Research on Generating Step Value Algorithm for Gray Level Co-occurrence Matrix and Its Application in Tool Monitoring

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Abstract: - The monitoring of tool wear condition can be processed by means of the analysis of workpiece surface texture images. In order to analyze the workpiece surface texture images accurately, the generating step value of Gray Level Co-occurrence Matrix is studied extensively. A new algorithm about generating step value is proposed in this paper. Through analysis and testified by experiments, the optimum value of the generating step value is the step value which makes the textural feature parameters obtain the extreme value(the maximum or minimum value) in the first period. The optimum value of the generating step value is only related with the feed rate. It is unrelated with the other machining parameters such as the tool wear and machining speed. Compared with the other step value, the optimum value of the generating step value makes GLCM more different and diverse for different texture images. Therefore the difference of textural feature parameter values based on the above GLCM is great. Consequently the feature parameters obtained by the reasonable generating step value are sensitive to the tool wear which are beneficial to monitor the tool wear.

Key-Words: - Image processing, Texture analysis, Tool wear monitoring, Gray Level Co-occurrence Matrix, Generating step value, Feature parameters

1 Introduction

The texture of workpiece surface is different which is machined with a different wear tool. Consequently, the tool condition can be analyzed by utilizing texture properties of workpiece surface [1,2]. Texture analysis needs to extract textural features from texture images.

Textural feature analysis technology based on Gray Level Co-occurrence Matrix(GLCM) is attributed to a statistical analysis technology. Its model was proposed by Haralick in 1973 which is utilized to analyze image texture[3-8]. GLCM is based on the conditional probability density function of the second order. The generating step value d is the distance between two sampling pixels. If the value d is different, the GLCM obtained will be different too. An appropriate generating step value is very important which depends on the specific image. The GLCM with an appropriate generating step value is more suitable to describe the texture image and the obtained feature parameters of the texture image are more reasonable which is beneficial to analyze texture of workpiece surface and monitor the tool condition.

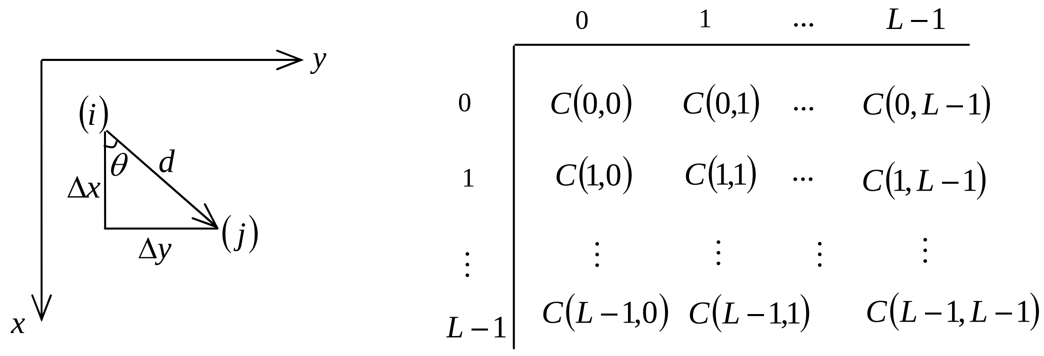
2 The concept of GLCM

In an image, the coordinate of a pixel is (x, y) and the gray value of this pixel is i. That is $f(x, y) = i$. Another pixel's coordinate is $(x+\Delta x, y+\Delta y)$ and the pixel's gray value is j. That is $f(x+\Delta x, y+\Delta y) = j$. GLCM is a matrix which calculates the number of pixel pair with gray value (i, j) for a specified spacing and a specified direction in an image. The GLCM matrix can be defined as $p(i, j / d, \theta)$. d is the distance of sampling pixel pairs. d is called generating step value of GLCM. θ is the angle of sampling pixel pairs. Usually the values of θ are 0 degrees, 45 degrees, 90 degrees and 135 degrees. The gray values of pixel pairs are respective i and j. GLCM can reflect the change of image gray.

If image I has L gray scale and $C(i,j)$ is the normalized GLCM, the dimension of the matrix $C(i,j)$ is $L \times L$. $C(i,j)$ is defined as

$$C(i,j) = p(i,j/d,\theta) / \sum_{i=0}^{L-1}\sum_{j=0}^{L-1} p(i,j/d,\theta) \quad (1)$$

The diagram is as shown in Fig.1.



(a)the diagram of pixel pair

(b) GLCM

Fig.1 the diagram of GLCM

3 Feature Parameters of GLCM

The algorithm of GLCM is a typically statistical analysis algorithm of texture feature. Haralick proposed 14 texture features based on GLCM[9-13].

The generating step value is researched by the two texture features of entropy and contrast in this paper. Then texture images are further researched and analyzed.

(1)Entropy

$$Ent = -\sum_{i=0}^{L-1}\sum_{j=0}^{L-1} C(i,j)\ln(C(i,j)) \quad (2)$$

Entropy can reflect the amount of texture image's information.

(2)Contrast

$$Con = \sum_{i=0}^{L-1}\sum_{j=0}^{L-1} (i-j)^2 C(i,j) \quad (3)$$

The contrast is also called the moment of inertia. The contrast can reflect image's definition and textural intensity. The stronger the textural intensity is, the deeper the groove of texture image is. Then the greater the contrast of texture image is, the better the visual effect of texture image is.

On the contrary, the smaller the contrast is, the smaller the textural intensity is. Then texture image blurs more. In GLCM, the greater the element value far away from the diagonal is, the greater the contrast of texture image is. Hence the texture image has high definition.

4 The influence of generating step value on textural Feature Parameters

The generating step value is an important factor for GLCM ,when computing the normalized GLCM $C(i,j)$. The generating step value is the distance between two sampling pixel pairs. If the generating step takes different values, the values of GLCM will be different much. Then the textural feature parameters are different which influence the result of textural analysis[14].

The GLCM is deferent based on the different generating step value. If the generating step value d is less than the amplitude of the texture element for the coarse texture image, the two sampling pixels have greater possibility with similar gray values. Consequently great numerical elements are concentrated near the diagonal line in GLCM. If the generating step value d is approximately equal to the amplitude of the texture element for the fine texture image, the distribution of great numerical elements is relative uniform in GLCM. Therefore the generating step value d needs to be determined based on a specific image. The determined generating step value needs to be reasonable. The GLCM based on the reasonable generating step value is beneficial to obtain the reasonably textural feature parameters which are more suitable for texture analysis and tool monitoring.

If applying an appropriate generating step value for a regular texture image, most elements of GLCM focus on the diagonal nearby. Consequently the entropy of this regular texture image is less which is calculated according to the formula (2). If applying an appropriate generating step value for an irregular texture image, the distribution of elements in GLCM is relatively uniform. Consequently the entropy of this irregular texture image is greater and this texture image is more complicated. According to the formula (3),the contrast value of GLCM for a regular texture image is relatively less because most elements of GLCM focus on the diagonal nearby. However the distribution of elements in GLCM is relatively uniform for an irregular texture image. Hence the value of contrast is relatively greater. In conclusion, the reasonable generating step value is beneficial to analyze texture image and monitor the degree of the tool wear by texture images of workpiece surface.

In order to research how the generating step value d influences on the textural feature parameters, the angle values of 0,45,90 and 135 are set as the generating direction values θ. Then four GLCMs are computed based on the four angle values. The eventual GLCM is the mean value of the four GLCMs. In order to reduce the calculated quantities, the gray levels of an image are set 16 levels. Based on the above, the relation between the textural feature parameters and the generating step value d are researched.

The values of the textural feature parameters, such as the value of contrast and the value of entropy, vary periodically as the generating step value increases. When the generating step value achieves a certain value in the first period, the value of contrast and the value of entropy achieve the minimum value of this period. This generating step value is the reasonable step value. The reasonable step value is the optimum value of the generating step value.

5 Experimental results and analysis

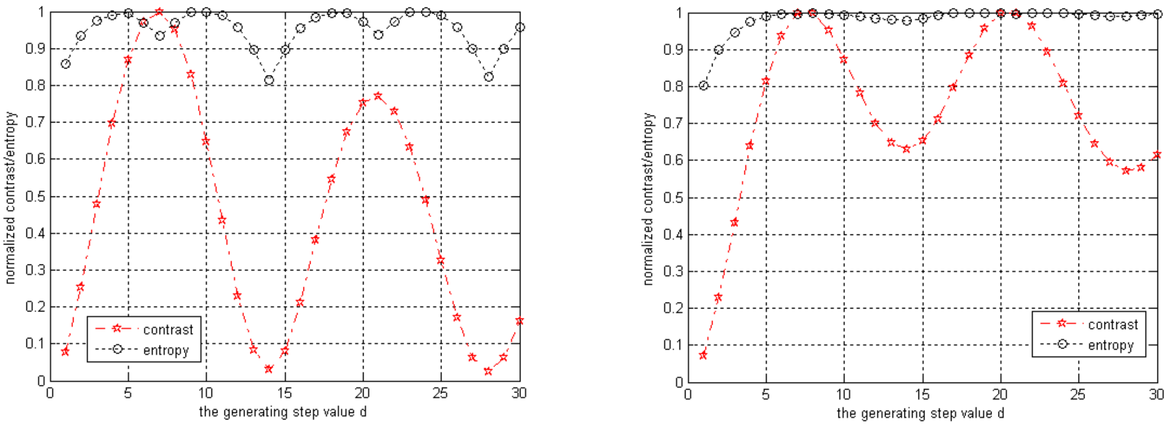
The workpiece surface whose image is as shown in Fig.2(a) is machined with a sharp cutting tool. Its feed rate is 0.2 millimeter per revolution. The simulation curve of contrast/entropy textural feature parameters (aiming at Fig.2(a)) is as shown in Fig.3(a). In Fig.3(a), the generating step values are from 1 to 30 which are as the abscissa axis. The textural feature parameters of normalized contrast and normalized entropy are as the ordinate axis. From Fig.3(a),when the generating step value is equal to 14, the value of entropy/contrast achieves the minimum value in the first period.

The workpiece surface whose image is shown in Fig.2(b) is machined with a dull cutting tool. The simulation curve of contrast/entropy textural feature parameters (aiming at Fig.2(b)) is shown in Fig.3(b). The parameters in Fig.3(b) are the same as those in Fig.3(a). From Fig.3(b),when the generating step value is equal to 14, the value of entropy/contrast achieves the minimum value in the first period.

(a) The texture image of a workpiece surface machined with a sharp cutting tool

(b) The texture image of a workpiece surface machined with a dull cutting tool

Fig.2 the texture image of a workpiece (feed rate $f = 0.2mm/r$)



(a) The simulation result of the relation between contrast/entropy and the generating step value about the texture image shown in Fig.2(a)

(b) The simulation result of the relation between contrast/entropy and the generating step value about the texture image shown in Fig.2(b)

Fig.3 The simulation of texture feature parameters (feed rate $f = 0.2mm/r$)

In Table 1 the GLCM is obtained when the generating step value is equal to 1. The GLCM is calculated aiming at Fig.2(a). In Table 2 the GLCM is obtained when the generating step value is equal to 14. The GLCM is calculated aiming at Fig.2(a) too. The workpiece surface whose image is shown in Fig.2(a) is machined with a sharp cutting tool.

In Table 3 the GLCM is obtained when the generating step value is equal to 1. The GLCM is calculated aiming at Fig.2(b). In Table 4 the GLCM is obtained when the generating step value is equal to 14. The GLCM is calculated aiming at Fig.2(b). The workpiece surface whose image is shown in Fig.2(b) is machined with a dull cutting tool.

In the four Tables, the values of GLCMs are the mean values of GLCMs of four generating direction values. The four generating direction values are 0,45,90 and 135.

The GLCMs shown as in Table 1 and in Table 3 are obtained when the generating step value is equal to 1. Because the generating step value 1 is unreasonable, the dispersion of the GLCM is not obvious. The one is machined with a sharp tool. The other is machined with a dull tool. But the dispersion of the former GLCM is close to that of the latter GLCM. Therefore the difference of textural feature parameter values is very small. Consequently the unreasonable step value is not beneficial to monitor the tool wear.

The GLCMs shown as in Table 2 and in Table 4 are obtained when the generating step value is equal to 14. Because the generating step value 14 is reasonable, the dispersion of the GLCM is obvious. The former GLCM is obtained from the workpiece surface which is machined with a sharp tool. The latter GLCM is obtained from the workpiece surface which is machined with a dull tool. Compared with the former GLCM, the latter GLCM is more disperse. Therefore the difference of textural feature parameter values is great. Consequently the reasonable step value is beneficial to monitor the tool wear.

In theory, the distribution of data values in GLCM which is calculated for the workpiece surface manufactured with a dull tool is more disperse than that with a sharp tool. However the disperse of data values is little difference between GLCM in Table 1 and that in Table 3,because the generating step value is unreasonable which is equal to 1. The disperse of data values is distinct between GLCM in Table 2 and that in Table 4, because the generating step value is reasonable which is equal to 14.

Through the simulation curve in Fig.3 and the above analysis, the following conclusions can be obtained. With the increase of machining time, the tool wear increases too. If machining parameters do not vary, the optimal value of the generating step is the same. That is the same optimal value of the generating step if machining parameters do not vary.

Table 1 GLCM (for Fig.2(a), d=1, $f = 0.2mm/r$)

Range of gray	0-15	16-31	32-47	48-63	64-79	80-95	96-111	112-127	128-143	144-159	160-175	176-191	192-207	208-223	224-239	240-255
0-15	2	12.25	2.25	0	0	0	0	0	0	0	0	0	0	0	0	0
16-31	12.25	985.5	954.75	132.5	11.5	0.25	0	0	0	0	0	0	0	0	0	0
32-47	2.25	954.75	2261.5	722.5	216.75	56	1.5	0.25	0	0	0	0	0	0	0	0
48-63	0	132.5	722.5	617	252.75	383	177	14.75	0.25	0	0	0	0	0	0	0
64-79	0	11.5	216.75	252.75	213	101	211.25	110.5	29	1.75	0.25	0	0	0	0	0
80-95	0	0.25	56	383	101	251.5	64.25	104	293.25	79.5	3.75	0.5	0	0	0	0
96-111	0	0	1.5	177	211.25	64.25	196	38.75	131.5	230	46.75	2	0	0	0	0
112-127	0	0	0.25	14.75	110.5	104	38.75	103	42.75	104.5	116.25	20.5	2	0	0	0
128-143	0	0	0	0.25	29	293.25	131.5	42.75	250	78.5	210.75	215.25	37	0.25	0	0
144-159	0	0	0	0	1.75	79.5	230	104.5	78.5	233	106.75	217.5	145	14.25	0	0
160-175	0	0	0	0	0.25	3.75	46.75	116.25	210.75	106.75	249	203	185	32.5	2	0
176-191	0	0	0	0	0	0.5	2	20.5	215.25	217.5	203	380.5	311.5	97.5	4.5	0
192-207	0	0	0	0	0	0	0	2	37	145	185	311.5	398	140.5	26.75	0.25
208-223	0	0	0	0	0	0	0	0	0.25	14.25	32.5	97.5	140.5	85	24.5	3
224-239	0	0	0	0	0	0	0	0	0	0	2	4.5	26.75	24.5	14.5	1.75
240-255	0	0	0	0	0	0	0	0	0	0	0	0	0.25	3	1.75	1

Table 2 GLCM (for Fig.2(a), d=14, $f = 0.2mm/r$)

Range of gray	0-15	16-31	32-47	48-63	64-79	80-95	96-111	112-127	128-143	144-159	160-175	176-191	192-207	208-223	224-239	240-255
0-15	0	5	5.75	0.75	0	0	0	0	0	0	0	0	0	0	0	0
16-31	5	609.5	914	114.5	18.25	3.5	0	0	0	0	0	0	0	0	0	0
32-47	5.75	914	1954	448.25	93.5	14.25	3.5	0.5	1	0	0	0	0	0	0	0
48-63	0.75	114.5	448.25	801.5	363.25	80	16.5	2.5	1.5	0	0	0	0	0	0	0

Table 2 (continued)

Range of gray	0-15	16-31	32-47	48-63	64-79	80-95	96-111	112-127	128-143	144-159	160-175	176-191	192-207	208-223	224-239	240-255
64-79	0	18.25	93.5	363.25	236	133	55.25	11	3.5	2.75	0.25	0.25	0	0	0	0
80-95	0	3.5	14.25	80	133	394.5	327.25	89	22.25	10.25	1	0.75	0	0	0	0
96-111	0	0	3.5	16.5	55.25	327.25	323	95	39.75	22.75	2.25	0.75	0	0	0	0
112-127	0	0	0.5	2.5	11	89	95	75	137.75	83.75	18	3.25	1.5	1.25	0	0
128-143	0	0	1	1.5	3.5	22.25	39.75	137.75	416	316.75	105.75	28.75	8	1.25	0	0
144-159	0	0	0	0	2.75	10.25	22.75	83.75	316.75	299	148	70.25	27.5	7.25	0	0
160-175	0	0	0	0	0.25	1	2.25	18	105.75	148	213.5	261.5	141.75	29.75	5	0
176-191	0	0	0	0	0.25	0.75	0.75	3.25	28.75	70.25	261.5	453	319.25	77.5	11.75	0.75
192-207	0	0	0	0	0	0	0	1.5	8	27.5	141.75	319.25	378.5	144.25	24.25	1.5
208-223	0	0	0	0	0	0	0	1.25	1.25	7.25	29.75	77.5	144.25	57.5	9.25	0.25
224-239	0	0	0	0	0	0	0	0	0	0	5	11.75	24.25	9.25	4	1.25
240-255	0	0	0	0	0	0	0	0	0	0	0	0.75	1.5	0.25	1.25	0

Table 3 GLCM (for Fig.2(b), d=1, $f = 0.2mm/r$)

Range of gray	0-15	16-31	32-47	48-63	64-79	80-95	96-111	112-127	128-143	144-159	160-175	176-191	192-207	208-223	224-239	240-255
0-15	30	17.75	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0
16-31	17.75	166	129.25	13.25	0.25	0	0	0	0	0	0	0	0	0	0	0
32-47	0.25	129.25	966.5	464.25	54.75	4.25	0.25	0.5	0	0	0	0	0	0	0	0
48-63	0	13.25	464.25	1260.5	565	139.25	22.5	3.25	1.25	0	0.25	0	0	0	0	0
64-79	0	0.25	54.75	565	958.5	513.5	204.25	26.25	7.75	3.25	1	0	0.25	0	0	0
80-95	0	0	4.25	139.25	513.5	690	429	175.25	51.25	7.75	2	2	0.75	0	0	0
96-111	0	0	0.25	22.5	204.25	429	552.5	338.5	217.25	53.75	16.25	4.5	2	1	0	0
112-127	0	0	0.5	3.25	26.25	175.25	338.5	323	232	160.75	88	20.5	4.75	2.5	0.75	0

Table 3 (continued)

Range of gray	0-15	16-31	32-47	48-63	64-79	80-95	96-111	112-127	128-143	144-159	160-175	176-191	192-207	208-223	224-239	240-255
128-143	0	0	0	1.25	7.75	51.25	217.25	232	310	187.25	154.75	74.75	23.75	7	2	0.75
144-159	0	0	0	0	3.25	7.75	53.75	160.75	187.25	206.5	128.5	123.25	86.5	17.5	4.25	1.75
160-175	0	0	0	0.25	1	2	16.25	88	154.75	128.5	176.5	112.25	123.25	73.5	14	3.25
176-191	0	0	0	0	0	2	4.5	20.5	74.75	123.25	112.25	150.5	103	123.25	41.5	13.75
192-207	0	0	0	0	0.25	0.75	2	4.75	23.75	86.5	123.25	103	175	136.75	117.25	32.75
208-223	0	0	0	0	0	0	1	2.5	7	17.5	73.5	123.25	136.75	217	133.75	105.25
224-239	0	0	0	0	0	0	0	0.75	2	4.25	14	41.5	117.25	133.75	218.5	204
240-255	0	0	0	0	0	0	0	0	0.75	1.75	3.25	13.75	32.75	105.25	204	1035

Table 4 GLCM (for Fig.2(b), d=14, $f = 0.2mm/r$)

Range of gray	0-15	16-31	32-47	48-63	64-79	80-95	96-111	112-127	128-143	144-159	160-175	176-191	192-207	208-223	224-239	240-255
0-15	0	0	0	0	0	0	0.5	0.5	0.5	0.75	0.25	1.75	0.5	2.5	1.25	9.5
16-31	0	1	26	29.25	21.5	20	21	12.5	9.75	9	5.5	6	5	5.25	5	19
32-47	0	26	255	293	212.75	136.75	111	72.75	56.25	32	32	24.25	22.75	21	20.75	43.75
48-63	0	29.25	293	409	316	234.5	164	97.5	79.75	49.5	58.75	41.75	43.75	49.5	38.25	71.5
64-79	0	21.5	212.75	316	315	248	203.25	132	101	48.25	53	40.25	42	47.75	55	87.5
80-95	0	20	136.75	234.5	248	258.5	206.75	112.25	94	61.25	51.25	31.75	31.25	32.25	45.5	85
96-111	0.5	21	111	164	203.25	206.75	213	144.75	128	64.75	45.25	28.25	30.75	29.25	33	69.5
112-127	0.5	12.5	72.75	97.5	132	112.25	144.75	129.5	107.25	82	57.25	40	33.25	28	21	49.25
128-143	0.5	9.75	56.25	79.75	101	94	128	107.25	123.5	90.5	51.5	37.5	34.75	32	23.75	52.75
144-159	0.75	9	32	49.5	48.25	61.25	64.75	82	90.5	61.5	58	50.75	45	36.5	22.5	58.25
160-175	0.25	5.5	32	58.75	53	51.25	45.25	57.25	51.5	58	84	69.75	57.5	38.75	27	55
176-191	1.75	6	24.25	41.75	40.25	31.75	28.25	40	37.5	50.75	69.75	52	47.5	46.5	34.75	62.25
192-207	0.5	5	22.75	43.75	42	31.25	30.75	33.25	34.75	45	57.5	47.5	63	76.25	59.5	86
208-223	2.5	5.25	21	49.5	47.75	32.25	29.25	28	32	36.5	38.75	46.5	76.25	74.5	63.75	98.75
224-239	1.25	5	20.75	38.25	55	45.5	33	21	23.75	22.5	27	34.75	59.5	63.75	56.5	101.75
240-255	9.5	19	43.75	71.5	87.5	85	69.5	49.25	52.75	58.25	55	62.25	86	98.75	101.75	188

In order to illustrate the importance of the reasonable generating step value, the textural feature parameter entropy is calculated for the image in Fig.2(a) and the image in Fig.2(b). The simulation result is as shown in Fig.4.

From Figure 4, the difference of entropy in the two simulation curves is maximized when the generating step value is equal to 14. The feature parameters obtained by the reasonable generating step value are sensitive to the tool wear which are beneficial to monitor the tool wear. Therefore, the reasonable generating step value is very important for the extraction of textural feature parameters.

The optimum value of the generating step value depends upon valley peak and valley bottom of the texture image of the machined workpiece surface when calculating GLCM. Therefore, the generating step value needs to be recalculated when the feed rate varies, as shown in Fig.5 and in Fig.6. The texture images in Fig.5 are captured from the workpiece machined with the feed rate 0.15 millimeter per revolution. The workpiece is machined with a sharp tool whose texture image is as shown in Fig.5(a). The workpiece is machined with a dull tool whose texture image is as shown in Fig.5(b).The texture feature parameters such as entropy and contrast achieve the minimum at the same time in the first period, as shown in Fig.6. The optimum value of the generating step value is 8 when the feed rate is equal to 0.15 millimeter per revolution.

Through the above analysis of Fig.2,Fig.3,Fig.5 and Fig.6, the following conclusion can be obtained: The optimum value of the generating step value is only related with the feed rate. It is unrelated with the other machining parameters such as the tool wear and machining speed.

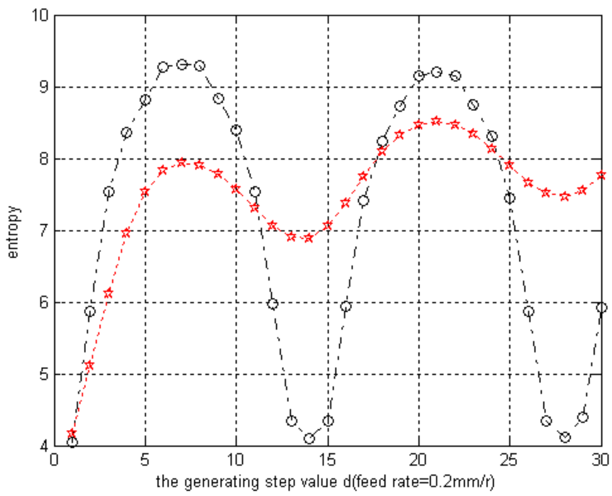
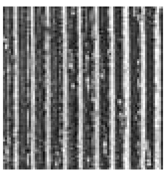
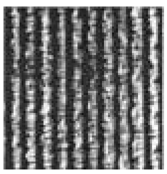


Fig.4 The simulation result of the textural feature parameter entropy

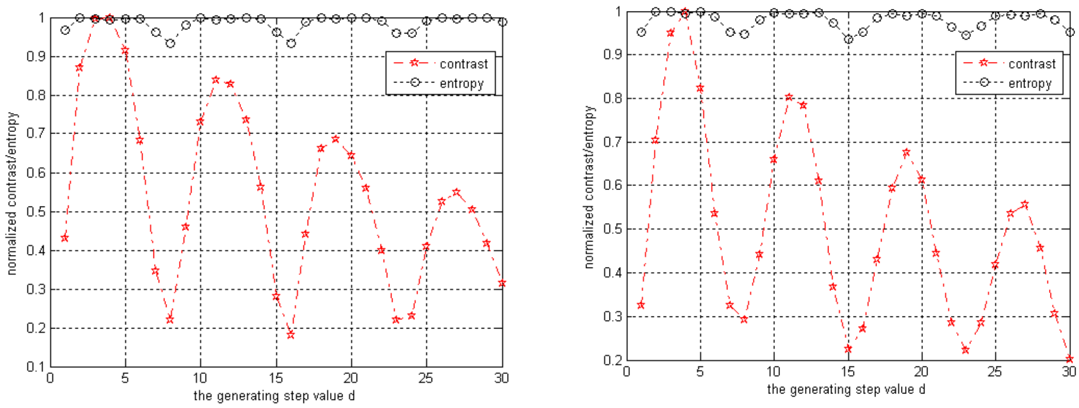


(a)The texture image of a workpiece machined with a sharp cutting tool



(b)The texture image of a workpiece machined with a dull cutting tool

Fig.5 The texture image of a workpiece (feed rate $f = 0.15mm/r$)



(a) The simulation result of the relation between contrast/entropy and the generating step value about the texture image shown in Fig.5(a)

(b) The simulation result of the relation between contrast/entropy and the generating step value about the texture image shown in Fig.5(b)

Fig.6 The simulation of texture feature parameters (feed rate $f = 0.15 mm/r$)

6 Conclusion

The workpiece surface texture images are analyzed to monitor the tool wear condition in this paper. In order to monitor the tool wear accurately, this paper studies the generating step value of GLCM deeply which is for image texture analysis.A new algorithm about generating step value is proposed in this paper. Through analysis and testified by experiments, the optimum value of the generating step value depends upon valley peak and valley bottom of the texture image of the machined workpiece surface when calculating GLCM. The optimum value is the step value which makes the textural feature parameters obtain the extreme value(the maximum or minimum value) in the first period. The optimum value is only related with the feed rate. It is unrelated with the other machining parameters. The optimum value of the generating step value makes textural feature parameter values more different and diverse for different texture images. Consequently the reasonable generating step value are beneficial to monitor the tool wear and makes tool wear monitoring accurately .

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