DESIGN OF AN ANFIS BASED BLOOD VOLUME CONTROL SYSTEM FOR RATS

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Abstract

Adaptive Network-based Fuzzy Inference System (ANFIS) can be employed directly in a wide variety of applications in decision making and control, because ANFIS is a class of adaptive network and it has minimal restrictions on modeling of the system. In this case study, ANFIS based approach has been implemented to develop a control system for the Blood Volume (BV) of rats. In order to achieve this aim, the effects of Glucagon-like Peptide-2 (GLP-2) on BV was used. In order to let the models to represent the forward and inverse relations between the hormonal effects of GLP-2 and BV of rats, the ANFIS models with the cluster partitioning of the data was trained, validated and tested using the clinical data. Therefore, the analysis based on simulations indicates that the control process using ANFIS based controller has sufficient performance .

Keywords: ANFIS, inverse learning, GLP-2, blood volume, rat

Introduction

Glucagon is a 29 amino acid peptide hormone liberated in the α cells of the islets of Langerhans. Glucagon-producing α cells represents one of the earliest populations of detectable islet cells in the developing endocrine pancreas. Glucagon is generally viewed as a hormone that opposes the action of insulin in peripheral tissues, predominantly in the liver, where the insulin/glucagon ratio determines the intricate control of gluconeogenesis and glycogenolysis. The action of glucagon in the liver is complex and involves a coordinate regulation of transcription factors and signal transduction networks which converge on regulation of amino acid, lipid, and carbohydrate metabolism.

Glucagon-like Peptide-2 (GLP-2) is a 33 amino acid peptide, co-secreted along with Glucagon-like Peptide-1 (GLP-1) from intestinal

endocrine cells in the small and large intestine. GLP-2 has a number of actions in the intestine including:

- Stimulation of mucosal growth in the small and large intestine,
- Inhibition of enterocyte and crypt cell apoptosis,
- Stimulation of enterocyte glucose transport and GLUT-2 expression,
- Increased nutrient absorption,
- Inhibition of gastric emptying and gastric acid secretion,
- Reduction of intestinal permeability,
- Stimulation of intestinal blood flow.

As can be seen from GLP-2 actions that were mentioned above, it is one of the vital mechanisms of part of the body. So, all the efforts to reveal mutual effects of GLP-2 are very valuable and basically, most of the physiological systems including GLP-2 have non-linearity as one of their characteristics. Therefore, when compared to Artificial Intelligence (AI) methods, the conventional numerical methods for modeling and controlling have difficulties with the non-linear systems. In our study, ANFIS was used to model and control this non-linear physiological system.

Designing an ANFIS Based BV Control System

The purpose of the design of an ANFIS based BV control system is to achieve the desired blood volume for the examined rat during the examination time. Thus, as a result of this aim, a controller designed by the inverse model of the ANFIS system was used to determine the required injection time of the GLP-2. Therefore, a specific group of rats was selected to take the training data, and a system model was obtained using the data collected from 4 rats with same method. In this method, the indomethacin (5 mg/kg) is injected through the initial 60min., and after that, GLP-2 is injected with 10µgr dose till the end of the examination time.

The recorded empirical blood volume data and smoothed & the average values are listed in Table 1.

Table 1. Empirical data for BV system of rat

Blood Volume (ml/100g Intestinal tissue)						
Time(min)	1. rat	2.rat	3.rat	4.rat	average	Smoothed
65	44.57831	40.46512	49.38272	60.93023	48.84	48.84
70	45.18072	38.37209	44.44444	55.5814	45.89	45.97
75	42.16867	36.27907	40.49383	53.83721	43.19	43.12
80	36.74699	33.37209	39.75309	51.27907	40.29	40.86
85	35.54217	32.55814	37.77778	50.46512	39.09	39.83
90	40.60241	34.30233	36.91358	48.60465	40.11	40.08
95	45.90361	30.23256	36.17284	51.86047	41.04	40.17
100	46.0241	30.81395	32.46914	48.13953	39.36	39.19

105	40.96386	29.65116	32.34568	45.81395	37.19	38.44
110	42.89157	30.46512	32.71605	48.95349	38.76	37.5
115	39.15663	30.34884	33.33333	43.37209	36.55	37.65
120	39.75904	29.65116	33.82716	47.32558	37.64	37.2
125	42.04819	30.81395	32.96296	43.83721	37.42	37.42

Since these empirical data are not enough to realize the control system, the new data set has been acquired using curve fitting method. Thus, the best fitting has been observed in 4th degree polynomial with 95% confidence bounds. This new curve is shown in Figure 1, and the goodness of this fit is given in Table 2.

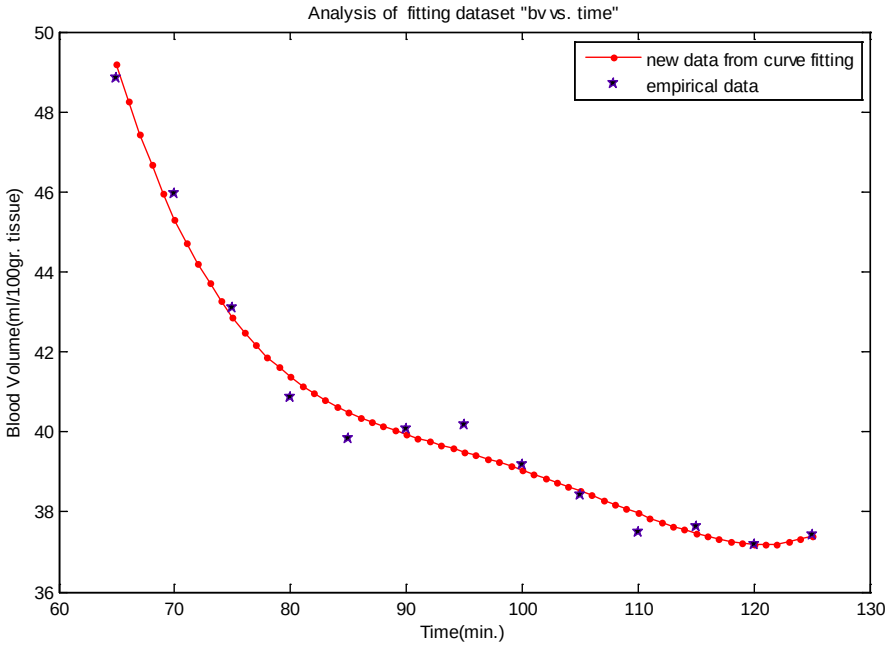


Figure 1. The new BV curve from empirical data

Table 2. Goodness of fit for the new BV curve

SSE	2.064
RMSE	0.508
R-square	0.9863
Adjusted R-square	0.9794

ANFIS based model of the BV system

The first step in designing the BV control system is to find the system and inverse model of BV as shown in Figure 2.

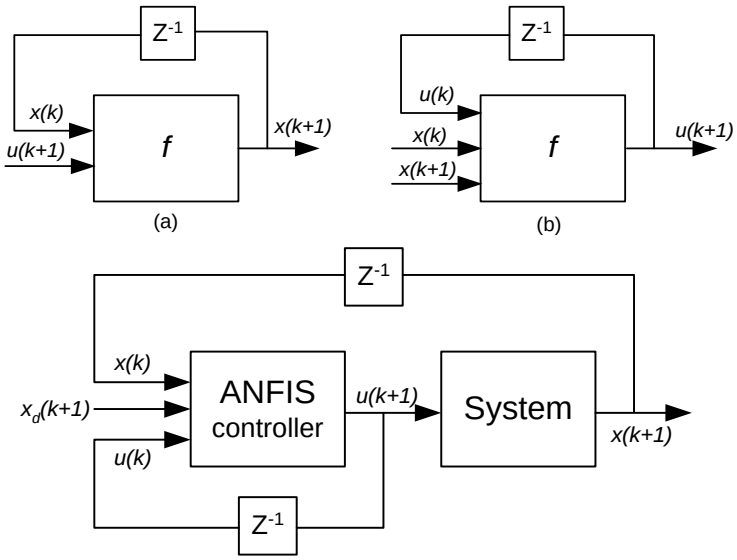
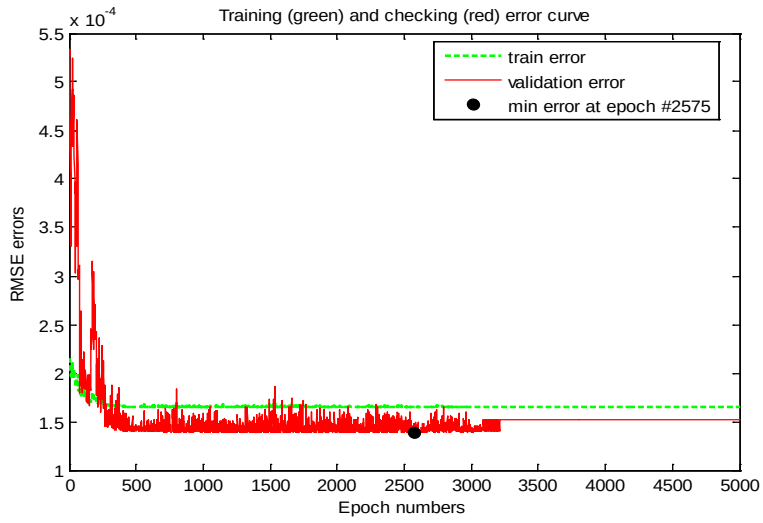


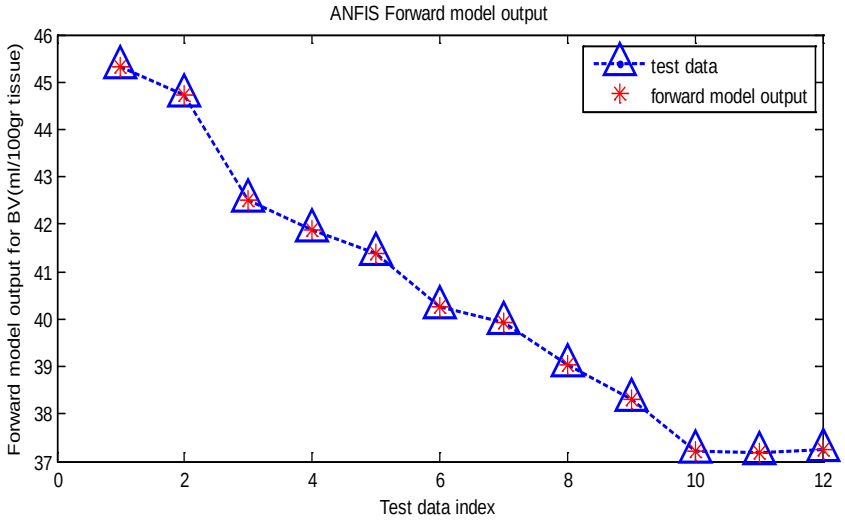
Figure 2. a) ANFIS forward model (system) b) ANFIS inverse model
c) Block diagram of a full control process

The input/output parameters shown in Figure 2 are assigned as follows: u(k) is the time (minute), x(k) is blood volume in kth step, x(k+1) is blood volume in (k+1)th step, u(k+1) is time in (k+1)th step, and z^{-1} is unit-time delay operator.

In the system and inverse models, the clustering structures were used. The data was used in training, validating and testing 29, 14, and 14 out of 57 data from new curve, respectively for both models. The error curves and test outputs are provided for each model in Figure 3 and Figure 4. Hence, table 3 shows the errors for both.



(a)

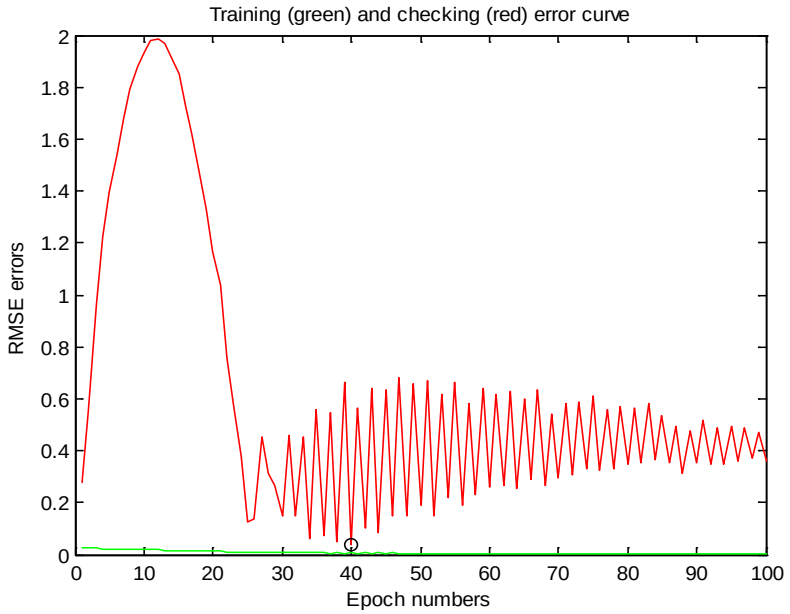


(b)

Figure 3. a) ANFIS forward model training and validation error curves(cluster radius=0.6) b) Forward model outputs for test data

Table 3. BV forward and inverse model errors (RMSE)

	Forward model (radius=0.6)	**Inverse model (radius=0.4)**
Training error	1.6566e-004	0.0064
Validation error	1.3918e-004 (at epoch: 2575)	0.0361(at epoch: 40)
Test error	1.9751e-004	0.9021



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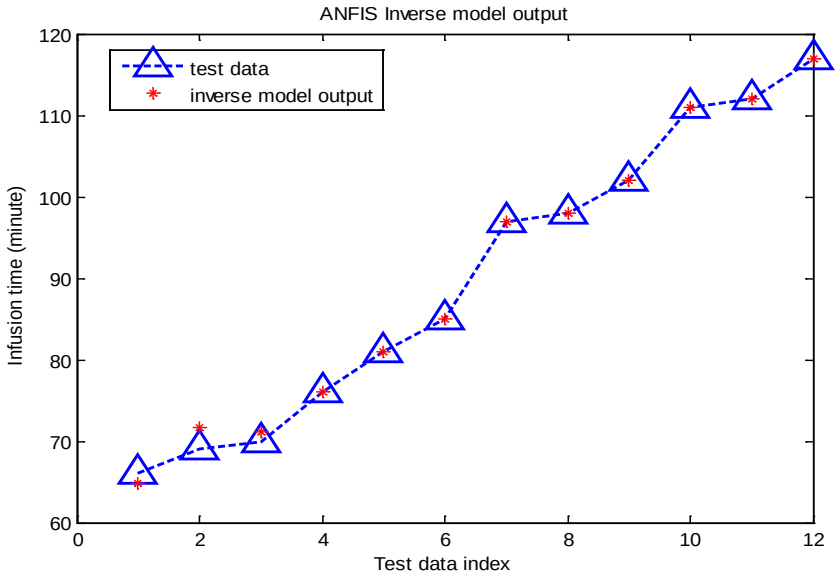

(b)

Figure 4. a) ANFIS inverse model training and validation error curves(cluster radius=0.4) b) Inverse model outputs for test data

BV control system design

The ANFIS based system model representing the BV system of the rat and inverse system model are cascaded in order to form the BV control system as shown in Figure 2. The desired value, xd (k+1), is a blood volume value which we want to see as the output. The inverse system block produces a required injection time, u(k), for GLP-2. The complete control system produces the desired blood volume at the output within the required injection time.

However, there are slight differences between the figure in the book of Jang, J. and Figure 2 that is a z^{-1} unit-time delay operator between the output and the input in the ANFIS controller part. If the control process is realized like the one in Figure 2, then the ANFIS controller output u(k) may give unpredicted values. Therefore, the aim of this BV control is to give the required amount of GLP-2 within the required injection time. Some death risk is possible for a rat if there is only x(k+1) observed from the system's output without controlling the required injection time. Therefore, u(k+1) and x(k+1) are used as the critical output parameters in our control process; and so, the Figure 2 has been modified here in order to reflect this idea that u(k+1) has been fed to the input as u(k) through z^{-1} unit-time delay operator.

The final performances of ANFIS based BV control system for various cluster radiuses are shown in Figure 5 and the errors are listed in Table 4 for these radiuses as shown in the figure below.

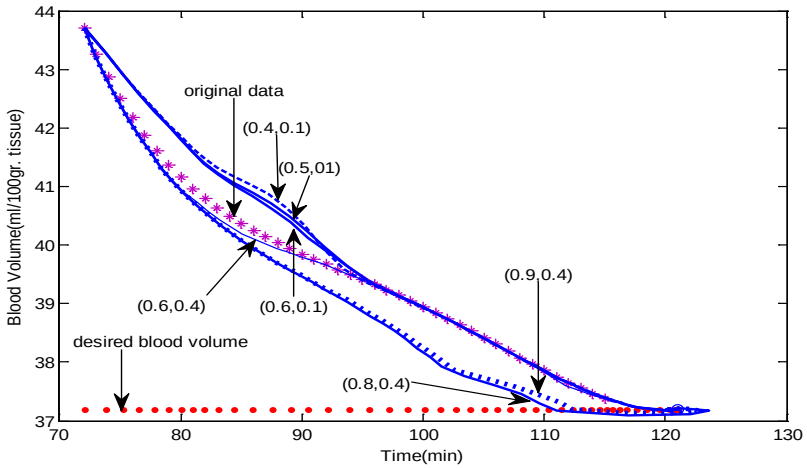

Figure 5. The final performances of ANFIS based BV control system for various cluster radiuses

Table 4. The errors for various radiuses if u(1) =72 and x(1) =43.7070 , thus initial values are provided in ANFIS based BV control system

forward radius	inverse radius	RMSE error for *x(k)*	RMSE error for *u(k)*
0.4000	0.4000	0,1157109	1,447899
0.5000	0.4000	0,1094906	1,432051
0.6000	0.4000	0,1079894	1,446063
0.7000	0.4000	0,4267693	3,789549
0.8000	0.4000	0,4308488	3,804638
0.9000	0.4000	0,3833604	3,271413
0.4000	0.1000	0,5929813	6,144506
0.5000	0.1000	0,5904976	6,261231
0.6000	0.1000	0,5940873	6,324248
0.7000	0.1000	2,9635394	6,532996
0.8000	0.1000	2,9436485	6,494353
0.9000	0.1000	2,5606431	6,256179

As seen from Figure 5 and Table 4, the best results were achieved when forward model's radius is 0.4-0.5-0.6 while the inverse model's radius was 0.4. The ANFIS based BV control system is stable when inverse model's radiuses are 0.1 or 0.4; thus, going out of these ranges gives an unpredictable results.

The summary of stability conditions are:

$0.4 \leq$ forward cluster radius ≤ 0.6

Inverse cluster radius = 0.1, 0.4

37ml/100g tissue < x initial blood volume < 49ml/100g tissue

x initial blood volume > xd desired blood volume > 37ml/100g tissue

One of the best outputs that yield the forward model's radius of 0.5 and the inverse model's radius of 0.4 is given in Figure 6. As it is clear from Figure 6, the control system provides all the desired values at its output.

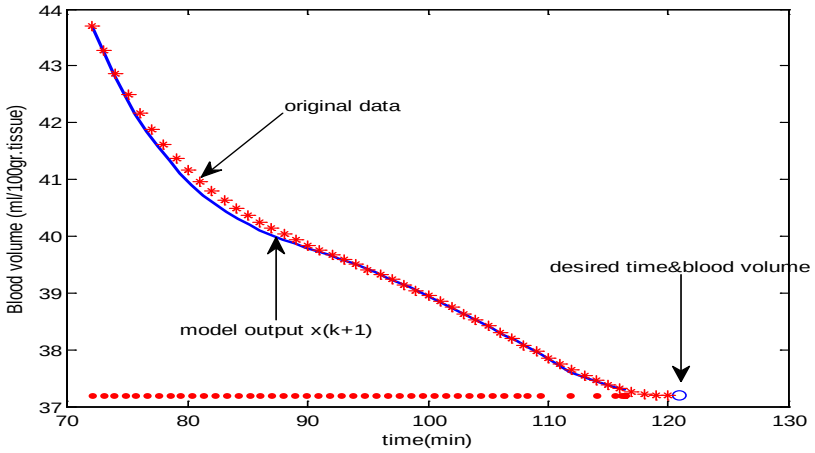

Figure 6. Output of the ANFIS based BV control system (forward radius=0.5 and inverse radius=0.4)

Conclusion

In this study, ANFIS based modeling was implemented in order to make the system models relates with the hormonal effects of GLP-2 on the BV variable of rats.

In order to control the BV variable of rat, the ANFIS inverse model as a GLP-2 controller was used. Simulation based analysis showed that the control process using the ANFIS based controller has sufficient performance.

Therefore, in conclusion, ANFIS based system modeling and controlling may have potential benefits on many physiological system studies like GLP-2 induced systems; thus, they can contribute to new challenges in decision making and control researches.

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