

Prediction method for Surface Roughness based on Cutting parameters and Cloud model reasoning

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Abstract. According to the problem of lower prediction accuracy and narrower prediction range for the common prediction method, a new method for surface roughness prediction is putted forward. on the basis of analyzing large simple data, and cloud reasoning prediction model was established. Then the accuracy surface roughness prediction was realized with this model. Finally, experimental results showed that the presented method is more accurate than other methods in the same conditions.

Introduction

Surface roughness is an important index to measure the quality of products, the surface roughness values should be consistent with the fatigue strength, the performance for the corrosion resistance, accuracy, tribology and aesthetic was required of the qualified products[1], so the surface roughness of the artifact was predicted to optimize the cutting parameters , which is very important to control the quality of the artifact. In recent years, domestic and foreign scholars has made many explorations for roughness prediction methods, which usually adopts the Fuzzy Model[2], Artificial Neural Network Model[3], Genetic Model[4], neural network and fuzzy network combination model, the model of support vector machine and so on. However these models still exists many deficiency, such as the great influence on the prediction accuracy for model structure and parameters selection, at the same time its generalization ability is not strong, the accuracy is not high.

The cloud model was put forward by Chinese scholar Professor Deyi Li[5]based on fuzzy set theory, probability and statistics in the tradition, which is a kind of qualitative and quantitative uncertainty conversion model. According to the information of limited samples, use the multidimensional rules of qualitative reasoning method to predict the roughness of products. At the same time the sample is predicted, the better prediction effect of this method is verified.

Description of Cloud Model for the Roughness Prediction

The Concept of the Cloud Cloud model is the uncertainty of model transformation between qualitative and quantitative. It through the expectation (Ex), entropy (En) and hyper entropy (He) 3 digital characteristics to describe the qualitative concept of the fuzziness and randomness. Define U is a $U=\{x\}$ domain, T is associated with the U language value. X is an element of U , X for the expression of qualitative concept T called membership degree $C_T(x)$ (or called compatibility or X and T) is a random number with a stable tendency, membership in the domain distribution called membership cloud, referred to as the cloud [13].

Definition: Containing three dimension of the set $U=\{x_1, x_2, x_3\}$ is called the domain. For the fuzzy sets of the three-dimensional universe U is $A=(\mu_A(x_1), \mu_A(x_2), \mu_A(x_3))$, in which $\mu_A(x_1)$, $\mu_A(x_2)$, $\mu_A(x_3)$ for every arbitrary elements x_1, x_2, x_3 to the fuzzy set A generated a stable tendency of the random number, so it will be referred to as elements x_1, x_2, x_3 to the membership degree of the fuzzy set A . If each element given the 3D in the domain of expectation, entropy and

excess entropy, then each element can be generated in a cloud model, the three one dimension cloud model are combined to form a three-dimensional cloud.

Surface Roughness Prediction Model Based on Three-dimensional Multi Rules Because the cutting speed, feed rate and cutting depth is the effect of surface roughness of main process parameters, the cutting speed is divided into four language description level called "bigger, big, general, small ", Feed rate is divided into three language description level called "big, general, small" cutting depth is divided into three language description level called "big, general, small", roughness is divided into six language description level called "biggest bigger, big, general, small, smaller". Try to use cluster analysis method in MATLAB software to deal with 400 samples of data existed, then obtained six cloud model qualitative reasoning rules (see Table 1).

Rule 1: IF cutting speed is bigger AND feed rate is small AND the cutting depth is small, THEN the roughness is smaller

Rule 2: IF cutting speed is bigger AND feed rate is small AND the cutting depth is big, THEN the roughness is small

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Rule 6: IF cutting speed is smaller AND feed rate is big AND the cutting depth is general, THEN the roughness is biggest

The above rules mainly displayed as fuzzy concept of qualitative linguistic value, the roughness of the characteristic parameters of cloud object after treatment as shown in table 1. Figure 1 is the cloud model roughness category diagram.

Table 1 Six regulation parameter table

Rule	Cutting speed			Amount of feed			Cutting depth			Roughness		
	Ex	En	He	Ex	En	He	Ex	En	He	Ex	En	He
Rule 1	1500	375	0.01	228.6	57.15	0.0	0.254	0.150	0.020	1.346	0.350	0.020
Rule 2	1500	375	0.01	228.6	57.15	0.0	1.016	0.225	0.117	1.828	0.045	0.023
Rule 3	1159.	142.	0.03	311.7	80.4	0.0	0.854	0.267	0.245	2.297	0.117	0.095
Rule 4	1145.	240.	0.03	393.7	82.54	0.0	0.889	0.337	0.251	2.688	0.089	0.073
Rule 5	1000	166.	0.03	476.2	63.31	0.0	0.508	0.281	0.223	3.309	0.244	0.169
Rule 6	750	87.5	0.03	533.4	106.6	0.0	0.508	0.225	0.117	4.331	0.168	0.087

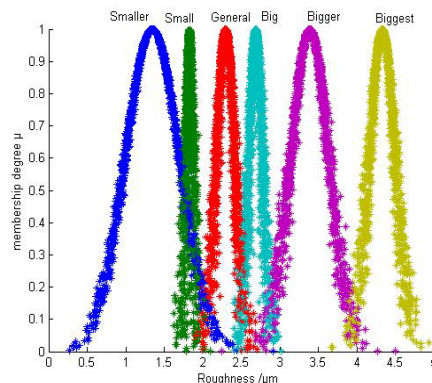


Figure 1 describes the cloud model roughness categories

Roughness Prediction Based on Multidimensional & Multi-rules Cloud Reasoning Algorithm

The cloud model rule generator was constructed based on X condition and Y condition of cloud model. Roughness prediction generator based on multidimensional rules cloud model qualitative reasoning was created by a plurality of n-dimensional X conditional clouds generator and a plurality

of one-dimensional Y conditional clouds generator.

According to the rules extracted from the data, under the given conditions roughness can be predicted. Roughness prediction index of the artifact have cutting speed, feed rate, cut depth and so on. Specific multidimensional cloud model based on the rules of qualitative reasoning process is as follows:

Algorithm: multidimensional rules of qualitative reasoning of cloud model algorithm

Step 1: A one-dimensional normal random number En_{bni} , expected value is En_{bni} , the standard deviation is He_{bni} , then according to the given condition value, calculate the membership of μ :

$$\mu = e^{-\left(\frac{(x_1 - Ex_{b11})^2}{2En_{b11}^2} + \frac{(x_2 - Ex_{b21})^2}{2En_{b21}^2} + \dots + \frac{(x_n - Ex_{bn1})^2}{2En_{bn1}^2}\right)}$$

Step 2.1: If activate a rule, then according to the obtained roughness prediction knowledge rules, produced by En_{U1i} as the expected value, He_{U1i} as the standard deviation of the n-dimensional normal value of En_{U1i} , then calculate y_i :

$$y_i = En_{U1i} \pm \sqrt{-2\ln(\mu)}En_{U1i}$$

Step 2.2: Define (y_i, μ) is a cloud. Return to step 2.1, repeated several times, the average value of expected value can be used as output.

Step 3.1: If activate the two or more than two rules. Generate μ_i , define μ_1 is the maximum, μ_2 is the second. The two corresponding single rules, according to the given consequents (En_{U11}, He_{U11}) , randomly generated with En_{U11} as expected value, He_{U11} as variance of the one-dimensional normal random value En_{U111}, En_{U112} ; According to the following formula, anti-computing two y_1 , under the conditions of μ_1, En_{U111} , anti-computing two y_2 , under the conditions of μ_2, En_{U112} :

$$\mu_1 = e^{-\frac{(y_1 - Ex_{U111})^2}{2En_{U111}^2}}, \mu_2 = e^{-\frac{(y_2 - Ex_{U112})^2}{2En_{U112}^2}}$$

Step 3.2: Select two outermost cloud droplets (y_1, μ_1) and (y_2, μ_2) , to construct a virtual concept with geometric method. The digital characteristics of the virtual cloud as (Ex, En, He) , a provisional hyper entropy $He=0$, through the geometric method for solving the variance components available virtual cloud expected value:

$$Ex = \frac{y_1\sqrt{-2\ln(\mu_2)} + y_2\sqrt{-2\ln(\mu_1)}}{\sqrt{-2\ln(\mu_2)} + \sqrt{-2\ln(\mu_1)}}$$

Step 4: Repeat steps 1-3 until the number of values for the surface roughness prediction value to meet the Y requirements.

Application Examples of Surface Roughness Prediction using Cloud Model

Experimental conditions: the artifact material is the 6061 aluminum block, machine tool is the CNC vertical machining center, cutting parameters is the four groove diameter of 3/4 high speed steel. Each sample object is described with the cutting speed x_1 , feed rate x_2 , depth of cut x_3 and machined surface roughness y . Production, $x_1 = 750, 1000, 1250, 1500$ (r/min), $x_2 = 152.4, 304.8, 457.2, 609.6$ (mm/min), $x_3 = 0.254, 0.762, 1.270$ (mm); y achieved by Hommel surface roughness instrument.

Apply the multidimensional rules of qualitative reasoning generator to predict 36 validation data on table 2. In table 2 y is the actual value, y^{\wedge} is the results of prediction. Figure 3 shows the prediction relative error distribution.

Table2 Validation sample forecast

Object	x_1 r/min	x_2 mm/min	x_3 mm	y	y^{\wedge}	Error
1	750	228.6	0.254	2.7686	2.7587	0.4
2	750	228.6	0.762	2.5134	2.7118	7.9
3	750	228.6	1.270	2.4130	2.2588	6.4
4	750	381.0	0.254	3.1750	3.3043	4.1
5	750	381.0	0.762	3.0988	2.9691	4.2
6	750	381.0	1.270	2.6416	2.7207	3.0
7	750	533.4	0.254	4.5212	4.3321	4.2
8	750	533.4	0.762	4.1402	4.3445	3.9
9	750	533.4	1.270	3.8100	3.8203	0.3
10	1000	228.6	0.254	2.3368	2.2493	7.7
11	1000	228.6	0.762	2.4381	2.6436	8.4
12	1000	228.6	1.270	2.5908	2.7211	5.0
13	1000	381.0	0.254	3.2766	3.0346	7.4
14	1000	381.0	0.762	2.7432	2.4173	11.9
15	1000	381.0	1.270	2.3368	2.6823	14.8
16	1000	533.4	0.254	3.7846	3.8573	1.9
17	1000	533.4	0.762	3.6830	3.3814	8.2
18	1000	533.4	1.270	2.8448	2.8085	1.3
19	1250	228.6	0.254	2.0320	2.1465	5.6
20	1250	228.6	0.762	2.0828	1.8219	12.5
21	1250	228.6	1.270	2.3368	2.3920	2.4
22	1250	381.0	0.254	2.7178	2.4932	8.3

23	1250	381.0	0.762	2.4638	2.4932	1.2
24	1250	381.0	1.270	2.2098	2.0070	9.2
25	1250	533.4	0.254	3.2766	3.1581	3.6
26	1250	533.4	0.762	2.4892	2.4256	2.6
27	1250	533.4	1.270	2.6670	2.6988	1.2
28	1500	228.6	0.254	1.3462	1.3462	0
29	1500	228.6	0.762	1.8796	1.8471	1.7
30	1500	228.6	1.270	1.7780	1.7969	1.1
31	1500	381.0	0.254	2.7940	2.7453	1.7
32	1500	381.0	0.762	2.1336	2.2323	4.6
33	1500	381.0	1.270	2.5146	2.5146	6.9
34	1500	533.4	0.254	3.0226	3.0899	2.2
35	1500	533.4	0.762	2.5908	2.4932	3.8
36	1500	533.4	1.270	2.8702	2.8020	2.4

Table3 Compare with the prediction model
error(Training samples 400,Validation sample 36)

Model	>25 %	20~25 %	15~20 %	10~15 %	5~10 %	0~5 %	Average Error/ %
MRA1 ^[2]	1	3	4	3	10	15	8.32
MRA2 ^[3]	2	5	3	5	9	12	10.74
MRA3 ^[3]	1	1	3	9	8	14	8.73
FN1 ^[2]	1	1	1	6	11	16	6.89
FN2 ^[2]	2	4	2	5	12	11	9.26
KM1 ^[2]	1	1	1	6	11	6	6.89
KM2 ^[2]	1	2	3	7	10	13	8.74
ANN1 ^[3]	1	0	2	9	11	13	7.93
Cloud Model	0	0	0	3	10	23	4.88

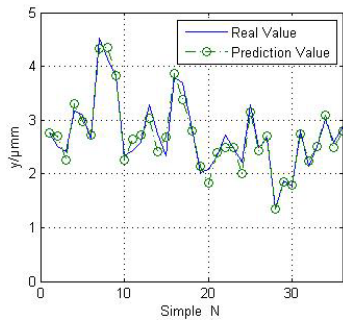


Figure 2 Compare with real value and prediction value

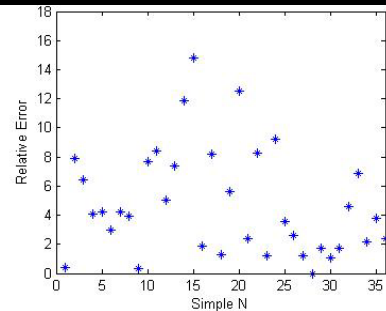


Figure 3 Error distribution

Conclusion

Prediction method for surface roughness based on cutting parameters and cloud model reasoning was put forwarded, and the uncertainty characteristic roughness prediction was described that will

be the first time to apply cloud model theory in the mechanical processing. Through the digital characteristics of surface effect on machining roughness factors, the digital features of cloud model was determined. Mix the fuzzy and randomness in together to overcome the membership functions of the fuzzy sets theory inherent defect, a new method for other similar problems was provided in mechanical engineering. In the prediction accuracy, this model has more superiority in dealing with uncertain problems, the experimental results also show that the proposed method has good effects in the aspect of prediction performance and prediction accuracy, has carried on the beneficial exploration to the roughness prediction method of high precision.

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