A Comparative Study of ANN and FES for Predicting of Cutting Forces and Tool Tip Temperature in Turning

Ilker Ali OZKAN, Ismail SARITAS, Suleyman YALDIZ

Abstract: *In this study, fuzzy expert system (FES) and artificial neural network (ANN) models are designed for the estimation of cutting forces in turning operations. On designed models, cutting forces and experimental temperature data obtained from different cutting conditions were used in process of turning. Cutting forces at different cutting conditions and temperature values can be estimated with the help of developed models. The results obtained with these models, compared with the experimental data. The regression values were found as 0.99505 between the Experiment-FES and, 0.9888 between Experiment-ANN in the analysis. As a result, the both artificial intelligence (AI) methods have made successful modeling, but it's seen that, realized BUS model has more successful results than the ANN model in the process of estimation of cutting forces.*

Key words: *Fuzzy Expert System, Artificial Neural Network, Cutting Force, Turning, Estimation Model*

INTRODUCTION

The cutting forces occur on pen and lathe during the metal removal process, depend on the pen geometry and cutting conditions. Knowing of cutting forces during turning is made itself important therefore, the machine design, pen geometry that will extend the life of the pen and selection of cutting parameters [1]. Modeling of cutting force is one of the involved areas of metal cutting theory. That's because there is a large number of parameters associated with each other that affects cutting forces makes it difficult to develop a model in this area. To eliminate these difficulties or in order to minimize them, there is modeling available such as artificial network, fuzzy expert systems, fuzzy neural network that uses artificial intelligence branches [2-7]. In this study, two different artificial intelligence models are designed with the use of fuzzy expert system and artificial neural network.

Fuzzy Expert System

Fuzzy Logic (FL) is a mathematical discipline that we use everyday and enables us to reach our structure to interpret our behavior. Fuzzy Sets Theory (FST) creates the basis of the values "true" or "wrong" and among them "party true" or "partly wrong" values.

FST is a theory that intended to express the uncertainties such as "less cold" or "quiet cold" which is between the certain expressions like "hot" and "cold" as mathematical. There is a unclear numeric value behind these linguistic values [8-14].

In general, fuzzy expert systems (FES) are knowledge-based or rule-based systems. So, on the basis of a fuzzy expert system there are "If-Then" rules. [11.14].
After it's decided to design a fuzzy system, the first thing to do is to achieve the rules "if-then". These rules are collected by benefiting from an expert often [9.10].

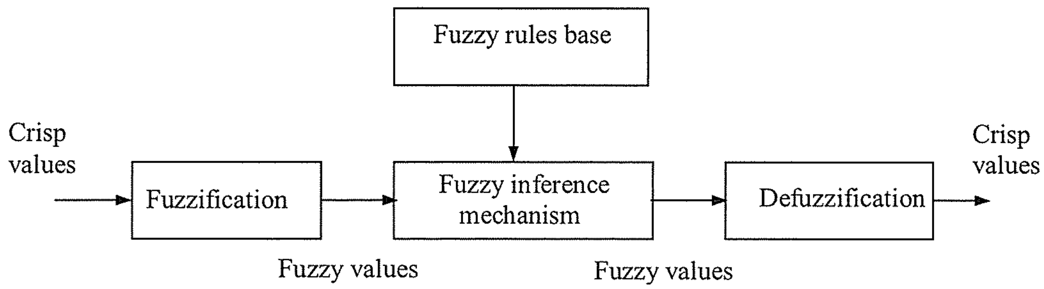


Figure 1. Structure of Fuzzy Expert System [9]

The system input and output values are the exact values in a fuzzy expert system (FES) model as shown in Figure 1. Membership degrees and values obtained by exact values of entry enabling fuzzy. Obtained fuzzy values are done to Fuzzy Inference Mechanism. Fuzzy output values obtained by using rules base are sent to defuzzification mechanism. Exact values obtained as output from the defuzzification mechanism [10].

Artificial Neural Networks (ANN)

Artificial Neural Networks are computer systems that developed to realize the capabilities automatically without getting any help such as “learning new information derived via, to create new knowledge and discovery” which are the some characteristics of human brain.

In general, it is consist of three layers as “an input layer, one or more hidden layers and an output layer”. Each layer has a certain number of elements connected to each other called “neurons” or “nodes”. Each of the neurons is connected to another through communication links associated with connection weights. Signals pass through the connection weights through the neurons. Each neuron receives multiple inputs from other neurons at a rate of connection weight and perhaps it produces an output signal that can also be producing by other neurons [15-20].

The network training process is stopped when the testing error reaches the desired tolerance value [19.21].

Backpropagation (BP) algorithm is the most popular algorithm that used in a wide area. BP is consisting of two phases impending feed forward process and backward propagation process. During the feed forward, the information processing from the input layer to the output layer is generated. In case of backward propagation, the difference between the network output value obtained from the feed forward process and desired output value is compared with the desired difference tolerance and the error in the output layer is calculated. This obtained error log spreads backward to update the links at input layer [19, 22].

BP training algorithm is a ramp descent algorithm. BP algorithm, works to improve the network performance by downsizes the total error through the ramp by changing the weights. Tested Mean Squared Error (MSE) values decline stopped as a sign of excessive increase in training time of initiation training is stopped. [19.22].

$$MSE\% = \frac{1}{n}\sum_{i=1}^{n}(d_i - O_i)^2 \qquad (1)$$

In here, “d_i” is intended or actual value, “O_i” is network output or estimated value, “n” is the number of output data [18].

MATERIAL AND METHODS

In this study; corresponding to the approach angle, cutting speed and rake angle; tangential cutting force, feed force, radial force and temperature output data were taken from literature [2]. The lowest and the highest values of input and output variables are given in Table 1.

Table 1. Input and output variables

Variable	Minimum	Mean	Maximum
Approach angle χ (°)	45	67.5	90
Cutting speed v (m/min)	75	146	236
Rake angle γ (°)	0	9.5	20
Tangential cutting force $F_{c\text{-}m}$ (N)	302	401	520
Feed force F_f (N)	60	160	379
Radial force F_t (N)	24	98	372
Temperature t (°C)	322	400	495

MATLAB Fuzzy Toolbox

and Neural Network Toolbox were used for making analysis and developing FES and ANN models.

Fuzzy Expert System Model

In this study; a multi-in/multi-out fuzzy expert system calculating rake angle in turning (γ), approach angle (χ), tangential cutting force (F_{c-m}) according to the inputs of cutting speed (v), radial force (F_t), feed force (F_f) and temperature (T) is designed (Figure 2) [2].

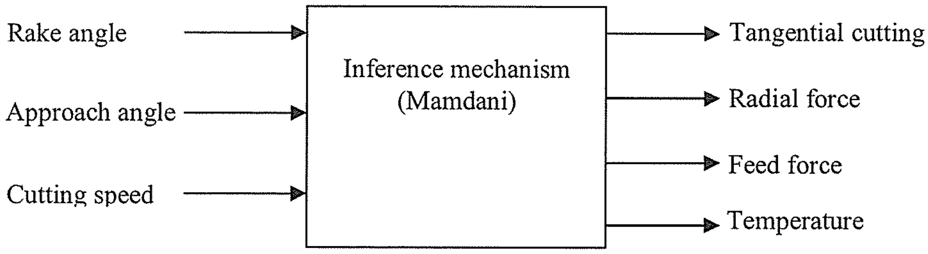


Figure 2. General Scheme of developed Fuzzy Expert System [2]

Rake angle, approach angle and cutting speed input variables are respectively γ={0,6,12,20}, χ={45,60,75,90} and v={75,113,160,236} and due to it's composed of four values the input parameters divided to four linguistic expression.

Because difference between the limit values with output variables of tangential cutting force [302-520 N], radial force [24-372 N], feed force [60-379 N], temperature [322-495 °C] and also because it's unable to separate the input parameters to enough linguistic expressions; tangential cutting force, feed force and temperature is separated to thirteen linguistic expressions and, due to difference between the radial force with limit values is much more high, it is separated to nineteen different linguistic expressions in order to reach a more accurate result.

These linguistic expressions designated as; Negative Medium (NM), Positive Medium (PM), very very very low (VVVL), very very low (VVL), very low (VL), Low (L), very low medium (VLM), low medium (LM) , Medium (M), high medium (HM), very high medium (VHM), High (H), very high (VH), very very high (VVH), very very very high (VVVH).

Linguistic expressions of rake angle (γ) input variable is determined and functions are builded (Figure 3) [2].

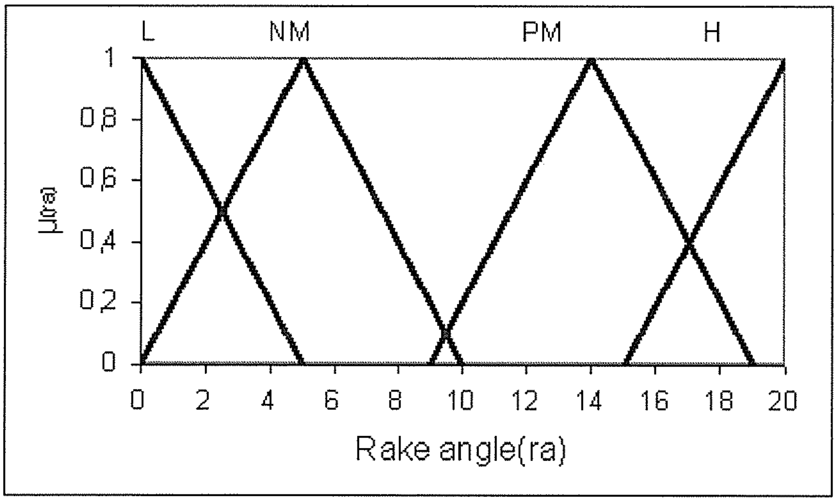


Figure 3. Membership functions of Rake angle

Other input and output variables' membership functions were created in a similar manner. The rules determined with the help of an expert for measured cutting forces in various cutting conditions in turning and for estimating of temperature are shown in Table 2.

Table 2. Created rules for developed FES [2]

Rule number	Rake angle		Approach angle		Speed		F_t		F_f		F_λ		T
Rule 1	L	and	L	and	L	Then	VVVL	and	VVVL	and	VL	and	VL
Rule 2	L	and	L	and	NM	Then	VH	and	HM	and	H	and	VLM
Rule 3	L	and	L	and	PM	Then	VH	and	LM	and	VHM	and	M
					...								
Rule 62	H	and	H	and	NM	Then	VL	and	L	and	L	and	VLM
Rule 63	H	and	H	and	PM	Then	VL	and	VL	and	VL	and	M
Rule 64	H	and	H	and	H	Then	VVL	and	VVL	and	VL	and	H

Mamdani is selected as Inference mechanism. Due to Mamdani max-min inference are applied, accuracy (α) for each rule are determined. Final outputs were obtained by using centroid defuzzification method due to the accuracy found in defuzzification process.

As an example for the values of rake angle value 0°, approach angle 90°, cutting speed 113 m/min; in response to the results of experiments F_t=474 N, F_f=341 N, F_λ=163 N, T= 344 °C, F_t=464 N, F_f=352 N, F_λ=155 N, T= 337 °C values is obtained in fuzzy expert system.

Received values as a result of FES with experimental data shown in Figure 4 in comparison.

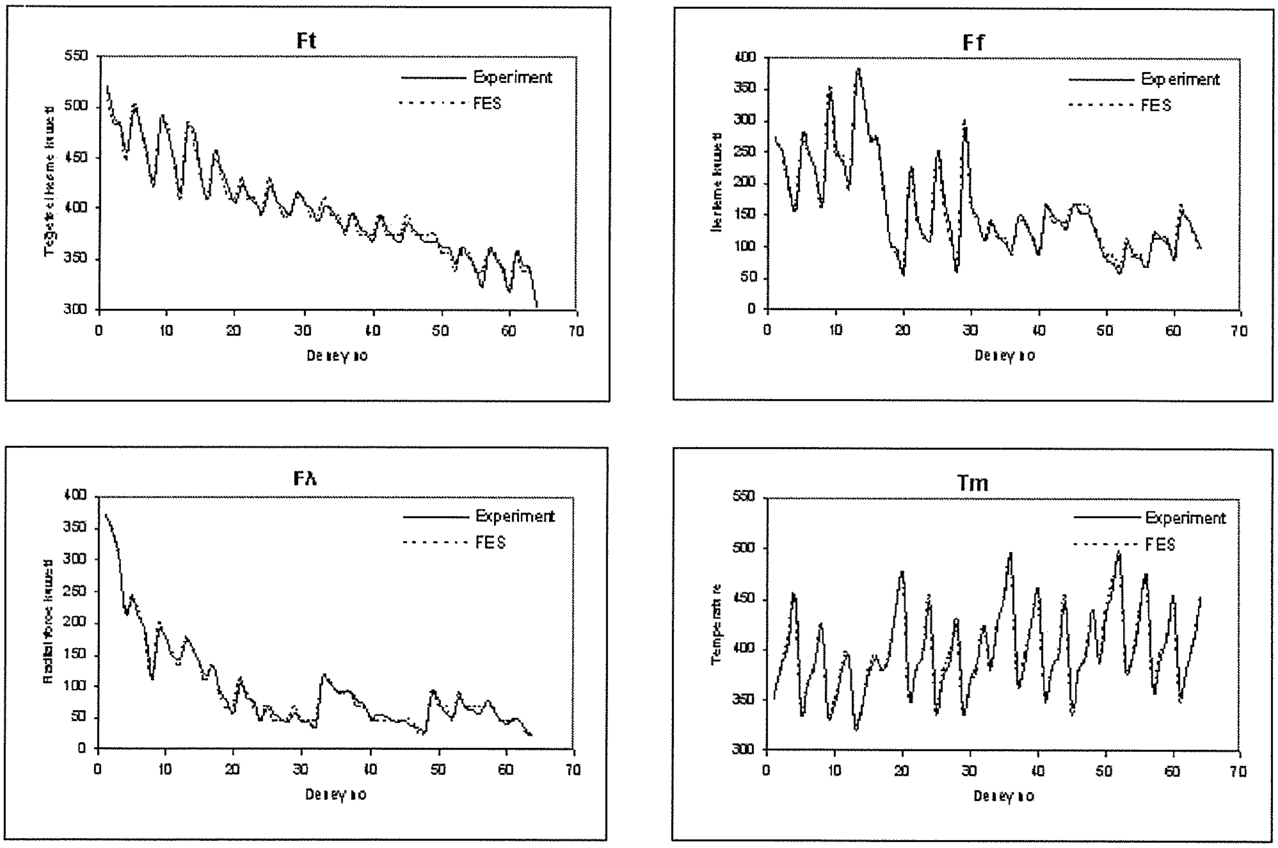


Figure 4. Graphical representation of data obtained by FES with experimental data.

Artificial Neural Network Model

Data is divided into two pieces as training and test data set. 49 randomly selected pieces of total of 64 pieces are used for ANN training and the remaining 15 pieces are used for the test of trained ANN. Feedforward network structure has been designed which is consist of One input layer (approach angle, rake angle, cutting speed), one hidden layer and one output layer (feed force, radial force, tangential cutting force, temperature) is shown in Figure 5 [2].

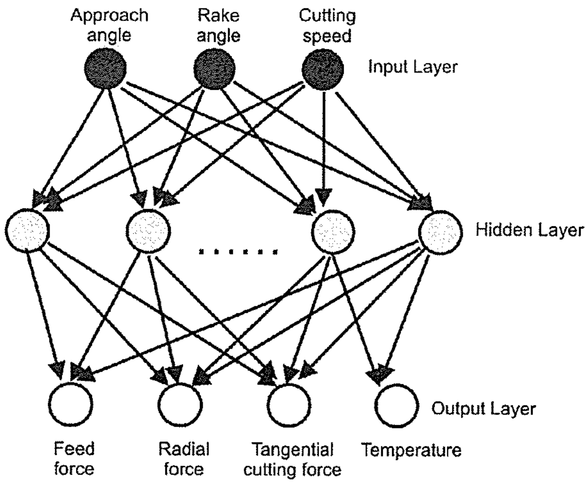


Figure 5. Designed ANN model

Different transfer functions (Purelin, Tansig, Logsig etc.) at hidden and output layers were tested by using back propagation (BP) algorithm in training process. As a result of the experiment as transfer function Hyperbolic Tangent Sigmoid (Tansig) is selected function that gives the most relevant results. Mathematical equation of hyperbolic tangent sigmoid transfer function is as in Equation 2.

$$f(x) = \frac{2}{1+e^{-2n}} - 1 \qquad (2)$$

Training data set was used for determining the bias values and the weights of developed ANN. The training was repeated by changing the number of neurons and iterations in hidden layer for getting the lowest error value in designed network. To determine the ANN structure that have the best Mean Squared Error (MSE), firstly each network structure trained by amending the number of neurons between 2 and 40 in hidden layer. MSE and Test regression values of trained networks are given in Figure 6.

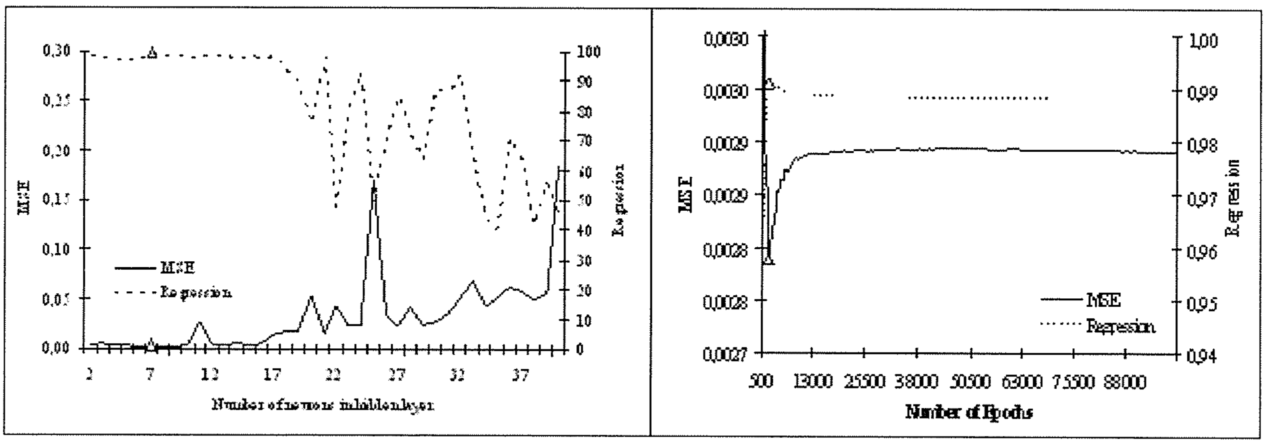


Figure 6. MSE and regression change due to the number of neurons and epochs.

As shown in Figure 6, ANN structure with 7 neurons on its hidden layer gave the best MSE performance and test regression value. Obtained network structure with 7 neurons on its hidden layer has been tested between 500 and 100,000 epoch by increasing 1,000 every time (Figure 6). As seen in Figure 6, the best test regression and MSE performance value is obtained at 2,000 epochs despite the best MSE performance is occur at 100,000 epochs.

Table 3. Network Parameters

Parameters	Property
Number of neurons in input layer	3
Number of hidden layers	1
Number of neurons in hidden layer	7
Number of neurons in output layer	4
Learning rate (α)	0.3
Training coefficient (β)	0.3
Learning algorithm	Gradient descent
Transfer function	Tansig

The best approach with minimum error was formed with 7 neuron backpropagation algorithm. F_j for NET_j obtained by using equation 3 depending on χ, γ and v.

$$NET_j = (W_1)_{i,1} * \gamma + (W_1)_{i,2} * \chi + (W_1)_{i,3} * v + (W_b)_{i,4} * b \tag{3}$$

F_j is calculated with Equation 4 by using equation 3 in transfer function.

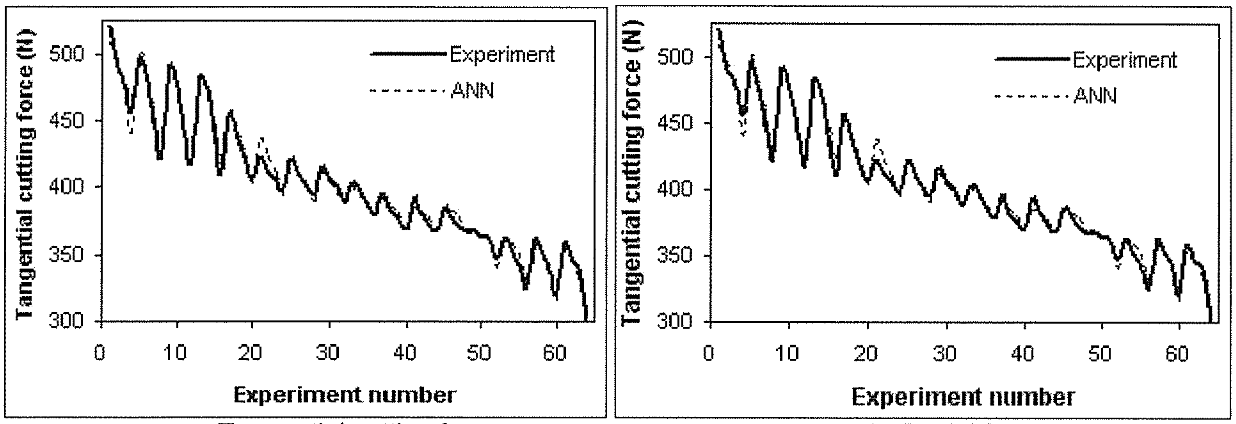
$$F_j = \frac{2}{1+e^{(-2*NETj)}} - 1 \tag{4}$$

Connection weight values of BP algorithm with 7 neurons in it's hidden layer which its are constants $(W_1)_{i,j}$ are give in Table 4. At the formula given in Equation 3, NET_j is equal with sum of the multiplication of input parameters and their weights. Subscript i and j are respectively input and hidden neuron numbers.

Table 4. Weight values for Equation 4

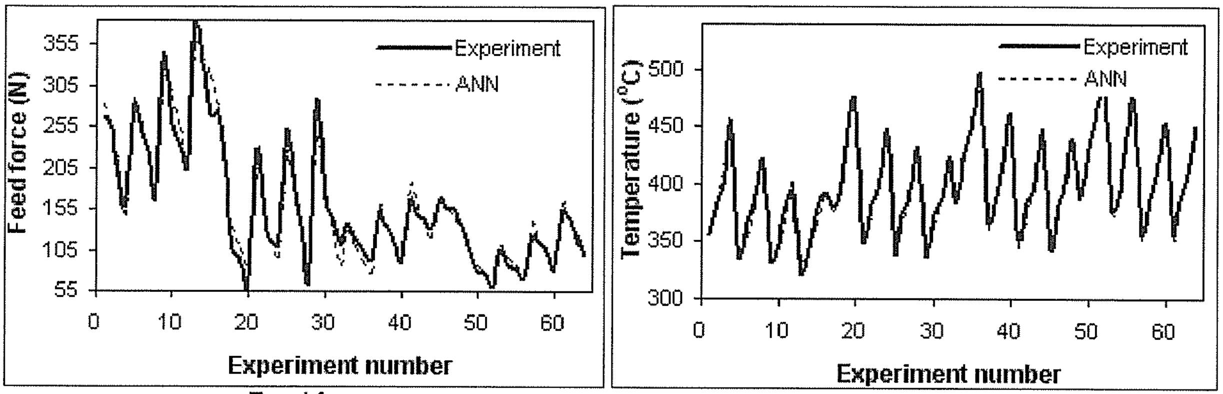
Number of neurons in hidden layer	$W_{1(i,j)}$ for χ	$W_{1(i,j)}$ for γ	$W_{1(i,j)}$ for v	$W_{1(i,j)}$ for b
1	0.1567	-0.3551	-0.3869	-0.6025
2	0.2885	-0.9239	-0.2960	-0.7215
3	-1.4248	-0.3206	-0.6160	2.9071
4	0.7117	-0.3290	0.0532	0.8432
5	-0.8739	-0.1885	-0.3311	-1.7160
6	-1.9515	0.5925	-0.1862	-1.1251
7	-3.3637	0.6346	-0.4345	-1.9063

Predictive values of $F_{c\text{-}m}$, F_f, F_t and T output parameters in ANN with all results obtained experimentally were compared as graphically (Figure 7).



a. Tangential cutting force

b. Radial force



c. Feed force
d. Temperature

Figure 7. Graphical representation of data obtained by ANN with experimental data

RESULTS AND DISCUSSION

Analysis have been made between the experimental data and FES data for Tangential cutting force, radial force, feed force and temperature parameters. According to these analysis regression values were obtained respectively 0.99258; 0.99626; 0.99673; 0.99461.Regression values between the all output data obtained in FES and all output data obtained as experimental was found as 0.995045. It is seen that designed FES can predict the cutting forces and temperature successfully in turning when the comparison of FES data, experimental data and regression values taken into consideration.

Analysis has been made between the ANN data and experimental data for tangential cutting force, radial force, and feed force and temperature parameters. According to these analysis regression values were obtained respectively 0.99364; 0.97764; 0.98465; 0.98545. Regression values between the all output parameters in ANN with All outputs obtained as experimental have been obtained as 0.98535. It is seen that ANN can predict the cutting forces and temperature successfully in turning when the comparison of experimental data, ANN data and regression values taken into consideration.

It is observed that FES is more successful than ANN in predicting of experimental data when ANN and FES designed for modeling the experimental data compared with each other. In addition, modeling of this experiment has also been provided by both artificial intelligence techniques which require cost and time. It is possible to learn the results corresponding to values of data which is not available in experimental data with this modeling.

More successful results can be obtained by using of artificial intelligence techniques as hybrid and increasing the experimental data used in ANN training and also increasing the number of linguistic expressions in future studies.

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