Prediction of Surface Roughness on CNC Machine: A Review

Manikant kumar
. M.E. Student,
Department of Mechanical Engineering,
NITTTR, Bhopal-462002.

Dr. A.K. Sarathe
Associate Professor,
Department of Mechanical Engineering,
NITTTR, Bhopal-462002.

***Abstract* - In present rapidly changing scenario in production industries, application of predictive techniques is essential for metal cutting industry. It is a challenge for every industry to achieve predefined performance parameter in first trial.Predictive model is very essential in production industry to respond efficiently to severe competitiveness and continuously increasing demand of quality product with minimum cost in the market. Predictive models in metal cutting industries are considered as a vital tool for continuous improvement of product quality as well as minimizing the product cost. Optimization can be carried out with the help of predictive model. Determination of optimum input parameter for predefined performance parameter through cost-effective mathematical model is a very complex task. However, over the years, the predictive techniques have undergone various development and expansion. In this review paper, various predictive techniques like ANN, ANFIS, fuzzy logic, response surface method, taguchi method which are used for prediction of surface roughness has been critically appraised.A comparative study is carried out in tabular form of these predictive models. Surface roughness is taken as performance parameter for this paper.**

Keywords: ANN, Fuzzy logic, ANFIS, Response Surface Methodology.

1. INTRODUCTION

Metal cutting is the most important and widely used production process in manufacturing industries. In recent time metal cutting operation is performed with the help of computer numeric control machine. The study of metal cutting withdraws attention toward cutting tool material, work piece, input parameters for operation and their responses (output). There is a need of minimization of total cost in development of product due to severe competition in market these days.A significant improvement in product quality can be obtained with the help of predictive model with the same cost. There are a number of input parameters are used in CNC in which spindle speed, feed rate, depth of cut are very important. Many performance parameters are also present in metal cutting industry like MRR, machining time, cost, tool wear, surface roughness, power etc. surface roughness is the most important performance parameter because it affects many factors like precision, frictional consideration, fatigue and notch sensitivity, electrical and thermal contact resistance, subsequent processing,corrosion resistance, appearance and cost. There are many non-conventional techniques available for development of predictive model. This paper brings to the glimpse of work done in this area.

II. ISSUES DURINGDEVELOPMENT OF PREDICTIVE MODEL

There are various issues in the development of predictive model; which are discussed below.

1.Work Piece Materials- there are many materials which are used in the development of predictive models. Those materials are AISI 1060 steel, Ti-6Al-4V (grade 5) alloy, AISI 1045 steel, mild steel, Al 7075-T6, GFRP/Epoxy composite, AISI 4340 steel, Al 6061, GLASS fiber, AA 6351, St 50.2 steel, 190 BHN steel, 95MnPb28K etc.

2.Tool Materials-various cutting tool materials are used for the development of predictive models; which are carbide tool, Taegu-TecRCMT10T300, MTT3500, Tungsten carbide, H.S.S tool, SNMG 120408, ISCAR end mill, PCD cutting tool, SNTR carbide tool, CBN grinding tool, AVMT 0903 PER-EMCTT 8020, cemented carbide tool, SECO-DCMY11Y304F7, TPUN160308P10 etc.

3.Input Parameters- There are several input parameters which used for development of predictive model to get performance parameters in machining operation arecuttingtool material, tool rake angle, feed rate, cutting speed, depth of cut, cutting fluid, cutting force, cutting velocity, vibration, types of chip formation, work-piece materials and its properties.

4. Performance Parameters–There are many performance parameters in predictive model; which are material removal rate, machining time, total cost, tool wear, vibration, surface roughness.

III. DIFFERENT PREDECTIVE TECHNIQUES

There are the different predictive techniques; which were applied by various researchers aregivenbelow:

- Artificial Neural Network (ANN)
- Genetic Algorithm (GA)
- Fuzzy Logic
- Taguchi Method
- Response surface method
- ANFIS
- SMO-SMV
- Model tree

- Taguchi-fuzzy
- SVR
- Regression model.

IV. LITERATURE SURVEY

- Girish Kant and Kuldip Singh Sangwan (2015)[1] proposed an alternative method to conventional method for prediction of the optimum value of machining parameters that leads to minimize the surface roughness. They developed a predictive and optimization model by coupling of the two artificial intelligence approaches, one is ANN and another is genetic algorithm (GA). They found predicted result is very closer to the experimental values up to 4.11 percentage mean absolute error that indicates the developed model had good accuracy in predicting of the surface roughness values. They also compared their result by ANN with result obtained by regression and fuzzy logic models. They obtained that ANN models outperforms the regression and fuzzy logic models. They also performed a hypothesis test of which result validate the use of ANN as a prediction model had statically satisfactory to fit from the modelling part of view. They used ANN as prediction model and Genetic algorithm as a optimisation model in a machining process which gives the accuracy of 95.89% and minimum roughness value of 0.099 micrometre.

- Kuldip Singh Sangwan and Sachin Saxena (2015)[2] gave the idea about coupling of two artificial intelligence techniques for better effectiveness and efficiency. In this paper an approach for determining the optimum parameters for machining which leads to minimization of the surface roughness by integrating ANN and GA. They checked the capability of the ANN –GA approach for prediction as well as for optimization by use of real data set which had obtained from real machining experiment. They took Ti-6Al-4V aluminium alloy for turning operation as real machining experiment and developed a feed forward neural network. MATLAB toolbox had been used for training and testing of neural network. They found that expected results and predicted results were almost similar and they used GA technique for optimization of process parameters to minimize surface roughness. This paper shows that integrated ANN-GA technique are well capable to give accurate predicted optimum result. Mean absolute percentage error achieved by this paper is 1.79 compared to 4.30 by rsm model applied by Ramesh et al.

- Girish Kant and Sangwan(2015)[3]applied ANN as a predictive model in optimization of power requirements necessary for machining. Prediction of power requirements became very necessary for process planning in industry nowadays. This paper took two artificial intelligence techniques one is ANN and another one is SVR (support vector regression) which were used for predicting the power consumption in machining. At first a real machining experiment was performed to check the capabilities of these models. They designed 3 factors 4 levels plan for experiment using Taguchi method so that they studied the effect of all parameters with minimum number of experiments. The power predicted by both techniques were compared and found that ANN gave better result than SVR. They obtained 1.749 mean error in ANN while 1.86 mean error in SVR. They also performed some type of hypothesis tests like t-test, f-test and lever test to check goodness and reliability of model.

- Rajesh and Manu (2014)[4]worked on prediction of surface roughness of free form surfaces by use of artificial neural network. Freeform surfaces were formed using CNC machine. Such type of surfaces had large application in aerospace field. So to maintain surface quality was very important task for aerospace industry. They used CNC ball end milling machine for development of freeform surfaces using speed, depth of cut, feed rate and step over as input parameters for machining. They used back propagation neural network to minimize error in prediction of surface roughness. 96.37% accuracy was achieved using this ANN based predictive model.

- B.Anuja and Kirubakaran (2014)[5]developed an Artificial neural network based predictive model to simulate hard turning of AISI H13 steel with minimum cutting fluid application to predict surface roughness of machined surface in a reference of cutting parameters. They trained networks using different set of training data for a fixed number of cycles and tested them using a set of input or output data reserved for that purpose. They analysed the ability of ANN model to predict surface roughness and determined the root mean square error for selected architecture. They used minimum cutting fluid application to promote green environment in the shop floor and minimized the industrial hazard due to the harmful Aerosols and usage of large quantity of cutting fluid. Their study focussed on development of predictive model for surface roughness of machined surface utilizing minimum cutting fluid. They achieved mean accuracy up to 95.96% even with smaller size of training data set giving the concept of as size of training data set increases mean accuracy of predictive model increases.

- SaroshHashmi (2014)[6]emphasized on the importance of surface roughness which plays incredible role in the quality of machined surface. They gave the idea to develop a mathematical model that can predict the precise and correct value of surface roughness as well as the associated machining condition that leads to minimal value of surface roughness. They used real experimental data from an end milling process to develop a predictive model by using two machine learning technique. One is model trees and another is sequential minimal optimization based support vector machine. Same data set were used for training of predictive model as well as testing of predictive model. In this paper result obtained by these predictive models were compared with previous research paper. They found that model tree gave minimum value of surface roughness up to 0.182 micron. By use of SMO-SVM and model tree, we obtained better result than regression model and commonly used ANN model. So there is scope of exploring various techniques for prediction.

- Thakur Paramjit Mahesh (2014)[7] described the application of Taguchi method integrated with fuzzy logic for the minimization of surface roughness along with maximization of the material removal rate simultaneously. Parameters like speed, feed, depth of cut and nose radius were taken into consideration as input parameters for end milling CNC machining of Al 7075 T6 aerospace aluminium alloy. L27 orthogonal array with 4 factors and 3 levels were chose in Taguchi method and S/N ratios were calculated. In this paper the S/N ratios of roughness and material removal rate were fed as input to fuzzy logic system and output received in form of Multi Response Performance Index (MRPI). Depth of cut and nose radius were identified as the most significant parameters that contribute about 31% of variance with the help of ANOVA. A test was performed as an experiment to confirm this approach and that test shown that there was convincing improvement in MRPI of optimum process parameters thanMRPI of initial process parameters. This paper presented the integrated fuzzy-Taguchi for optimization of process parameters in CNC end milling for Al 7075T6 Al alloy with multiple performance characteristics.

- The work presented by HariVasudevan and Deshpande (2014) [8]deals with optimisation of machining parameters for CNC turning of glass fibre reinforced plastic (GFRP) or Epoxy composites.They considered hybrid technique for optimisation in this paper that means fuzzy logic coupled with Taguchi methodology was used for optimization of process parameter. Three levels of four process parameters selected for experiment which was nose radius of tool, cutting speed, feed rate and depth of cut. Output performance measures like surface roughness, tangential cutting force and material removal rate (MRR) were chosen. The design of experiment was carried out using L27 orthogonal array of Taguchi methodology. PCD cutting tool was selected for machining. Grey relational coefficient for three performance measures were obtained and converted into single multi performance characteristic index (MPCI) with the help of Mamdani type fuzzy inference system. MPCI get optimized with the help of Taguchi method. 0.8mm tool nose radius 120m/min cutting speed, 0.05 mm/rev feed rate and 1.6 mm depth of cut produced optimum value for this machining. In this study basically a fuzzy rule based was developed using 3 input variables using 1 output variable.

- N.Baskar (2012)[9] gave a novel approach by carried out the integration of fuzzy logic (FL) with response surface methodology (RSM). This integration introduced to reduce the cost and the time consumption for investigation of optimum cutting process. They also investigated the detailed analysis of thrust force for characterizing the cutting process. They told that spindle speed and feed rate are important factors which play a vital role in surface finish of work piece.They took combination of low, middle and upper levels of spindle speed with low and upper levels of feed rate on surface finish and cutting force through the experimental set up in an optimum manner. The FL model for surface finish and thrust force were developed from the collected experimental data. The FL model has developed two combinations of data without experiment through MATLAB. The result obtained reflects that predicted FL values are within the range of experimented value so FL values were selected for further investigation with RSM and they generate the result of FL-RSM model. Values obtained by FL-RSM model were also within the range of experimented value and produce more effective output than FL model. This paper gave the proof about that coupling of AI techniques like fuzzy with other method gives more precise and effective output than solo AI technique.

- Leo Dev Wins (2012)[10] proposed a predictive model with minimal fluid application in milling machining with the help of artificial neural network. The model was developed to predict surface roughness in terms of the fluid parameters such as the frequency of pulsing, rate of fluid application and pressure at the fluid injector. They explored that such model will have very importance in the automated control of fluid parameters to maintain surface roughness within predefined tolerance in computer aided manufacturing. Several architectures of neural network was trained for a define number of cycle and tested by set of input and output data. The root mean square error were calculated for every architecture and found that 3-6-6-1 architecture gave minimum RMSE value upto 0.01. They also found that predicted results were very close to experimental result. It is totally new technique of fluid minimization by use of high velocity pulsing jet of cutting fluid to maintain surface roughness. 3-6-6-1 architecture gave 0.011% standard error and 0.93% mean error.

- Hossain and DR. Nafis Ahmad (2012)[11] proposed an ANFIS model in 2012 for predicting surface roughness of aluminium for three dimensional milling operations. They took 84 experimental set and splits them at random basis in two parts; one was of 68 training sets and another was of 16 testing sets. They used training data set for training of different ANFIS and ANN model for surface roughness prediction. Testing data set had used for validate the predictive model. Model was selected by observing minimum value of RMSE and MAPE. They observed that ANFIS gave better predicted result on training data set than ANN and RSM but gave inferior result on testing data set due to the smaller size of data set as training data set had 68 sets whereas testing data set had only 16 sets. Errors in ANN is very close to ANFIS as ANN had 0.003014% error while ANFIS had 0.0314% but ANN provides different results every time as its MATLAB code was run. ANFIS gave more accurate result than ANN or any other technique for large data set.

- Mohd. Adnan and Mohd. Zain (2012) [12]used rule based reasoning and fuzzy logic to develop a model for predicting the surface roughness values obtained in milling process. They considered cutting speed, radial angle of rake, feed rate as process parameters and each parameter had of five significant values. They used fuzzy logic toolbox in MATLAB to develop a fuzzy rule based model. Nine significant values and twenty four if then rule were created for development of model. The error obtained by fuzzy logic with absolute error was tends to zero as approximate to 0.0008 estimated value of error. They gave the minimum value of surface roughness at high cutting speed, very low feed rate and at high radial rake angle. They made a successful attempt to predict surface roughness in titanium alloy (ti-6Al-4v) with fuzzy rule based model and achieved minimum surface roughness.

- Ahmed A.D Sarhan and Sayuti (2012)[13] developed a predictive model based on fuzzy logic for the prediction of surface roughness of a finished surface in milling operation of glass. They used CBN grinding tool for milling operation. They took four input machining parameters which were spindle speed, lubrication pressure, and depth of cut and feed rate. Design of experiment was generated by L13 experimental array method. In this experiment four parameters and four levels were chosen. After collecting data from real experiments four membership functions were allocated and they connected with every input of model. The predicted result found by fuzzy logic model was compared to experimental result. The compared result between experimental and fuzzy model hold 93.103% accuracy. This research work contributed to the enhancement of machined surface quality of glass fibre where high accuracy is needed.

- S Harikrishna and BapiRaju (2011)[14] proposed a prediction model for surface roughness by use of ANN and ANFIS. They used aluminium alloy AA6351 for machining operation which was machined on computer numeric control lathe (CL20TL5) turning machine. They took speed, feed, and depth of cut as cutting parameter with constant nose radius. Surface test STYLUS instrument with diamond tip was used for measuring surface roughness of machined surface. In this paper study of effect of each cutting parameter over surface finish of machined surface was carried out. Input parameters were selected in levels as speed in three levels, feed and depth of cut in four levels. They construct two models viz; The Artificial neural networks model and Adaptive neuro fuzzy interface models were constructed. It reflects that ANFIS predictive model has better prediction capabilities than artificial neural network based predictive model and also ANFIS trained data with faster speed than ANN.

- A.M ZAIN (2010)[15]focused on the application of ANN as a potential modelling technique and a very efficient technique for the development of predictive model for prediction of surface roughness in machining. They took 24 samples of data concerned with the milling operation were collected based on eight samples of data of two level DOE, four samples of centre data and twelve samples of axial data. The MATLAB ANN toolbox was used for the modelling purpose. Feedforward or backpropagation used as algorithm with traingdx, learngdx, MSX, logsig as the training, learning, performance and transfer function respectively. Eight networks were developed by using different number of nodes in the hidden layer with three nodes at input layer and one node in output layer which possess structure like 3-1-1, 3-3-1, 3-2-1, 3-7-1, 3-6-1, 3-6-6-1, 3-7-7-1. They found that efficiency and effectiveness of prediction depends on the number of layers and nodes in the hidden layer of ANN network structure. The accuracy of prediction didn’t depend up on size of data set as large or small. AS large and small dataset both gave good prediction by selecting optimal network. They found that 3-1-1 network structure gave best ANN based predictive model to predict surface roughness value. This paper focussed on the very basic idea that relates to the understanding of the network structure of ANN. It gives idea about our focussed must be on determination of number of layers and nodes in hidden layers using the trial and error method because it is very important for the researcher for good prediction. This paper proved that by modifying the number of layers and nodes in hidden layer within the same ANN training algorithm and same training sample different output result generate each time.

- DurmusKrayel (2009)[16] gave a novel approach in the prediction and control of surface roughness in a CNC lathe with help of artificial neural network. A large data set was obtained through experiment for training as well as testing of a neural network. They considered three parameters which were depth of cut, cutting speed and feed rate. Several parameters like tool nose radius, tool overhung, approach angle, work piece length, work piece diameter and work piece material were taken as constant. They developed a feed forward multi-layered neural network and they trained them with Scaled conjugate gradient (SGA) algorithm. They used one hidden layer with ten numbers of neurons. They used back propagation methodology of ANN for adaptive control mechanism by putting required value of surface roughness as they got value of input machining parameters for desired roughness. When developed ANN model integrated with the software of CNC m/c tool along with control system then surface roughness can be encoded in the programming to control roughness.

- TugrulOzel and J. Paulo Davim (2009)[17] presented the paper about effects of design of insert tools in the surface roughness of machined surface. They took AISI 1045 steel and their surface finishing had investigated with wiper insert tool. They found that with help of wiper insert tool surface smoothness increases. They used ANN model as predictive model for prediction of surface roughness. Neural network based prediction of surface roughness was carried out and compared with non-training experimental data set. These results shown that neural network models were suitable to predict surface roughness patterns for a wide range of cutting conditions and can be utilised in intelligent process planning for turning with wiper tool. This paper emphasizes the use of different type of inserts to increase in smoothness of machine surface and also discuss the importance of ANN as predictive model. Predicted RMS error of 0.745 obtained in wiper insert and RMS error of around 0.475 obtained in conventional insert.

- J.PauloDavim (2008)[18] developed a prediction model to investigate the effect of cutting parameters on turning of steel. ANN model was developed for prediction of surface roughness with input parameters like feed rate, cutting speed and depth of cut. A knowledge base was developed by use of back propagation training algorithm and design of experiment was carried out by L27 orthogonal array method. They also generate the 3D surface plot to study the effects of cutting parameters on surface roughness. They also found that there exist non-linear relationship between roughness and cutting parameters; so this justified the application of ANN based predictive model. This paper consists of details of experimentation, their validation and training of ANN. They found that cutting speed and feed rate had significant effect on roughness while depth of cut contributes little effect on surface roughness.

- HasanOktem and Erzurumlu (2006)[19]worked on optimization of cutting parameters in the machining of mold surfaces of an ortez part used in biomedical instruments. They optimized the parameters with the help of genetic algorithm coupled with neural network. A feed forward neural network was developed and trained as well as tested in MATLAB. simulation model for the component of ortez part was developed to determine the optimum cutting parameters which leads to minimum surface roughness without any constraints and produced the product of plastic by finding critical regions which to be used in measurements of surface. They also validate their predicted results with experimental result by additional measurement and found the very good agreement between them. They introduced machining tolerance as new cutting parameters in the experiment. They found that ANN along with GA gave more satisfactory results than ANN. Percent of error obtained was less than 1.33%.

- FranciCus and UrosZuper (2006)[20] proposed a neural network based approach for complex optimization of cutting parameters. They took all the technological, economical and organisational limitation. They developed a neural optimization algorithm to ensure simple, fast, and efficient optimization of all important turning parameters and to obtain higher precision of the predicted result.This proposed approach is more advantageous than partaken approaches especially for job shop manufacturing systems where product mixture is dynamic and diverse. Implementation of proposed approach to real world problems and extensions of the proposed approach to adaptive control of machining operations or on line adjustment of cutting parameters were based on information from sensors. They gave information that there approach should be used where the quick approximate determination for optimized cutting condition of machine is required and when there was not enough time for deep analysis. This research paper gave the information about where use of artificial neural network is economically beneficial to us.

- TugrulOzel and Karpat (2005)[21]worked on prediction of surface roughness and flank tool wear in hard turning of steel using cubic boron nitride (CBN) tool. They utilizes neural network predictive model to predict surface roughness and to determine specific process parameters. They took some data from previous research of this field and remaining data was collected from real experimental of turning of AISI H-13 steel which had to utilized in training, testing as well as for validation of neural network. Regression model was also developed for the prediction of surface roughness and tool flank wear. A comparative study was also carried out between predictive model of ANN and regression technique. They found that ANN based predictive model was more capable of prediction within the range of they had been trained. It happen because of ANN generally offer the ability to model more complex nonlinearities than linear and exponential regression model can offer. Bayesian regularization with lavenberg-morquardt algorithm was used for training of neural network. They also found that neural network with single output gave more accurate predicted result than multiple output network. In prediction of surface roughness 5.4 avg. rms error was found and 2.1 avg. RMS error obtained for tool flank wear.

- Benardos and Vosniakos (2003)[22]they gave various methodologies and practices that are used for the prediction of surface roughness. The approaches were

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classified on the basis of machine theory, experimental investigation, design of experiments and artificial intelligence (AI). They told that every technique possess its own advantages and disadvantages however artificial intelligence models seems the most realistic, accurate and has highest level of integration with computers. So this approach can be used in conjunction with other more conventional techniques to increase its efficiency. This paper forced to use AI based model for prediction.

- Benardos and Vosniakos (2002)[23] proposed a ANN based predictive model for surface roughness in CNC face milling. They performed experiment to get data set that was going to use in training of network and testing of neural network. The experiment conduct according to the principles of Taguchi design of experiment method. They consider various factors like depth of cut, feed rate per tooth, cutting speed, the engagement and wear of the cutting tool, the use of cutting fluid and the three components of the cutting forces as cutting process parameters. They used feedforward ANN trained with the Levenberg-Marquardt algorithm and by using this combination they determined the most influential factors for machining. They obtained 5-3-1 ANN structure with 1.86% mean square error in the prediction of surface finish. This paper gave the characteristics of ANN as like a powerful tool, easy to use in complex problems, extreme reliable and accurate for modelling of the surface roughness prediction. This technique can also be used in reverse way to get desired defined output. This methodology can be extend to building a database of trained ANN's for a variety of cases.

V. COMPARATIVE STUDY

An overview of various research works in the field of development of predictive model has presented below.

Table 2 comparative study of various research works carried out by different researchers.

S.N	Paper title	Author and published year	Impleme-ntation	Machining parameters	Model/ Technique	Remarks
1	Novel machine learning based models for estimating minimum surface roughness value in the end milling process.	SaroshHashmi et.al. (2014)	CNC end milling machine	a)cutting speed b) feed rate c)radial rake angle	a) Model tree b) SMO-SVM	Predictive model based on model tree gave minimum value of roughness upto 0.182µm.
2	Predictive modelling and optimization of machining parameters to minimize surface roughness using ANN coupled with GA	Girish Kant and Sangwan (2015)	CNC milling machine	a) depth of cut b)cutting speed c) feed rate	a) ANN b) GA	4.11% mean relative error achieved.
3	Predictive modelling for power consumption in machining using AI techniques.	Girish Kant and Sangwan (2015)	CNC milling machine	a) depth of cut b)cutting speed c) feed rate	a) ANN b) GA	1.79% mean absolute error achieved.
4	Surface roughness prediction using ANN in hard turning of AISI H13 steel with minimal fluid application.	B. Anuja Beatrice et.al. (2014)	CNC lathe machine	a) feed rate b) cutting speed c) depth of cut	ANN	Accuracy achieved upto 95.96%.
5	Prediction of surface roughness in the end milling using ANN.	AzlanMohdZain et.al. (2010)	CNC end milling machine	a) rake angle b) feed rate c) cutting speed	ANN	Predicted result depends upon configuration of neural network and no. of training data set. They found 3-1-1 config. gave best result with 24 data set.
6	Optimal selection of process parameters in CNC end milling of AL 7075-T6 aluminium alloy using a Taguchi-Fuzzy approach	Thakur paramjit and R.Rajesh (2014)	CNC end milling machine	a) cutting speed b) depth of cut c) feed rate d) nose radius	Taguchi-Fuzzy	A3B1C3D2 combination gave optimum result with surface roughness 0.14µm.
7	Optimization of machining parameters to minimize surface roughness using integrated ANN-GA approach.	Sachin saxena et.al. (2015)	CNC lathe machine	a) cutting force b) cutting speed c) feed rate d) depth of cut	a) SVR b) ANN	Mean error obtained by SVR is 1.86 where as ANN gave 1.749 mean error.
8	Prediction and control of surface roughness in CNC lathe using ANN.	DurmusKarayel (2009)	CNC lathe machine	a) depth of cut b)cutting speed c)feed rate	ANN	The predicted result is extremely close to measured result.
9	Neural network process modelling for turning of steel parts using conventional and wiper inserts.	TugrulOzel et.al. (2009)	CNC lathe machine	a)nose radius b)depth of cut c) feed rate d) cutting speed	ANN	With conventional insert roughness of 0.26µm obtained while from wiper insert 0.22µm roughness obtained.
10	Prediction of surface roughness of freeform surfaces using ANN.	Rajesh.M and R.Manu (2014)	CNC ball end milling machine	a) feed rate b) depth of cut c) step over	ANN	Accuracy upto 96.37% achieved.

11	Grey fuzzy multiobjective optimization of process parameters for CNC turning of GFRO/Epoxy composites.	HariVasudevan et.al. (2014)	CNC lathe machine	a) nose radius b)cutting speed c)feed rate d)depth of cut	a) Fuzzy logic b) Taguchi	Combination of 0.8mm tool nose radius, 120 m/min cutting speed, 0.05 mm/rev feed rate and 1.6 mm depth of cut gave optimum value.
12	Integration of fuzzy logic with RSM for thrust force and surface roughness modelling of drilling on titanium alloy.	B.Suresh and N.Baskar (2013)	CNC milling machine	a) spindle speed b) feed rate	a) Fuzzy logic b) RSM	9.77% of average deviation obtained in thrust force.
13	Simulation of surface milling of hardened AISI340 steel with minimal fluid application using ANN.	Leo Dev Wins et.al. (2012)	CNC milling machine	a) pressure at fluid injector b) frequency of pulsing c) quantity of cutting fluid	ANN	0.011% standard error obtained and mean error achieved 0.93% with 3-6-6-1 architecture of neural network.
14	Artificial intelligence based surface roughness prediction modelling for 3D end milling.	Hossain and Ahmad (2012)	CNC end milling machine	a) spindle speed b) feed rate c) radial depth of cut d) axial depth of cut e) cutter axis inclination angle	a) ANN b) ANFIS c) RSM	ANFIS gave best result as MAPE is 0.003014% obtained while in ANN this is 0.0314% and in RSM 27.72% obtained. But ANN gave better result in testing of data.
15	Fuzzy rule based for predicting machining performance for SNtr carbide in milling titanium ally (Ti-6Al-4v).	Mohd Adnan et.al. (2012)	CNC milling machine	a) cutting speed b) feed rate c) radial rake angle	Fuzzy logic	0.9845 correlation value obtained between real experiment and fuzzy rule based prediction.
16	A fuzzy logic based model to predict surface roughness of a machined surface in glass milling operation using CBN grinding tool.	M. Hamdi et.al. (2012)	CNC milling machine	a) lubricant pressure b)feed rate c)spindle speed d)depth of cut	Fuzzy logic	93.103% accuracy achieved.
17	Surface roughness prediction model using ANN and ANFIS.	S. Hari Krishna et.al (2011)	CNC lathe machine	a) cutting speed b) feed rate c) depth of cut	a) ANN b)ANFIS	ANFIS gave 3.39% testing error where as ANN gave 3.868 % testing error.
18	Investigation into the effect of cutting conditions on surface roughness in turning of free machining steel by ANN model.	J.P Davim et.al. (2008)	CNC lathe machine	a) depth of cut b) cutting speed c) feed rate	ANN	Combination of low feed rate and high cutting speed gave minimal surface roughness.
19	Prtediction of minimum surface roughness in end milling mold parts using neural network and GA.	HasanOktem et.al. (2006)	CNC end milling machine	a) cutting speed b) feed rate c) axial depth of cut d) radial d.o.c e) machining tolerance	a) ANN b) GA	Error reduced upto 1.33% by the integration of GA with ANN.
20	Approach to optimization of cutting conditions by using ANN.	FranciCus and UrosZuper (2006)	CNC lathe machine	a) feed rate b) cutting speed c) tool life d) cost of production e) depth of cut f) time of production	ANN	It gives the idea about where use of ANN is economically beneficial for us.
21	Predictive modelling of surface roughness and tool wear in hard turning using regression and neural networks.	Ozel and Karpat (2005)	CNC lathe machine	a) cutting force b) cutting speed c) feed rate d) depth of cut e)cutting tool	a) ANN b) Regression model	Average rms error was found 5.4 for prediction of roughness while 2.1 rmserror was found for prediction of tool flank wear.
22	Prediction of surface roughness in CNC face milling using neural networks and Taguchi's design of experiments.	P.G. Benardos et.al. (2002)	CNC face milling machine	a) depth of cut b) feed rate per tooth c) cutting speed d) tool wear e) cutting fluid	a) ANN b) Taguchi's method	Mean square error upto 1.86% can be achieved in the prediction of surface roughness consistently.

VI. CONCLUSION

CNC plays a vital role in the manufacturing sector. Prediction model is very necessary to eliminate over machining which is directly proportional to cost. Many researchers have developed intelligent systems for prediction of surface roughness for machined surface. From the above literature survey it seems the artificial intelligent systems are the most appropriate solution for the quick and precise predictive model. Most of the researchers have worked on fuzzy logic system, ANN and ANFIS for prediction and genetic algorithm for optimization of machining parameter in CNC. Some of them also suggested to couple two AI technique like fuzzy and ANN or ANN and GA to get most précised and optimized predicted result.Models obtained from coupling gave better result than individual model like ANFIS.Result obtained

ANN based predictive model always varies as shown in table 2. They depend upon number of layers and number of nodes on intermediate layer so optimum number of layer and intermediate node is very essential for good prediction and this is obtained by trial and error method.

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