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FPGA implementation of an adaptive neuro fuzzy inference system for controller driven insulin injection system

Manoj M#1, Bhuvaneshwari S #2

#1 PG Student
#2 Assistant Professor
Department of Electronics and Communication Engineering
Kings College of Engineering
Thanjavur, India

Abstract - *Diabetes is one of the pandemic diseases and causes 4 million deaths per year and ranks fifth by causing specific mortality in the most high-income countries. One should maintain the glucose concentration in blood, within the normal range (70-120 mg/dl or 3.6-6.9 mmol/L). Lower glucose levels (<50mg/dl) are said to be hypoglycemia, which is characteristized by excessive thirst, sweating, seizures and coma. Higher glucose levels (>200 mg/DL) are known as hyperglycemia, which leads to long term vascular complications, diabetic retinopathy, neuropathy, and nephropathy. The Diabetes Control and Complications Trail (DCCT), has stated that, strict glycemic control significantly reduces the short term and long term complications of diabetes. Self tuned insulin injection system becomes necessary to inject required amount of either insulin or glycogen based on the present condition of the diabetic patient. Developing and testing an intelligent control System is required to achieve the above task. An Adaptive Neuro Fuzzy Inference System (ANFIS) is proposed to read the glucose level of the diabetic patient to decide the displacement range of the injection pump and to generate the required control signal. The proposed ANFIS controlled System will be deployed in an experimental test bed (to be developed) as a closed loop controller to maintain the glucose level at the patient. Due to the nature of the control system. i.e low power, portable pipelined parallel computation, obviously FPGA(Field Programmable Gate Array)is the optimal choice. Therefore building a digital architecture inside the FPGA to implement ANFIS Suitable for this task and testing/validating its entire control action is the primary objective of the project*

Key words: Diabetes, Insulin pump, ANFIS, FPGA

1. INTRODUCTION

Diabetes is a metabolic disorder resulting from the permanent lack of insulin production from the pancreas (type 1 diabetes) or the chronic degradation of the functionality of endogenous insulin (type 2 diabetes), which results in raising the glucose concentration in blood because without insulin, the cellular system cannot properly convert carbohydrates such as sugars, starches, or other foods into energy usable by the body. These factors eventually result in several complications, such as cardiovascular disease, chronic renal failure, retinal damage, nerve damage, and micro vascular damage. People with type 1 diabetes cannot make insulin because the beta cells in their pancreas are damaged or destroyed. Therefore, these people will need insulin injections to allow their body to process glucose and avoid complications from hyperglycemia. Type 1 diabetes is a chronic life-threatening disease that is characterized by a total failure of the pancreas to deliver insulin, thereby rendering the body incapable of regulating blood glucose. An insulin pump is an alternative to multiple daily injections of insulin by insulin syringes. Insulin delivery is described as continuous; in reality the pump infuses a small bolus every few minutes to provide the cumulative hourly dose. Insulin pumps allow continuous subcutaneous infusion of insulin 24 hours a day at present levels, and the ability to program bolus doses of insulin as needed at meal times.

2. PROPOSED METHODOLOGY

An adaptive Neuro Fuzzy Inference System (ANFIS) is proposed to read the glucose level of the diabetic patient. It decides the displacement range of the injection pump and to generate the required control signal. The proposed ANFIS controlled System will be deployed in an experimental test bed (to be developed) as a closed loop controller to maintain the glucose level at the patient. The control system uses low power, portable pipelined parallel computation. Therefore building a digital architecture inside the FPGA to implement

ANFIS Suitable for this task and testing/validating its entire control action is the primary objective of the project.

An intravenous insulin delivery system was designed such that it followed the real pancreas functionality of the non-diabetic. Typically, the closed-loop system for type 1 diabetes therapy utilizes the glucose sensor and schematically consists of three phases: blood glucose measurements, insulin demand calculation, and insulin injection. The closed-loop system repeats this sequence. So far, along with the glucose sensor, the closed-loop system also employs an insulin pump which continuously infuses insulin via a subcutaneous root.

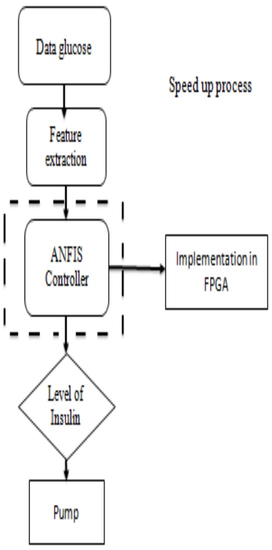

Fig -1: Proposed flow diagram

Adaptive network based fuzzy inference system (ANFIS) is a neuro fuzzy technique where the fusion is made between the neural network and the fuzzy inference system. In ANFIS the parameters can be estimated in such a way that both the Sugeno and Tsukamoto fuzzy models are represented by the ANFIS architecture. This ANFIS methodology comprises of a hybrid system of fuzzy logic and neural network technique. The fuzzy logic takes into account the imprecision and uncertainty of the system that is being modeled while the neural network gives it a sense of adaptability.

3. ANFIS MODEL

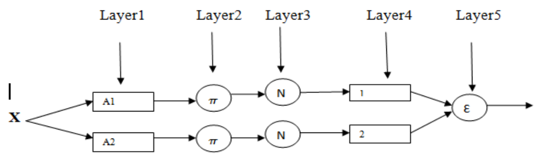

Fig-2: One-input one-output zero order ANFIS

Layer 1: This layer consists of input variables (membership functions), viz., input 1 and input 2. Here, triangular or bell-shaped MF can be used. This layer supplies the input values to the next layer,where i=1 to n. In other words, layer 1 is the input layer with n nodes.

Layer 2: This layer (membership layer) checks the weights of each MF. It receives the input values xi from the *1st* layer and acts as MFs to represent the fuzzy sets of the respective input variables. Furthermore, it computes the membership values that specify the degree to which the input value xi belongs to the fuzzy set, which acts as the inputs to the next layer. Note that layer 2 has nK nodes, each outputting the MF value of the *ith* antecedent of the *jth* rule given by $y^{ij}(2)=\mu A^{ji}\, x(i)$, where A is a matrix defining a partition of the space xi and $\mu A^{ji}(x(i))$ is typically selected as a generalized bell MF defined by the equation: $\mu A^{ji}(x(i))= \mu(x^{i},c^{ji},a^{ji},b^{ji})$. Note that the parameters c^{ji},a^{ji},b^{ji} in the above equation are referred to as the premise parameters.

Layer 3: This layer performs the pre-condition matching of the fuzzy rules, i.e., they compute the activation level of each rule, the number of layers being equal to the number of fuzzy rules. Each node of these layers calculates the weights that are normalized. Layer 3 has K fuzzy neurons with the product t-norm as the aggregation operator. Each node corresponds to a rule and the output of the *jth* neuron determines the degree of the fulfillment of the *jth* rule given by for j=(1,………, K.)

Layer 4: This layer provides the output values y, resulting from the inference of rules. Connections between the layers $l3$ and $l4$ are weighted by the fuzzy singletons that represent another set of parameters for the neuro-fuzzy network. Each neuron in layer 4 performs the normalization, and the outputs are called normalized firing strengths, which are given by for j=1,…..,K. (3.1)

Layer 5: This layer is called the output layer, which sums up all the inputs coming from layer 4 and transforms the fuzzy classification results into a crisp (binary). The output of each node in the layer can be defined by for j=1,……,K, where is given for the *jth* node in layer 5. The outputs of layer 5 are summed up and the final output of the network can be re-written as . The ANFIS structure is tuned automatically by least-square-estimation and the back-propagation algorithm . The algorithm shown above is used in the next section to develop the ANFIS controller to control the various parameters of the IM.

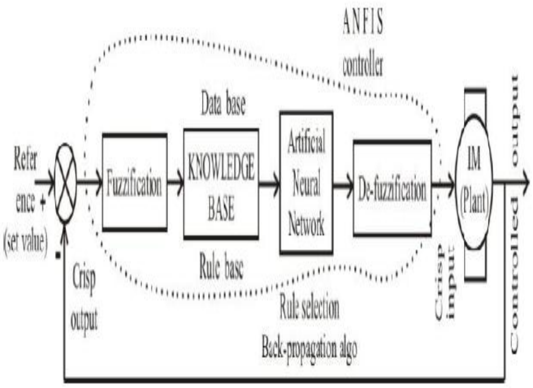

Fig-3: Block diagram of the ANFIS control scheme

- Fuzzification converts initial sugar level into insulin level.
- Fuzzy base rules define some rules on the information provided by fuzzification. The interference insulin provides us appropriate coherence and analysis for an output simulation.
- Artificial neural networks are mathematical creation inspired by explanation made in the study of biological systems, while loosely based on the actual biology. Artificial neural networks can be described as mapping an input space to an output space. The purpose of neural network is to map an input into a preferred output.
- Defuzzification gives us an output on the basis of defined set of membership function and rules.

4. SIMULATION RESULTS AND OBSERVATIONS

The fuzzy rule set has to be invoked first from the command window in the Matlab. Initially, the fuzzy file where the rules are written with the incorporation of the T-S control strategy is opened in the Matlab command window, after which the fuzzy editor (FIS) dialogue box opens. The *.fis* file (sugenos even rules2.fis) is imported using the command window from the source and then opened in the fuzzy editor dialog box using the file open command. Once the file is opened, the TS-fuzzy rules file gets activated.

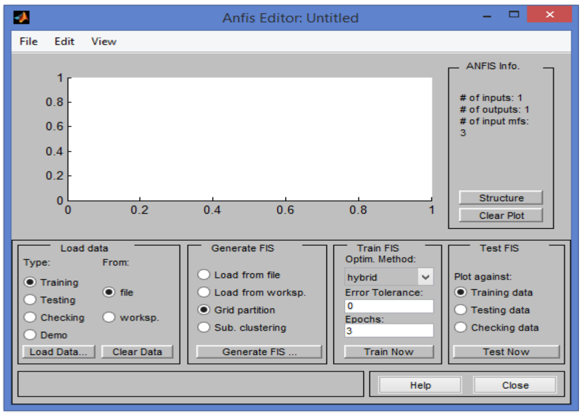

Fig-4: AN FIS editor window

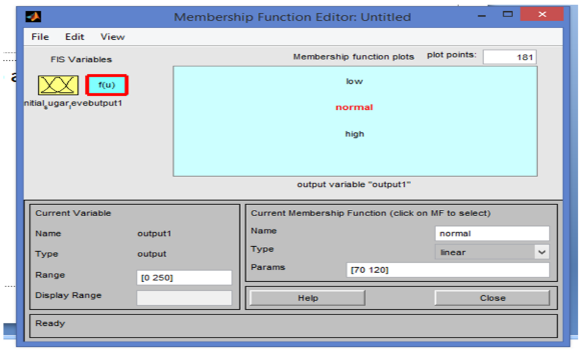

Fig-5: ANFIS controller output variable

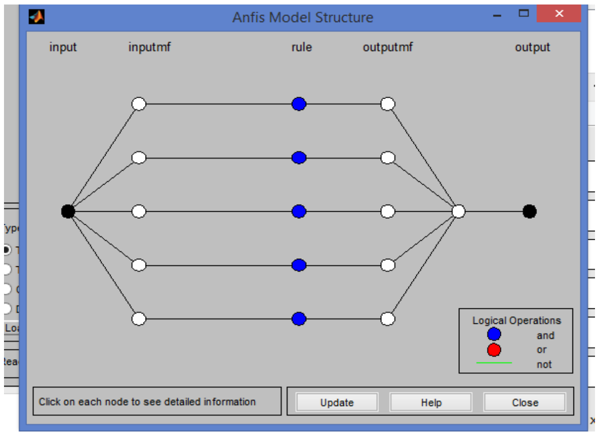

Fig-6: ANFIS Model structure.

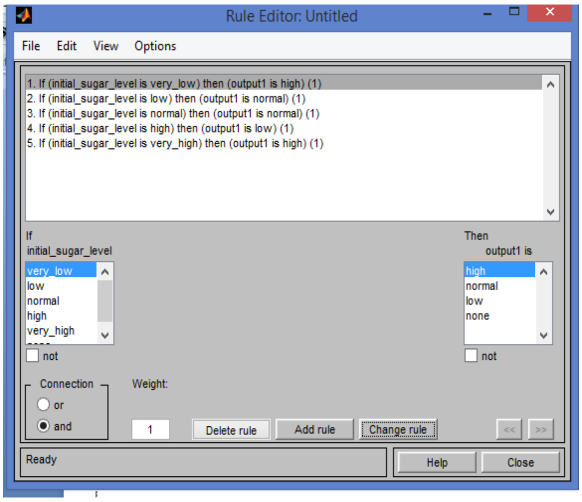

Fig-7: ANFIS control rules

The written TS-fuzzy rules also can be viewed from the rule view command. The rule viewer for the 1 inputs and 1 output can be observed pictorially. The fuzzy membership function editor is then obtained using the view membership command from the menu bar.

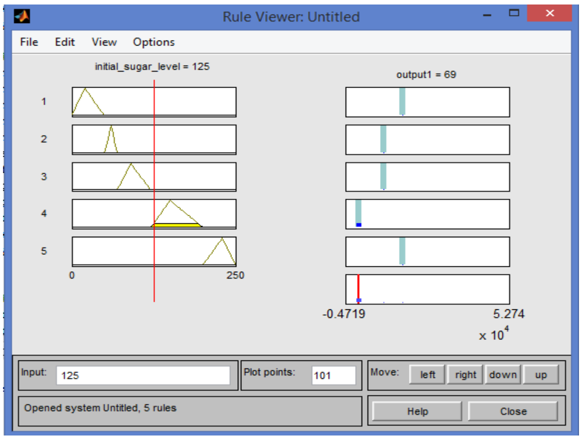

Fig-8: Rule base of ANFIS simulated in MATLAB

The proposed ANFIS controlled System will be deployed in an experimental test bed as a closed loop controller to maintain the glucose level at the patient. The control system uses low power, portable pipelined parallel computation

5. CONCLUSION

The simulation results have shown that this ANFIS Controller overrides the conventional controller in handling insulin pump. In this project it is assumed that the patient is continuously attached to the infusion pump and the blood glucose level is monitored at regular intervals. The designed controller has self tuning capability that over comes tracking insulin. In this project Insulin is administered to diabetic patients with Type I Diabetes using an ANFIS Controller system. An adaptive Neuro Fuzzy Inference System (ANFIS) is designed to read the glucose level of the diabetic patient to decide the displacement range of the injection pump and to generate the required control signal. The designed ANFIS controlled System will be deployed in an experimental test bed (to be developed) as a closed loop controller to maintain the glucose level at the patient

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