3D SIMULATION OF PLANT GROWTH MODELING USING NEURO-FUZZY, LINDENMAYER SYSTEM, AND TURTLE GEOMETRY

[1]WIWIET HERULAMBANG, [2]RETANTYO WARDOYO

[1]Program Studi S2 Ilmu Komputer, FMIPA UGM, Yogyakarta

[2]Jurusan Ilmu Komputer dan Elektronika, FMIPA UGM, Yogyakarta

e-mail: [1]herulambang@ubhara.ac.id, [2]rw@ugm.ac.id

ABSTRACT

Applications that are able to predict plants growth patterns as a function of the nutrients obtained from fertilization pattern, is very useful in agriculture. The purpose of this study was to design and build a system of plants growth simulation models with Neuro-fuzzy method, then visualized by methods Lindenmayer system represented by three-dimensional use of Turtle Geometry. As the object of research is Soybean (Glycine max (L.) Merrill). Modeling parameters is long growth trunk / branches (L), a wide cross section of the leaf (W), and branch growth (B), as a function of changes in the fertilizing elements Nitrogen (N), Phosphate (P) and potassium (K). Modeling done on the vegetative phase of the soybean crop.

First step is the modeling output L-W-B as a function of changes in the values of NPK using neurofuzzy (ANFIS). The final step is to combine plant growth pattern parameters (L-W-B) and L-system strings into the visualization process plant structure using Turtle Geometry.

The test results on the system to grow plants pattern proves that ANFIS method is quite adaptive to variation of NPK value changes, and able to predict the output value L, W, and B. The final result of string-set of L-system and also it's visualization by Turtle Geometry, has proven to be influenced by variations in the composition of NPK values. Overall, the system has been running as expected.

Keywords: *plant growth simulation, neurofuzzy, Lindenmayer system, Turtle Geometry*.

1. INTRODUCTION

The modeling of plant growth patterns is combination of multidisciplinary scientific include: botany, agronomy, plant physiology, meteorology, soil science, and mathematics and computer science and has been used widely in agriculture, including to support the decision-making system [1]. Plant growth is categorized in two phases, namely vegetative phase (which includes the growth of roots, stems / branches, and leaves), and generative phase (characterized by the growth of flowers and fruit) [2]. The research of the characteristics of plant growth models are dynamic and very complex, so it is very difficult to approach using mathematical equations and conventional geometric [3]. The modeling of plant growth includes the natural process of biological systems of plant life, following the influence of environmental characteristics. For that purpose, artificial intelligence system approach, such as neuro-fuzzy method, is used. According to [4], neuro-fuzzy system is the mechanism of fuzzy inference system mapped into the architecture of artificial neural network. In the field of graphical computing, mathematical formulation of the plant growth structure that is widely applied is Lindenmayer system (L-system). The result of L-system is a string in L-system's grammar. To display in 3-D graphically, the L-system result needs to be translated into the formation of 3-D coordinates using Turtle Geometry [5] [6]. With displayed in 3-D, the representation of the plant growth model as the function of environmental factors is expected to be more easily understood [13].

2. RESEARCH METHODS

The research began by identifying the parameters that influence plant growth, both internal and external, as the input and output of the system [7]. It can be concluded that the parameters such as nutrients, water, oxygen, and sunlight generally affect the growth of the trunk and branches and increment of leaves number [13].

2.1 System Architecture

The architecture of plant growth simulation system that was built in this research is shown in Fig. 1, which describes the usage steps of plant growth simulation system using neuro-fuzzy, Lindenmayer system, and Turtle Geometry. The flowchart of the system is shown in Fig. 2.

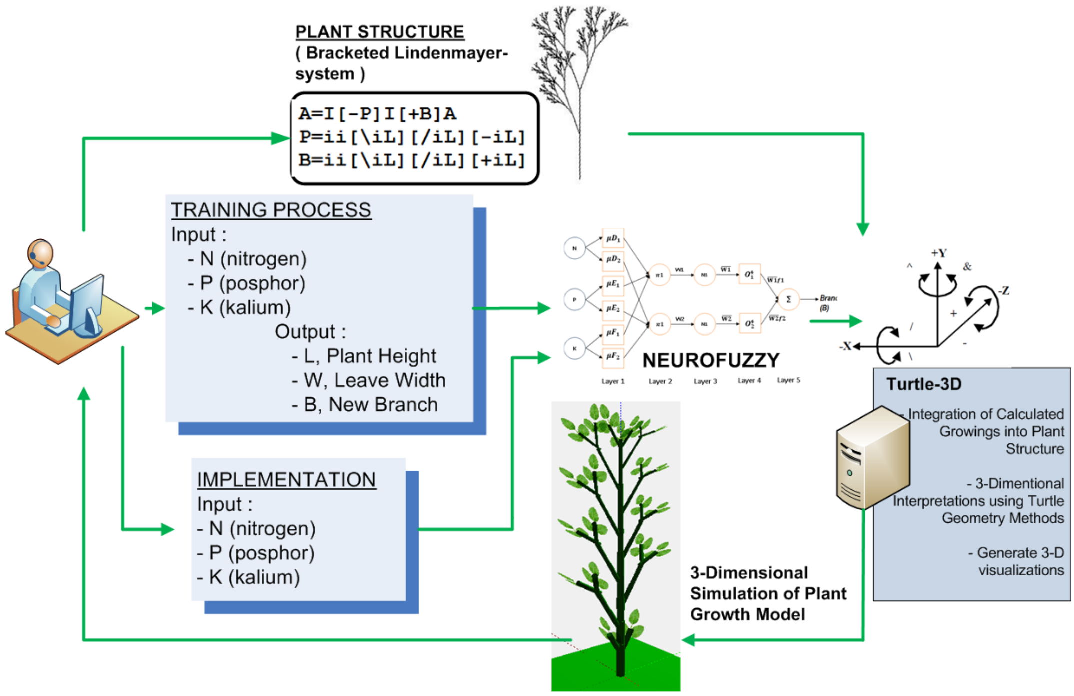

Figure 1. The architecture of plant growth simulation system

2.2 Lindemayer System Model (L-system)

2.2.1 Bracketed L-system with Turtle Geometry Representation

The L-system design in this research is based on the Bracketed L-system method that represented visually in 3-D using Turtle Geometry. As explained in [5] and [8], to display the 3-D visualization of L-system string, the Turtle Geometry method has two steps, which are:

1) Interpret the Bracketed L-system string by adding direction symbols which corresponds to Turtle Geometry method.
2) Using the matrix formula of Turtle Geometry to calculate the 3-D coordinates of the points in displaying the plant visually, such as the direction and position of the trunk, branch, twigs, and leaves.

In the first step, several direction symbols, such as shown in Table 1 and Figure 3, is added on the L-system string. Then in the second step, the main concept is to represent the orientation of the current position in a space with three vectors which shown the direction on X, Y, and Z axis. Those three vectors are orthogonal unit vectors. The rotation of the turtle, which represents the plant growth, is expressed by (1) – (3). Using (1) – (3), the coordinates of the next positon of each iteration in interpretation result of Bracketed L-system string of plant structure can be calculated [13].

Table 1. Rules of Turtle Geometry

$$R_X(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & Cos(\theta) & -Sin(\theta) \\ 0 & Sin(\theta) & Cos(\theta) \end{bmatrix} \quad (1)$$

$$R_Y(\Theta) = \begin{bmatrix} Cos(\Theta) & 0 & -Sin(\Theta) \\ 0 & 1 & 0 \\ Sin(\Theta) & 0 & Cos(\Theta) \end{bmatrix} \quad (2)$$

$$R_z(\theta) = \begin{bmatrix} Cos(\theta) & Sin(\theta) & 0 \\ -Sin(\theta) & Cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (3)$$

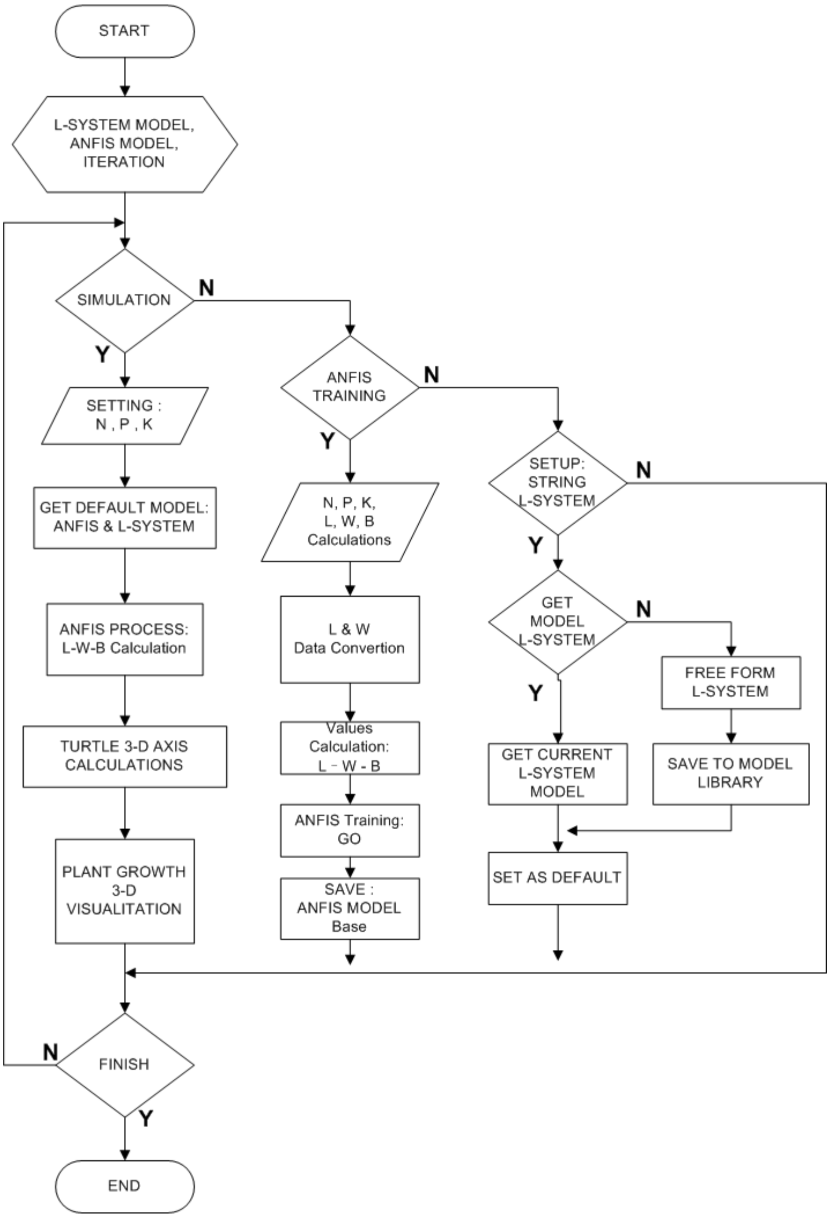

Figure 2. The flowchart of plant growth simulation system

2.2.2 Standard Model of L-system for Soybean Plant

Based on [8], the Bracketed L-system rules with Turtle Geometry representation when applied to the plant modeling simulation has a frame of reference as follows:

{
Axiom
Production Rules
End Rule
}

where Axiom is the determinant of growth starting point at each iteration starts, Production Rules are strings production which will produce the effect of plant growth simulation, and End Rule is the string to end the re-writing process. As the standard model in this research, some models of Production Rules that has been produced by earlier researchers are used, as shown in Figure 4 where :

A = apex, the tip of the plant in an iteration,
P = re-writing rule for internode (I) that leads to the left, and
B = re-writing rule for internode (I) that leads to the right.

Symbol	Meaning
I	Add internode (trunk segments)
i	Add short-internode (branch segments)
L	Add leaf
[	Change position to create new branch
]	Back to the position before creating new branch
+	Turn left according to X axis with angle α using rotation matrix $R_H(\alpha_X)$
-	Turn right according to X axis with angle α using rotation matrix $R_H(-\alpha_X)$
&	Pitch down according to Z axis with angle α using rotation matrix $R_U(\alpha_Z)$
^	Pitch up according to Z axis with angle α using rotation matrix $R_U(-\alpha_Z)$
\	Roll left according to Y axis with angle α using rotation matrix $R_L(\alpha_Z)$
/	Roll right according to Y axis with angle α using rotation matrix $R_L(-\alpha_Z)$

Figure 3. THE LIST OF BRACKETED L-SYSTEM WITH TURTLE GEOMETRY REPRESENTATION

No.	Reference Model	Standard Model of L-system for Soybean Plant
1.	Model [8]	*somporn1* *{* *Axiom=I[+iL][-iL]A* *A = I[-P]I[+B]A* *P = IIII[\pL][/pL][-pL]* *B = IIII[\pL][/pL][+pL]* *Endrule* *B = IL* *P = IL* *A = IL* *}*
2.	Model [9]	*Hongminsun* *{* *Axiom=I[+iL][-iL]A* *A = I[+P]A* *Endrule* *P = P[\iL][/iL][-iL]* *}*
3.	Model [3]	*Malika* *{* *Axiom=I[+iL][-iL]A* *A = I[-P]I[+B]A* *P = I[\pL][/pL][-pL]* *B = I[\pL][/pL][+pL]* *Endrule* *B = IL* *P = IL* *A = IL* *}*
4.	Model [10]	*Manabe* *{* *Axiom=F* *F = FF-[[-F][+F][+F]]+[[+F][-F][-F]]* *Endrule* *F = I* *}*

Figure 4. Standard model of L-system for Soybean plant

2.2.3 Free-form Model of L-system for Soybean Plant

In this free-form mode, L-system models have a common frame of reference with the standard model. The difference is based on the free-grammar context which is the characteristics of the Bracketed L-system that provides the flexibility of defining strings Production Rules, then the Production Rules string may use any letter symbols freely. Which means, the user can define the L-system strings specifically to their own needs. The free-form options are provided to assist the research process and further development of this research.

2.3 Neuro-Fuzzy (ANFIS) Model

2.3.1 Plant Growth Prediction Using Neuro-Fuzzy

The system is designed to be capable of providing predictions of the growth rate of soybean plants as a function of the N-P-K nutrients composition applied in plants. Function was created as predictor by utilizing the advantages of neuro-fuzzy method (ANFIS). Some advantages of method neuro-fuzzy method (ANFIS) are as follows:

- Able to generate and associate,
- Able to tolerate uncertainty,
- Able to resolve the issue of non-linearity, and
- Can be operated in real-time

Those advantages are utilized in this system to build a pattern model of correlation between the changes of input value N-P-K with the changes of output value L-W-B. Through the simulator system designed in this research, by varying the composition of the input value N-P-K, the changes in the growth amount of soybean plants produced by the simulator can be predicted.

2.3.2 Neuro-Fuzzy Architecture

To perform the modeling of soybean growth patterns, it takes ANFIS structure that can accommodate the needs of the growth parameters which are:

- 3 inputs (for fertilizer N, P, K), and
- 3 output (for L, W, and B)

Fundamentally, the ANFIS structure is only possible for one output. Then to accommodate the system which has 3 outputs, three identically structured ANFIS are used, each for output L (growth of trunk / branches / twigs), output W (growth of leaves width), and output B (growth of the branching) as shown in Fig. 3. The number of nodes in the first layer (membership function) can be varied, but to simplify the system, in this research we used the same number of nodes in the first layer.

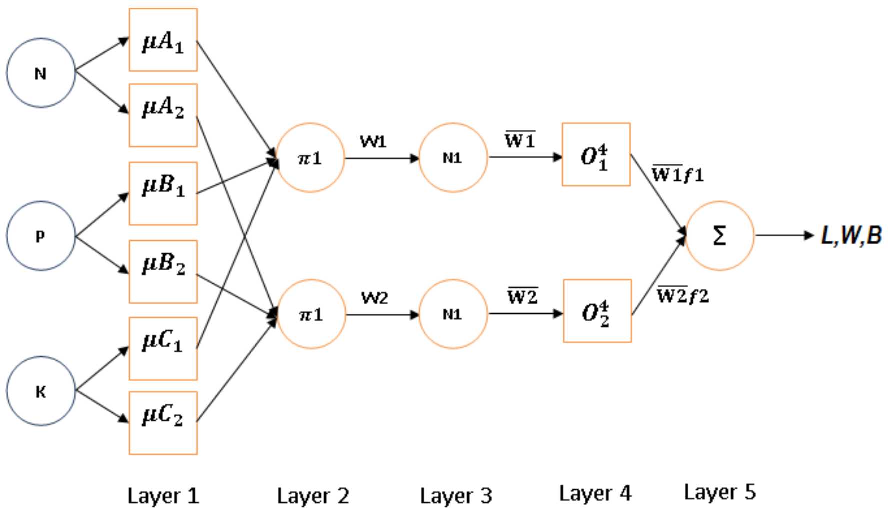

Figure 5. The ANFIS architecture for soybean growth simulation

2.3.3 Neuro-Fuzzy Algorithm

To obtain the model of soybean growth patterns, the data that has been inputted into ANFIS structure will be processed using the training process of ANFIS. In ANFIS training process, determination of the parameters to stop the training process is required. The parameters are:

- Error system < 0.01
- Epoch variable, with default value is 500.

The training process will stop if the epoch has reached the stopping value, although the error value of the system has not reached the stopping value yet. If that happens, then the re-training process is needed with increasing the epoch value until the error value reached the stopping value that has been determined (less than 0.01).

2.4 The Merging of L-System Model with Neuro-Fuzzy Model

Once the L-system string of the plant structure had been obtained, we calculate the coordinates of trunk, branches, twigs, and leaves position. This require the calculation of the final coordinates (x2, y2, z2) of an object based on:

- The coordinates of start position (x1, y1, z1),
- The length or distance to the end position (l), and
- The directions (α degrees) towards the end position.

In 3-D L-system modeling using GL Scene, coordinates of trunk and branch segments are calculated at their segment's midpoint. To determine the L-system coordinates of the trunk and branch, calculation using Turtle Geometry is used.

3. RESULTS AND DISCUSSION

Data used in the experiment is secondary data, which means that the data has been obtained by the previous researches of soybean plant, among others was obtained from [8], [11], and [12]. The experimental results of the ANFIS system are shown in Table 3. The experimental results in Table 2 shows that the average error of the system decreases with the increasing number of the membership function (MF). A decrease in the average error value of a system means the increase of ANFIS system performance.

The example of experimental result of the system in 3-D animation which are dynamic and adaptive to the changes of N-P-K input are shown in Fig. 6. All the simulations result in Fig.6 was performed in 3 iterations and has a same L-system string as follows:

```
{
Axiom : I[+iL][-iL]A  ;
Rule : A=I[-P]I[+B]A ;
  P=ii[\iL][-iL] ;
  B=ii[/iL][+iL] ;
End Rule : A=I[L][+iL][-iL] ;
 P=I[+iL][-iL] ;
 B=I[+iL][-iL]
}.
```

Table 2. Experimental Results

MF	TEST DATA			RESULTS OF DATA			THE RESULTS			DIFFERENCE			ERROR (%)		
	N	P	K	L	W	B	L	W	B	L	W	B	L	W	B
MF=3	Tabel 6.2 (b)														
	5	5	5	0.2	0.2	0.2	0.19	0.16	0.18	0.01	0.04	0.02	5	20	10
	25	25	25	1.6	0.8	0.6	1.5	0.76	0.7	0.1	0.04	0.1	6.25	5	16.67
	40	40	40	3.2	1.4	1	3	1.38	0.92	0.2	0.02	0.08	6.25	1.42	8
	Tabel 6.3 (b)														
	0	40	40	3.1	1.6	0.6	2.65	1.46	0.42	0.45	0.14	0.18	14	8	30
	50	25	25	1.4	0.5	0.6	1.43	0.7	0.72	0.03	0.2	0.12	2	40	20
	50	50	50	4	1.9	1	3.6	1.82	0.88	0.4	0.08	0.12	10	4	12
	Tabel 6.4 (b)														
	25	25	25	2.6	1.05	0.6	1.6	0.65	0.41	1	0.4	0.19	38	38	31.67
	50	50	0	2.98	1.18	0.6	1.96	1.4	0.47	1	0.25	0.13	33	21	21.67
	25	50	0	4.85	1.85	1	4.55	1.25	0.81	0.3	0.5	0.19	6	28	19
	The average error												13.39	18.38	18.78
MF=4	Tabel 6.2 (b)														
	5	5	5	0.2	0.2	0.2	0.17	0.22	0.22	0.03	0.02	0.02	15	10	10
	25	25	25	1.6	0.8	0.6	1.58	0.86	0.65	0.02	0.06	0.05	1.25	7.5	8.333
	40	40	40	3.2	1.4	1	2.9	1.36	0.88	0.03	0.04	0.12	0.95	2.85	12
	Tabel 6.3 (b)														
	0	40	40	3.1	1.6	0.6	3.23	1.61	0.62	0.13	0.01	0.02	4	0.6	3.333
	50	25	25	1.4	0.5	0.6	0.9	0.4	0.68	0.5	0.1	0.08	35	20	13.33
	50	50	50	4	1.9	1	4.75	2.25	0.9	0.75	0.35	0.1	18	18	10
	Tabel 6.4 (b)														
	25	25	25	2.6	1.05	0.6	2.4	1.14	0.45	0.2	0.09	0.15	7.7	8.6	25
	50	50	0	2.98	1.18	0.6	2.7	1.07	0.51	0.2	0.1	0.09	6.7	8.5	15
	25	50	0	4.85	1.85	1	4.5	1.9	0.89	0.25	0.15	0.11	5.15	8.6	11
	The average error												10.42	9.406	12
MF=5	Tabel 6.2 (b)														
	5	5	5	0.2	0.2	0.2	0.14	0.25	0.18	0.06	0.05	0.02	30	25	10
	25	25	25	1.6	0.8	0.6	1.43	0.71	0.55	0.17	0.09	0.05	10	11	8.333
	40	40	40	3.2	1.4	1	3.4	1.28	0.96	0.2	0.12	0.04	6.25	8.5	4
	Tabel 6.3 (b)														
	0	40	40	3.1	1.6	0.6	2.9	1.55	0.68	0.2	0.05	0.08	6	3	13.33
	50	25	25	1.4	0.5	0.6	1.44	0.48	0.52	0.04	0.02	0.08	2.8	4	13.33
	50	50	50	4	1.9	1	4.05	2	0.93	0.05	0.1	0.07	1.25	5	7
	Tabel 6.4 (b)														
	25	25	25	2.6	1.05	0.6	2.52	1	0.52	0.08	0.05	0.08	3	4.75	13.33
	50	50	0	2.98	1.18	0.6	2.8	1.2	0.51	0.18	0.03	0.09	6	2.1	15
	25	50	0	4.85	1.85	1	4.8	1.82	0.89	0.05	0.07	0.11	1	4	11
	The average error												7.367	7.483	10.59

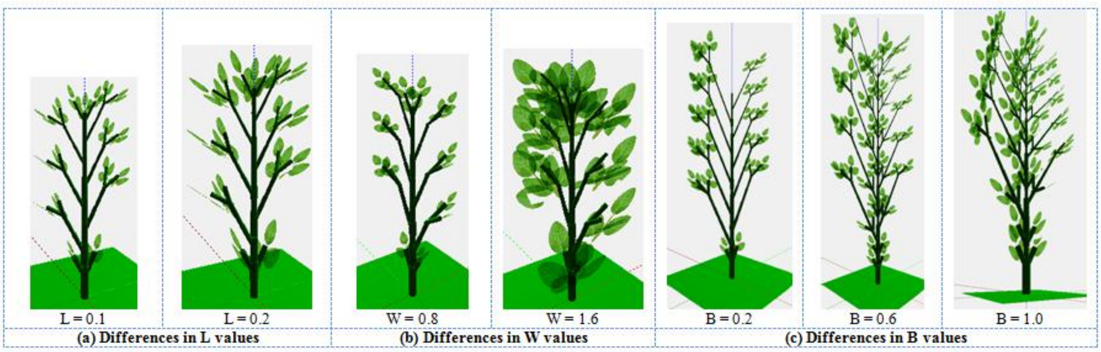

Figure 6. Simulation results with the difference in L-W-B values

4. CONCLUSION

In this research, a system that can help to model and visualize the growth of soybean plants based on the variation of the given NPK nutrition has been built. Neuro-fuzzy method (ANFIS) can be applied to calculate the input data which are the quantities of N-P-K nutrients and produce the output which are the growth of branch (L), growth of leaf's width (W), and the increase of branch number (B). The final result of L-system string with its visualization has proven to be influenced by the changes in N-P-K values composition. The visualization method with Turtle Geometry has proved able to interpret L-system string into 3-D visualization and adaptively accommodate the differences in N-P-K quantity patterns based on the input-output data in the ANFIS training process.

Based on the experimental results, the increment in number of membership function has correlation with the average error value of the system, as well as the ANFIS training time. The average error value is decreased when the number of membership value is increased, so in this research the minimal average value of this system is reached when the number of membership function is 5. The minimal error values for the L, W, and B are 7.4%, 7.5%, and 10.6% respectively.

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