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Closed Loop Control of Insulin Regulatory System for Diabetes

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Abstract: In recent times, one third of the world population is prone to many health issues. Among these, the most commonly faced problem is the diabetes. Diabetes is said to be the condition where pancreas is not able to secrete enough amount of insulin to balance the glucose level in the blood. The measurement of blood glucose level in the existing system is done by an invasive device called the Glucometer. With diabetic condition, balance in the level of blood glucose for a person is done by manual injection of insulin or by placing an insulin tablet under tongue at regular intervals which depends upon the measured blood glucose levels. By the use of the proposed system, the blood glucose level is balanced by using a closed loop control mechanism where the blood glucose level is being continuously monitored and the corresponding variations are taken into consideration for exerting the controller action to produce the required amount of insulin which can be injected automatically. The proposed system uses Arduino IDE to perform the controller action. The system consists of a Pulse oximeter for non-invasive measurement of blood glucose levels, a Zigbee module to transmit and receive data, an insulin reservoir and a pump to store and eject insulin at required conditions. Existing methods for blood glucose measurement uses manual techniques and the rise / fall in blood glucose level cannot be identified as and when it happens. The proposed system overcomes this limitation where the monitoring of the blood glucose level is automated and its regulation is also done with high accuracy.

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I. Introduction

Extensive research work is done for the purpose of leading to a healthy world free of fearful diseases like diabetes. All these work have been done to find solutions for detecting and treating diabetic disease with ease and high accuracy. One of the methods is to design automated insulin regulatory system to control glucose level in the blood. A completely automated insulin regulatory system could be the only solution for control of blood glucose level in patients suffering from diabetes. The function of a

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normal pancreas is being brought into simulation scenario by means of this system and maintains the blood glucose levels for diabetic patients who are insulin dependent.Such a closed loop insulin regulatory system can theoretically produce compact glucose level control in non-contact methodology and elimination of the usage of insulin injections or hypo-glycemic/hyper-glycemic events is made possible. This greatly improves the diabetic patient life standard who is hanging on insulin. The automated insulin regulatory system is a systematic way of devices that are combined for substituting pancreas which is done by reading the concentration of plasma glucose, computing the amount of insulin needed, and gives the correct amount of insulin.The system is comprised of a sensor that measures glucose level, a pump that pumps insulin, and it makes use of a control algorithm for pump regulation not to deliver insulin for retaining normal glycemia in presence of sensor readings taken from the patient. The closed loop control is formed into usage by placing the sensor in the fingertip which measures the glucose level in body.The output of the sensor is used as an input to the controller and the value of error between the two is computed. On the amount of error computed, automatic pumping of insulin is done.The controller plays a vital role in this automated system. For the controller to be highly efficient, it provokes the design of a control algorithm, using the model basics of the glucose insulin for a normal person is to be developed and simulated. The simulation results are computed and stored. This stored data is retrieved where and when necessary by the automated system.The data acquisition of the input reading and itscorresponding control is simulated using proteus. [10, 11].Rapid increase of sugar concentration in blood leads to Diabetes. This irregular pattern of high concentrations of glucose leads to lack of insulin production by Pancreas. The right concentration of glucose is mandatory for proper functioning of the body. Advanced research literature say that an automated implantable system for retaining the blood glucose level is possible that mimics the function of an ordinary pancreas.GlucoseConcentration measurement was done using a glucose sensor which is close to the readings got from a glucose The use of continuous glucose monitoring system (CGMS) is an area which helps in consistent monitoring of blood glucose level. [1].A closed loop insulin regulatory system was proposed to control the amount of insulin transported by the system [2]. Glucose level abnormalities in prediction methodology made use of development of algorithms to minimize/stop the abnormalities that occurs due to hike/decrease of blood glucose level. [4]

A prototype model that uses a glucose sensor connected to a microcontroller is called “Insulcagon” that initiates either insulin or a glucagon pump which varies as per the reading got from the patient [12]. Glucagan is a hormone secreted by the pancreas thatincreases blood glucose levels which acts in opposite nature to that of insulin. Glucagon is secreted by Pancreas when glucose level in the blood falls below the threshold value. A continuous glucose monitoring system used for implantation will satisfy various objectives such as testing of full custom integrated circuit (IC) design of a closed loop control circuit together with Programming of the Microcontroller algorithm.In addition, hardware can be used to implement algorithm stored in the microcontroller that simulates insulin pump which will lead to automatic control of the glucose level concentration in the blood. This leads to a closed loop implantable glucose control system that helps in preventing and treatment of diabetes. Because of this, a number of medical complications are reduces and there is a great reduction in medical costs involved in blood glucose level regulation. The design of the automated regulatory system of insulin is the primary part of concentration and its

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interface with the microcontroller unit is focused in this work.

II. Earlier Systems

Diabetes is a condition that comes with different abnormalities in the metabolism function of insulin. The Insulin converts sugar, starch and other food components into energy. Researchers are keen into focus for the development of external insulin that can be injected at a certain rate to retain the level of carbohydrate in normal values of 60-120 mg/dl.Type-1 and Type-2 are the two categories of diabetes .It is very tough to regulate insulin level in type 1 Diabetes. The carbohydrate concentration in the blood is maintained by external insulin that is released by the insulin infusion system.

The insulin pump is an important section in whose purpose is dispatch of insulin through a plastic tube near the abdomen of the patient. This insulin pump gives out drops of insulin as per the glucose level reading of the patient by comparing it with standard level of glucose. The concentration of Carbohydrate changes which depends upon the physical activities engaged by the patient. This mainly varies the insulin requirement from one patient to another. The first diabetic model was developed by Bolie which made use of differential equations for demonstration of carbohydrate and insulin.

A model similar to Bolie was developed by Ackerman et al. for predicting the levels of carbohydrate insulin. These models had the limitation of taking into account the distribution of insulin and carbohydrates. The minimal model developed by Bergman et al. (1981) made use of 3-sections which was used as an altogether representation of human body in proposing the study of diabetes and its related effects.It made it necessary that the dynamics carbohydrate transportation and its administration in tissues raises the blood carbohydrate concentration. Cobelli et al. in 1982 formulated 5- section models for carbohydrate, insulin and glucagon effects, which were combined together in resemblance with whole body blood. Lehmann and Deutsch in 1992 produced a model for insulin regulation which was nonlinear in nature .A single section extra cellular pool was taken into consideration and a two section model of insulin representing plasma and active concentrations was also taken into account. Puckett in 1992 produced a modelling study of diabetes mellitus in which a two blood pool system was formulated which considered the concentrations of insulin and carbohydrate concentrations were discussed that were directly affected by metabolic flux terms and exogenous signals.

Along the work of Light foot in the year 1995, Puckett practically showed inter and intra patient variability by deeply studying the system via his proposed study and steady state behavior of signal levels using his models [8]. Separate handling of carbohydrate and insulin along with coupling over metabolic effects employing threshold functions was studied. A whole body combined representation was also done to complete the carbohydrate-insulin system along counter regulation. A small addition into this model was made by Sorenson which takes into account the signals that arises due to meal disturbances.

III. Suggested System

This suggested system consists of the control part in addition to that of the measuring system. The non-invasive measurement of glucose level in mg/dL is done by the means of the pulse oximeter sensor. The specific voltage for each body level is constituted through the sensor output which feeds the input value to the Arduino UNO [11]. The values such as gender and age of the patient are provided as input through the serial communication interface “PUTTY” which acts as the display source for the system. Each of these input values are fed to the Arduino which acts as the controller. The PID logic is computed in the Arduino where the relation is equated to produce the glucose level of each individual. Based on the table that depicts the relation between glucose and insulin, the required quantity of insulin to be injected is calculated. Vice Versa, the “Insulin Injection System” prepares to inject the specified value of insulin. Thus depending upon the value required the specific amount of insulin is being injected.

The glucose voltage relationship is being given by the following equation.

$$G=Q*S+R*A + (T*V)-U$$

Where:

S: Gender of the Patient"male=0 or female=1"

A: Age of the patient in years

G: Concentration of blood glucose "mg/dl"

V: Output voltage of the ADC in"volts"

Q, R,T and U are constants, where Q=19.71,R=4.15,T=0.27 and U=54.16

IV. Closed Loop Control System Algorithm

0-80	0
81-100	0
101-150	0
151-200	2
201-250	4
251-300	6
301-350	8
351-400	10
>401	12

Table 1: Equivalent Insulin Levels required for the measured Glucose condition

V. Methodology & Working

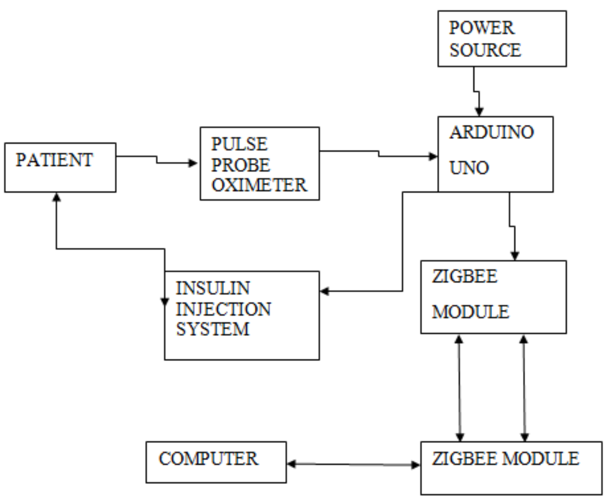

Fig 1: Block Diagram of Closed Loop Cotrol of Insulin Regulatory System

VI. Pulse probe oximeter

Pulse oximeter is a non-contact method used for measuring the saturation level in blood oxygen. The pulse probe oximeter is a sensor that measures the pulse count and produces an equivalent voltage level which is unique to every person. This value is correlated to the Glucose calculation relation. Thus the amount of blood glucose level which is analog in nature is converted to its equivalent digital value.The digital value can be easily used for comparison with its theoretical counterpart to proceed with further actions as required by the patient.

VII. Arduinouno

The Arduino UNO is an open-source microcontroller board. It is widely used because of its flexible use of hardware and software features and ease of usage. Here a circuit board acts as a hardware and Arduino IDE (integrated Development environment) acts as the software.Arduino boards are capable of reading both analog and digital signals. The functions of the circuit board can be controlled by using a set of instructions to the microcontroller. Simplified version of C++ is used for the purpose of Programming. Communication in both parallel &serial form is possible via Arduino. A Collection of Code is available in the form of libraries which can be used to connect a sensor, display or a module.

VIII. Zibbee Module

Zigbee is an IEEE 802.15.4-based specification for a suite of high-level communication protocols used for controlling and monitoring applications covering a range of 10-100m.Long distant zones can be covered by using a set of intermediate devices. A total of 240 applications to the maximum can be covered by a single Zigbee node. The most preferred topology is star topology in Zigbee. The Application scenario for zigbee is so much diversified from automation, security & home applications. It is also used in fire extinguisher systems in automated usage applications. In spite of the protocol having limitations, its unique features make it remarkably helpful in the development of a small prototype model of any application.

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IX. Insulin Injection System

The insulin injection system plays the vital role in the automated control of system used for insulin regulation where the insulin is being injected into the human body. The DC motor controls the flow of the insulin and the indication is being observed in the syringe which acts as the reservoir for insulin. The directions for the DC motor are given by the instructions from the Arduino.

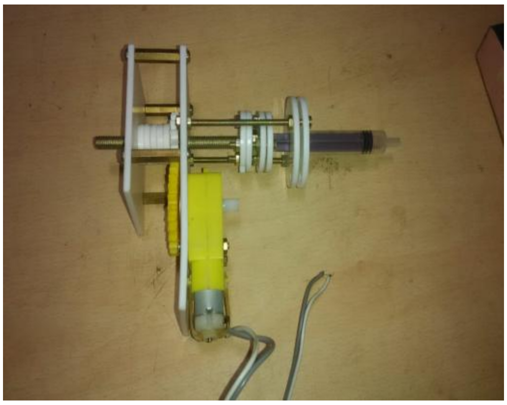

Fig 2: Block Diagram of Closed Loop Cotrol of Insulin Regulatory System

X. Results & Discussions

The closed loop control of an insulin regulatory system comprises of two sections namely the measuring and the controlling section. The non-invasive measurement of glucose level in the blood of the patient constitute for the measurement part. The ejection of insulin from the syringe by the motor action with reference to the glucose levels computed, act as the controlling part. Here the input is obtained from the patient from the pulse probe sensor and then given to the Arduino for processing. Further thevalues are transmitted through the means of the Zigbeemodule.The ZIGBEE module acts as both transmitter and receiver. Thus the doctor is able to monitor the patient from any place in the hospital as the transmission ability of the Zigbee module is from 10m to 100m. Thus the received information is viewed on the computer screen via the serial communication interface. Thus the response for the given input is produced by the movement of piston of the Syringe. This thereby injects the required amount of insulin into the patient's body, thereby forming a closed loop system.

S.NO	Gender value	Age	O/p voltage	Measured Reading	Glucometer reading
1	1	21	207	108	105
2	0	25	225	110	111
3	1	22	213	114	119
4	0	25	229	113	120
5	1	21	202	107	108

Table 2: Non-Invasively Measured Glucose value to the Glucometer measured value

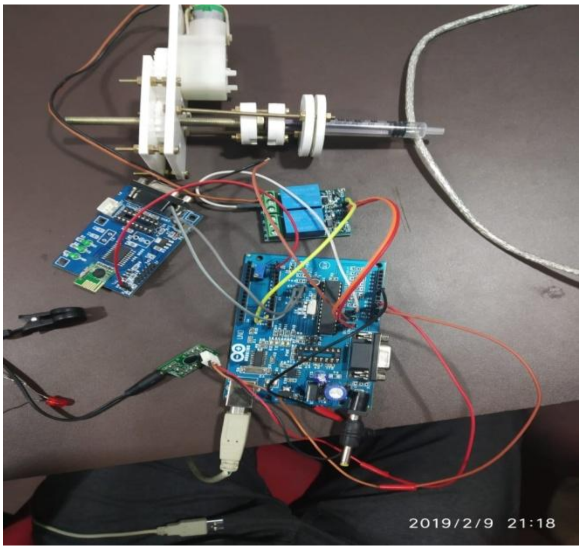

Fig 3: Hardware setup of The Closed Loop Control of an Insulin Regulatory System

XI. Conclusion& Future Works

This paper presents automated control of insulin regulation applicable for diabetes. The entire model is nonlinear with uncertainty involved in parameter measurement. Therefore, a classical linear control theory provides a limited performance for this class of problems. PID controller is the candidate to be used where it has proved its performance in the literature to control nonlinear systems and parametric uncertainty. The proposed closed loop system consists of Arduino, Pulse Probe Oximeter,

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Insulin injection system and ZIGBEE module. Micro-needle provision is made at the syringe end head for injection of necessary amount of insulin with decreased pain. In future the setup can be made available as a handy product.

XII. Reference

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