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Artificial Neural Network modeling for Surface Roughness and Cutting Force during Conventional Turning Process

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Abstract : *Surface roughness quality of a machine part ensures its performance and fatigue life. It depends on various factors such as cutting speed, feed rate, depth of cut, vibrations, tool wear, tool life, surface finish and cutting forces etc. Hence to improve the efficiency of process and quality of the product it is necessary to control the process parameters. In this study, a part factorial experimental design is analyzed using Artificial Neural Network in MATLAB software. A relation between cutting parameters and surface roughness is investigated through two back-propagation algorithms. The created ANN models are used to predict the surface roughness of the sample data using simulation application. And the results of both the models are compared. Neural network is one of the important components in Artificial Intelligence (AI).*

Keywords: *Artificial Neural Network (ANN), MATLAB, Back propagation algorithms, Surface Roughness.*

I. INTRODUCTION

Machine parts are significantly influenced by surface roughness quality. For efficient use of machine tools, optimum cutting parameters are required. The turning process parameter optimization is highly constrained and nonlinear. Many researchers have used an Artificial Neural Network (ANN) model for the data obtained through experiments to predict the surface roughness. ANN is found to be very useful with simulations tasks which have complex and explicit relation between control factors and result of process. It has been studied for many years in the hope of achieving human-like performance in many fields, such as speech and image recognition as well as information retrieval. Artificial Neural Network can be created using feed forward back propagation technique for simulation of the process. With assurance of accuracy of the predictive capabilities of the neural network; it may be then used for optimization.

A. Artificial Neural Network

Artificial neural networks are nonlinear information (signal) processing devices, which are built from interconnected elementary processing devices called neurons. An Artificial Neural Network has three components: network architecture, an activation function and training or learning rule.

i) Network Architecture: It is an arrangement of neurons into layers and the patterns of connection within and in-between layer. Some of their types are feed forward, fully interconnected net, competitive net, etc.

ii) Setting the weights (Training): It is the process of modifying the weights in the connections between network layers with the objective of achieving the expected output. There are three types of training: supervised, unsupervised and reinforcement training.

iii) Learning rule: It is the process by which the free parameters of a neural network get adapted through a process of stimulation by the environment in which the network is embedded. Some examples are: Hebb's learning rule, Perceptron learning rule, Delta learning rule etc.

iv) Activation rule: It is a local procedure that each node follows in updating its activation level in the context of input from neighboring nodes. Types of activation functions include: Threshold function, Piecewise-linear function, and Sigmoid function. The sigmoid function, whose graph is s-shaped graph, is by far the most common form of activation function used in the construction of neural networks.

There are different types of Neural Network: Perceptron Backpropagation networks, Associative memory neural networks, Radial basis function networks (RBFN), Adaline networks, and Probabilistic networks.

There are many applications of ANN such as in arts, bioinformatics, forecasting, health care, intrusion detection, communication, robotics, control, pattern recognition etc [19].

B. Neural Network Tool in MATLAB

MATLAB (matrix laboratory) is a multi-paradigm numerical computing environment and fourth-generation programming language. It is a high-level language and interactive environmentfor numerical computation, visualization, and programming. Using it, we can analyze data, develop algorithms, and create models and applications. Neural Network Toolbox provides functions and apps for modeling complex nonlinear systems that are not easily modeled with a closed-form equation. With the toolbox we can design, train, visualize, and simulate neural networks. We can use Neural Network Toolbox for applications such as data fitting, pattern recognition, clustering, time-series prediction, and dynamic system modeling and control. It supports a variety of training algorithms, including several gradient descent methods, conjugate gradient methods, the Levenberg-Marquardt algorithm (LM), and the resilient Backpropagation algorithm (Rprop). The toolbox's modular framework let us quickly develop custom training algorithms that can be integrated with built-in algorithms. While training neural network, we can use error weights to define the relative importance of desired outputs, which can be prioritized in terms of sample, time step (for time-series problems), output element, or any combination of these. We can access training algorithms from the command line or via apps that show diagrams of the network being trained and provide network performance plots and status information to help us monitor the training process.

C. Network design steps

There are standard steps for designing neural networks to solve problems in four application areas: function fitting, pattern recognition, clustering, and time series analysis. The work flow for any of these problems has seven primary steps. (Data collection in step 1, while important, generally occurs outside the MATLAB environment).

1. Collect data
2. Create the network
3. Configure the network
4. Initialize the weights and biases
5. Train the network
6. Validate the network
7. Use the network

Neural Network tool is one of the applications of MATLAB in which one can manage data and cancreate a Neural Network by using different algorithms. It is a data manager in which one can customize a network by choosing number of hidden layer, number of neurons and also training parameters can be changed during training of the network

Using the NN tool:

1. Import the input and target variables into the MATLAB workspace.
2. Open the NN tool and import the above chosen variables into this data manager.
3. Then click NEW to create a new network. Select network properties and layer properties according to use and create it.
4. Open the network and select training parameters.
5. Train the network and plot regression graph. After several attempts, when the desired graph appears, stop the training.
6. Simulation can be performed by providing a sample to the network and getting the predicted values.
7. Export all the variables to the MATLAB workspace and close the NN tool.

II. LITERATURE REVIEW

Ranganath M. S. et al, "Experimental Investigation of Surface Roughness and Cutting Force on Conventional Dry Turning of Aluminium (6061) " June 2015 [17], has scrutinized the effect of the cutting speed, feed rate and depth of cut on surface roughness, in turning of Aluminium (6061). Design of experiments (DOE) were conducted for the analysis of the influence of the turning parameters on the surface roughness by using Taguchi design and then followed by optimization of the results using Analysis of Variance (ANOVA) to find minimum surface roughness. The study concluded that the optimum surface roughness was reached when the feed rate and depth of cut were set as low as possible.

Durmus Karayel, "Prediction and control of surface roughness in CNC lathe using artificial neural network" (2009) [7],has used neural network approach for the prediction and control of surface roughness in a computer numerically controlled (CNC) lathe. A feed forward multi-layered neural network was developed and the network model was trained using the scaled conjugate gradient algorithm (SCGA), which is a type of back-propagation. The adaptive learning rate was used. He concluded that the appropriate cutting parameters can be determined for a desired value of surface roughness.

Diwakar Reddy V. et al, "ANN Based prediction of Surface Roughness in Turning", December 2011[6] have carried out machining process on Mild steel material in dry cutting condition in a lathe machine and surface roughness was measured using Surface Roughness Tester. To predict the surface roughness, an artificial neural network (ANN) model was designed through back propagation network for the data obtained. Comparison of the experimental data and ANN results showed that there is no significant difference and ANN was used confidently.

Ranganath M S ,et al [15] "Optimization of Surface Roughness and Material Removal Rate on Conventional Dry Turning of Aluminium (6061)" In this paper Taguchi's (DOE) approach is used to analyze the effect of process on Surface Roughness of Aluminium 6061 work material. The first objective was to demonstrate by the use of Taguchi parameter design in order to identify the optimum surface roughness with particular combination of cutting parameters and a systematic procedure using Taguchi design in process design of turning operations. The second was to determine the optimum combination of process parameters more accurately by investigating the relative importance of process parameters using ANOVA. The obtained results are analyzed using Minitab software. The optimal combination process parameters for minimum surface roughness are obtained at 710 rpm, 0.2 mm/rev and 0.2mm. Also find that Speed is the most critical parameter when finish is the criterion.

TugrulOzel et al, [22] studied the effects of tool corner design on the surface finish and productivity in turning of steel parts. Surface finishing has been investigated in finish turning of AISI 1045 steel using conventional and wiper (multi-radii) design inserts. Multiple linear regression models and neural network models have been developed for predicting surface roughness, mean force and cutting Power. The Levenberg-Marquardt method was used together with Bayesian regularization in training neural networks in order to obtain neural networks with good generalization capability. Neural network based predictions of surface roughness were carried out and compared with a non-training experimental data. These results showed that neural network models are suitable to predict surface roughness patterns for a range of cutting conditions in turning with conventional and wiper inserts.

IlhanAsiltürk a, Mehmet Çunkas [8] used Artificial neural networks (ANN) and multiple regression approaches to model the surface roughness of AISI 1040 steel. Full factorial experimental design is implemented to investigate the effect of the cutting parameters (i.e. cutting speed, feed rate, and depth of cut) on the surface roughness. In order to predict the surface roughness, the second-order regression equation can be expressed as: $R_a = \beta_0 + \beta_1 . V + \beta_2 . f + \beta_3 . a + \beta_4 . V^2 + \beta_5 . f^2 + \beta_6 . a^2 + \beta_7 . V. f + \beta_8 . V . a + \beta_9 .a .f$

Multilayer perception (MLP) architecture with back-propagation algorithm having two different variants is used in neural network. The back-propagation learning algorithms such as scaled conjugate gradient (SCG) and Levenberg–Marquardt (LM) were used to update the parameters in feed forward single hidden layers. The Logsig processing function and single hidden layer had been used. A trial and error scheme had been used to determine the appropriate number of hidden neurons.

Ranganath M S, et al, [14] analyzed surface roughness of Aluminium (6061) through neural network model. To predict the surface roughness, neural network model was designed through Multilayer Perceptron network for the data obtained. The predicted surface roughness values computed from ANN were compared with experimental data and the results obtained showed that neural network model is reliable and accurate for solving the cutting parameter optimization. They concluded that the appropriate cutting parameters can be determined for a desired value of surface roughness. For the analysis the experimental data has been retrieved from Ranganath M.S, et al , "Experimental Investigation of Surface Roughness And Cutting Force on Conventional Dry Turning of Aluminium (6061)" International Journal of modern Engineering Research, volume 5. The objective of this paper is to optimize the cutting parameters for obtaining minimum surface roughness. Taguchi techniques and ANN have been employed for the analysis. Further comparison has been performed based on the result obtained from two techniques.

III. NETWORK MODELING AND DATA ANALYSIS

Two Neural Network architectures are created using NN Tool in MATLAB software. Training parameters used in NN Tool are given in Table 1:

TABLE 1: Network Parameters

Parameters	**Network 1**	**Network 2**
Network Type	Feed forward back propagation	Feed forward back propagation
Training function	Levenberg Marquardt (LM)	Scaled Conjugate Gradient (SCG)
Learning function	LEARNGDM	LEARNGDM
Performance function	MSE	MSE
Transfer function	LOGSIG	LOGSIG
Number of layers	2	2
Number of neurons	8	8

A part factorial experimental design is analyzed through these networks. This part data is taken from the paper Ranganath M. S. et al, "Experimental Investigation of Surface Roughness and Cutting Force on Conventional Dry Turning of Aluminium (6061)" [17] (Table 2):

TABLE 2: Data [17]

DOC	**SPEED**	**FEED**	**ROUGHNESS**
0.6	156	0.05	2.2
0.6	289	0.1	3.21
0.6	409	0.15	4.25
1.2	156	0.05	1.77
1.2	289	0.1	2.46
1.2	409	0.15	3.99
1.8	156	0.05	2.53
1.8	289	0.1	2.95
1.8	409	0.15	3.64

The depth of cut, cutting speed and feed rate are taken as input and roughness values are taken as target values. The network is trained till the regression plot of the particular network fits the ideal line. After the final training, the outputs & errors are recorded separately for each network.

A. Simulation

A sample data (Table 3) is fed to each network and the predicted surface roughness values are recorded for both the network

TABLE 3: Sample data

DOC	**SPEED**	**FEED**
1.2	409	0.10
1.8	156	0.15

IV. RESULTS AND OBSERVATIONS

The network predicted values and errors for Network 1and 2 are recorded in Table 4 and Table 5 respectively:

TABLE 4: Results of Network 1

Roughness	**NN Results**	**Mean Square Error**
2.2	2.200091	-9.12E-05
3.21	3.226223	-0.01622
4.25	4.249567	0.000433
1.77	1.783154	-0.01315
2.46	2.530367	-0.07037
3.99	3.990957	-0.00096
2.53	1.773487	0.756513
2.95	3.056848	-0.10685
3.64	3.639946	5.41E-05

TABLE 5: Results of Network 2

Roughness	**NN results**	**Mean Square Error**
2.2	2.1494	0.050577
3.21	3.1983	0.011681
4.25	4.2064	0.043572
1.77	1.8666	-0.09657
2.46	2.4567	0.003333
3.99	3.8584	0.131588
2.53	2.4893	0.040664
2.95	2.9596	-0.00959
3.64	3.8103	-0.17027

Regression plots of both the networks are given below:

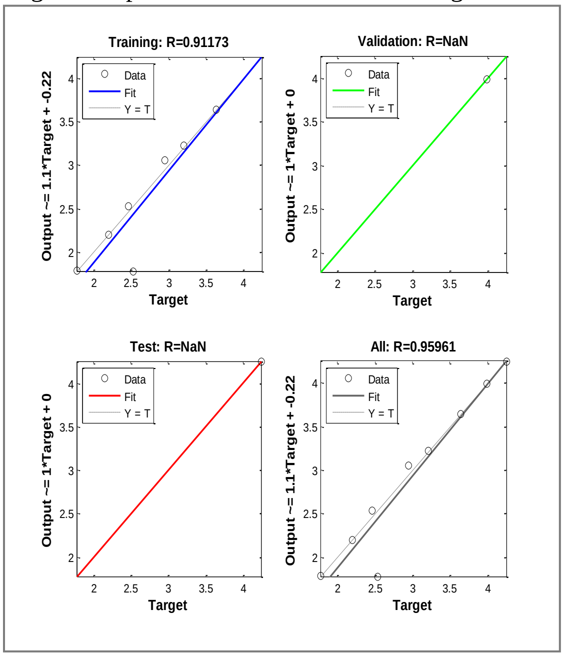

Fig 1: Regression plot of Network 1

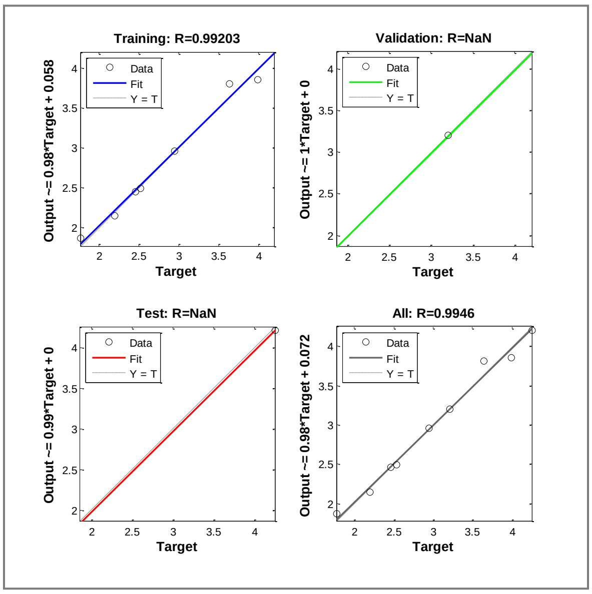

Fig 2: Regression plot of Network 2

The simulation results of both the networks, for sample data, are recorded in Table 6:

TABLE: 6 Simulation results

DOC	**SPEED**	**FEED**	**Network 1**	**Network 2**
1.2	409	0.10	3.6013	3.981456
1.8	156	0.15	2.6891	4.043552

A. Observations:

1. There are very minimum errors between the experimental values and the network results.
2. Both the Neural Network models predicted the roughness values close to the experimental values.
3. Regression plots of both the networks nearly fit the ideal line.
4. Mean square error values of Network 1 i.e. of LM algorithm are somewhat lower than the values of SCG algorithm based Network.
5. Simulation results of both the Networks are within the appropriate range.

It can be observed that in the sample data only the feed rate is varied and speed & depth of cut is kept same as of the experimental data. Surface roughness increases with feed and vice-versa. So, in this regard, it can be observed that the Simulation results of Network 1 are closer to the experimental roughness values as compared to the Network 2 results.

V. CONCLUSIONS

1. With Neural Network, designed with the network parameters (Table1), accurate results can be obtained.

2. Although both the Networks show very minimum errors between the experimental and Network predicted values but by observing simulation results, it can be concluded that the LM algorithm based network is more accurate than the SCG based Neural Network in predicting surface roughness values.

3. By analyzing surface roughness values at different cutting parameters, an optimum cutting parameter can be obtained at which the surface roughness would be minimum.

4. NN Tool in MATLAB is a precise application for predicting surface roughness.

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