whenever they are triggered, it senses the human body temperature, pressure and glucose level from the human blood and veins. The sensed data is forwarded to the timer controller. In the proposed system, this module will be triggered in every 5 min.

Red/white/plasma cell sensor: These sensors are triggered once in a month or 15 days once. This sense the red blood cells count, white blood cells count and plasma cell count present in the blood. All these readings are transfer to the timer control.

Diabetic controller: This performs the important block of the proposed system. It is triggered by the timer control and will be triggered in every 5 min. It maintains set of rules according which it has to take decisions. It receives all the readings from the timer control and maps the reading according to the rule set provided and acts accordingly. Based on the rules it triggers the regulator for the injection of insulin to the human body. If the sugar level is little high at the time of lunch, it ignores the injection; it handles according to various timing values. The rules used here are as follows:

- R1: if P is A1 and Q is B1 and R is C1 and T is T1 then Z is D1
- R2: if P is A2 and Q is B2 and R is C2 and T is T2 then Z is D2
- Rn: if P is An and Q is Bn and R is Cn and T is Tn then Z is Dn

Based on the values of pressure, temperature, glucose and time the proposed system controls the injection of insulin. The proposed system ignores the increase of pressure and sugar at some times based on certain rules.

Fuzzy algorithm:

```
Input: Ω-mapping function value//normal moderate ubnormal
        Φ-sensor values of pressure/temp/glucose
Output: gml-volume of glucose to be injected
Step 1: start
Step 2: read Ω, initialize gmL = 0;
Step 3: If (Ω == Normal)
            Break;
            End.
            If (Ω == Moderate)
             If (Φ(t)<>T{4, 5}||Φ(t)<>T{7, 8}||Φ(t)<>
             T{9, 10})//Food Time
                 If(Φ(p)<>P(2, 3))//temp between 98, 100
                     If(Φ®<>R(3, 6)  && Φ®<> Q(3, 6))
                      //pressure
                        gmL = ((Φ®-140)/10)×0.35
                 end
                 If(Φ®<>R(7, 10) && Φ®<> Q(3, 6))
                     gmL = ((Φ®-140)/10)×0.5
                 end
                 If(Φ®<>R(7, 10) && Φ®<> Q(6, 9))
                     gmL = ((Φ®-140)/10)×0.25
                 end
          End
      Else //end of food time
          If(Φ(p)<>P(2, 3))//temp between 98, 100
              If(Φ®<>R(3, 6)  && Φ®<> Q(3, 6)) //pressure
                  gml = ((Φ®-140)/10)×0.75
```

```
            end
            If(Φ®<>R(7, 10) && Φ®<> Q(3, 6))
                gmL = ((Φ®-140)/10)×1
            end
            if(Φ®<>R(7, 10) &&Φ®<> Q(6, 9))
                gmL = ((Φ®-140)/10)×0.5
            end
        End
    End //End of moderate
    If(Ω == abnormal)
    If(Φ(t)<>T{4, 5} || Φ(t)<>T{7, 8} || Φ(t)<>T{9, 10})
    //Food Time
        If(Φ(p)<>P(4,6))//Temp between 100,104
            If(Φ®<>R(8, 12) && Φ®<>Q(8,14))//Pressure
                gmL = ((Φ®-140)/10)×0.75
        Else
        if(Φ®<>R(6, 8) && Φ®<> Q(8,14)) //Pressure
            gmL = ((Φ®-140)/10)×0.5
        Else
        if(Φ®<>R(8, 12) && Φ®<> Q(4, 7)) //Pressure
            gmL = ((Φ®-140)/10)×1
        end
    else
        If(Φ®<>R(8, 12) && Φ®<> Q(8, 14)) //Pressure
            gml = ((Φ®-140)/10)×0.75
        Else
        if(Φ®<>R(6,8) && Φ®<> Q(8, 14)) //Pressure
            gmL = ((Φ®-140)/10)×0.5
        Else
        if(Φ®<>R(8,12) && Φ®<> Q(4, 7)) //Pressure
            gmL = ((Φ®-140)/10)×1
        end
    end
Else //end of food time
    If(Φ(p)<>P(4, 6))//Temp between 100, 104
        If(Φ®<>R(8, 12) && Φ®<>Q(8, 14))//Pressure
            gmL = ((Φ®-140)/10)×2
        Else
        if(Φ®<>R(6,8) && Φ®<>Q(8,14))//Pressure
            gmL = ((Φ®-140)/10)×1
        Else
        if(Φ®<>R(8,12) && Φ®<>Q(4, 7))//Pressure
            gmL = ((Φ®-140)/10)×1.5
        end
    else
        If(Φ®<>R(8,12) && Φ®<> Q(8, 14))//Pressure
            gmL = ((Ô®-140)/10)×1.5
        Else
        if(Φ®<>R(6,8) && Φ®<> Q(8, 14)) //Pressure
            gmL = ((Φ®-140)/10)×0.5
        Else
        if(Φ®<>R(8, 12) && Φ®<> Q(4, 7)) //Pressure
                gmL = ((Φ®-140)/10)×1
            end
        end
        End
    End
    End //end of abnormal
Step 4: send gmL value to glucose regulator
Step 5: wait for next signal from timer
Step 6: stop
```

RESULTS AND DISCUSSION

The proposed system produces efficient results and the performance of the system is comparatively huge than other systems proposed earlier. The proposed system has used various set of rules and the fuzzy system has controlled the human glucose level in better manner other than several instrumental control systems.

Figure 4 shows the results of values received from various sensors attached to the human body and the

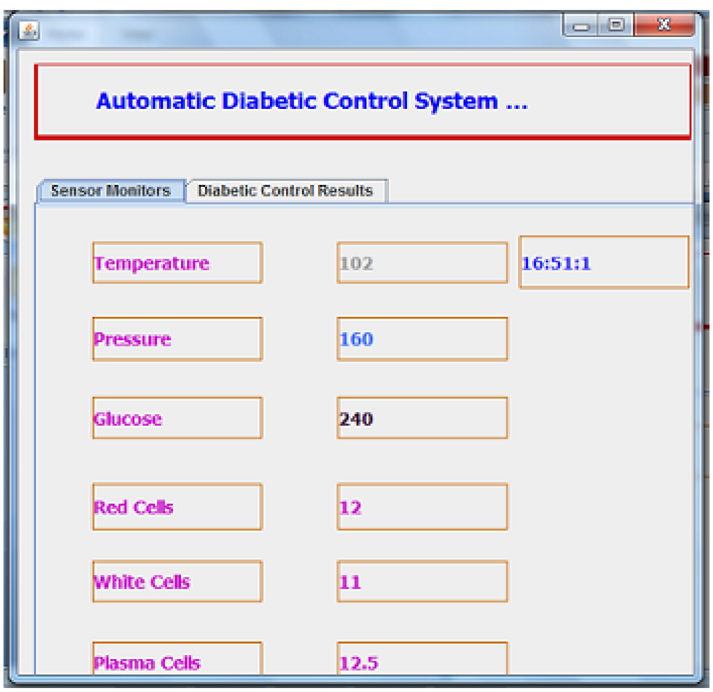

Fig. 4: Values of different attributes received from sensors

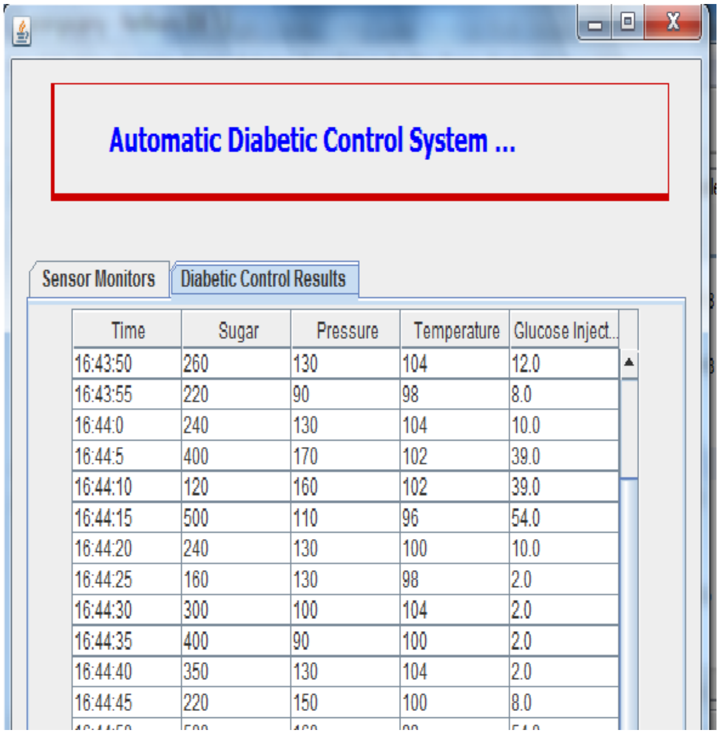

Fig. 5: Various readings analyzed and computed glucose level

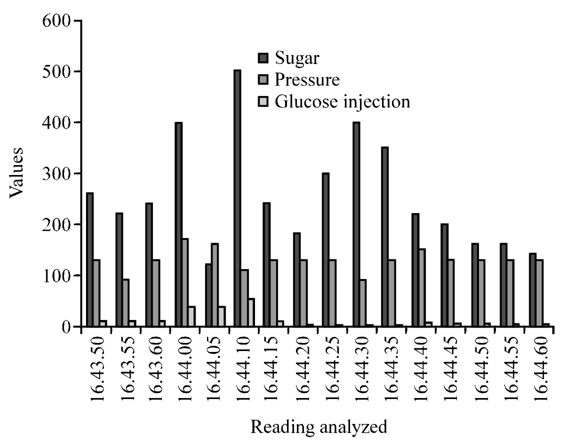

Fig. 6: Various readings analyzed and computed (sugar, pressure and glucsoe insulin)

values are shown. The values are monitored in every time slot with 5 min of time. Figure 5 shows the values of temperature, pressure, glucose level in each time it received from the sensors attached with the human body. Therse results are produced based on the factors specified and based on the fuzzy rule set.

Figure 6 shows the fuzzy systems have calculated the amount of glucose insulin to be injected to the human biological system and it can be viewed from the figure clearly.

CONCLUSION

This Fuzzy Logic Diabetic Control System has various merits towards the performance of device controlled biological systems. The proposed method have controlled the biological system according to the fuzzy rules given to the system and have controlled the glucose level of the human using the rules. This makes easier for the diabetic patients to survive freely without any fear and the sugar level will be maintained according to many different factors. The proposed method have produced very good results according to time complexity and cost factor.

REFERENCES

Bequette, B.W., 2005. A critical assessment of algorithms and challenges in the development of a closed-loop artificial pancreas. Diabetes Technol. Ther., 7: 28-47.

Huang, Y.L., H.H. Lou, J.P. Gong and T.F. Edgar, 2000. Fuzzy model predictive control. IEEE Trans. Fuzzy Syst., 8: 665-678.

Koschinsky, T. and L. Heinemann, 2001. Sensors for glucose monitoring: Technical and clinical aspects. Diabetes Metab. Res. Rev., 17: 113-123.

Lee, C.C., 1990. Fuzzy logic in control systems: Fuzzy logic controller. II. IEEE Trans. Syst. Man Cybernet., 20: 419-435.

Lenhard, M.J. and G.D. Reeves, 2001. Continuous subcutaneous insulin infusion: A comprehensive review of insulin pump therapy. Arch. Intern. Med., 161: 2293-2300.

Li, W., Y. Wang, G. Zhou, Q. Fan, X. Yang and G. Ye, 2011. Fuzzy control system simulation of retractable tail frame of scraper conveyor. Proceedings of the 3rd International Conference on Advanced Computer Control, January 18-20, 2011, Harbin, pp: 302-306.

Mamdani, E.H. and S. Assilian, 1975. An experiment in linguistic synthesis with a fuzzy logic controller. Int. J. Man-Mach. Stud., 7: 1-13.

Mastrototaro, J.J., 2000. The MiniMed continuous glucose monitoring system. Diabetes Technol. Ther., 2: S13-S18.

Molitch, M.E. and S. Korenman, 2000. Atlas of Clinical Endocrinology: Neuroendocrinology and Pituitary Disease. 4th Edn., Wiley-Blackwell, USA.

Morath, C. and M. Zeier, 2009. Transplantation in type1 diabetes. Nephrol. Dial. Transplant., 24: 2026-2029.

Roe, J.N. and B.R. Smoller, 1998. Bloodless glucose measurements. Crit. Rev. Ther. Drug Carrier Syst., 15: 199-241.

Sandhu, G.S., T. Brehm and K.S. Rattan, 1996. Analysis and design of proportional plus derivative fuzzy logic controller. Proceedings of the National Aeronautics and Electronics Conference, Volume 1, May 20-23, 1996, Dayton, OH, pp: 397-404.

Shapiro, A.M., J.R. Lakey, E.A. Ryan, G.S. Korbutt and E. Toth *et al*., 2000. Islet transplantation in seven patients with type 1 diabetes mellitus using a glucocorticoid-free immunosuppressive regimen. N. Engl. J. Med., 343: 230-238.

Tuan, H.D., P. Apkarian, T. Narikiyo and Y. Yamamoto, 2001. Parameterized linear matrix inequality techniques in fuzzy control system design. IEEE Trans. Fuzzy Syst., 9: 324-332.

Verma, O.P. and H. Gupta, 2012. Fuzzy logic based water bath temperature control system. Int. J. Adv. Res. Comput. Sci. Software Eng., 2: 333-336.

Zadeh, L.A., 1965. Fuzzy sets. Inform. Control, 8: 338-353.

Zhang, Q., J. Liu, X. Yang and H. Liu, 2008. Research on intelligent feeding paper control system based on fuzzy parameter self-adaptive PID for fruit-bag machine. Proceedings of the PACIIA, Pacific-Asia Workshop on Computational Intelligence and Industrial Application, Volume 2, December 19-20, 2008, Wuhan, pp: 773-776.