Machine Vision Based Study on State Recognition of Milling Cutter

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Abstract. As a major cutting tool in machining, the wear state of a milling cutter has a directly impact on machining quality and production efficiency. In order to detect the wear conditions of milling cutter, an inspection platform based on machine vision principle is designed. Hardware arrangement of the platform is introduced and the related equipment is analysed and selected accordingly. The milling cutter clamping device used in the platform is also designed. The collection of the measured milling cutter end image is realized successfully. The image processing methods of worn cutter are studied in detail. Adaptive greyscale adjustment and median filtering are used to decrease the noise in the image. Automatic threshold segmentation and edge extraction based on Sobel operator are also designed to achieve image pre-processing. A series of image processing experiments are carried out. The feature extraction algorithm for worn milling cutter end image is presented. Through comparative experiment, the presented machine vision measurement method is efficient.

1. Introduction
Milling cutter is one of the most widely used tools in mechanical processing. Normally, it may be damaged at the same time in cutting metal materials. The damage form is divided into two categories, wear and broken. If an excessive wear tool is not replaced in time, it will reduce the size and surface accuracy of the work piece being processed, increase the cutting force and temperature of the machine tool, and even damage the machine tool. It can be seen that tool wear is directly related to the efficiency, quality and cost of machining. The detection quality of worn milling cutters is highly required in production practice. The traditional detection method of milling cutter wear is tedious, low accuracy and low efficiency. As a result, it is an urgent problem to improve the detection efficiency and accuracy of milling cutter wear. In general, tool wear detection and recognition are mostly on the basis of cutting force, noise, vibration and other physical quantities produced in the machining process. Appropriate sensor is generally collected to capture the required information to determine the tool wear status[1]. Most of these methods are qualitative or indirect measurement. They are difficult to be applied in actual production because of their poor reliability [2]. Because of advantages of high automation, high detection accuracy and efficiency, non-contact measurement method on the basis of machine vision is widely used in various fields [4][5]. Because it overcomes most shortcomings of traditional tool detection, it has become an important tool in the field of tool detection nowadays. On the basis of machine vision detection technology, a special milling cutter detection platform is developed in this paper, in which three main parts, the milling cutter clamping mechanism, movement platform and system control, are included. A milling cutter clamping equipment is also designed to fit the machine vision experiment. The image acquisition is successfully realized. A series of image processing experiments are carried out on the collected images of milling tool with defects, such as
automatic grey adjustment, adaptive median filter for noise reduction, automatic threshold segmentation by Sobel operator to extract the edge, etc. On the basis of the experiments, the wear defect image of milling cutter is analysed in detail, and a reasonable feature extraction algorithm is proposed, which is verified by experiments. The experimental results show that the method proposed in this paper can achieve higher detection accuracy and efficiency, which is of great practical significance for improving the measurement level of milling cutter and promoting the development and progress of milling cutter industry.

2. Design of Milling Cutter Detection System
Firstly, the end image of a wearing milling cutter is needed to be collected to realize the inspection of its wear conditions through the machine vision method. The fundamental principle is to extract the feature of wear area in milling cutter image and wear condition is then determined accordingly. The parameters of the wear conditions of a milling cutter are calculated in the computer, through which wear conditions of a milling cutter is finally determined.

The hardware part of machine vision inspection system is mainly composed of two parts, one is machine vision experiment platform, and the other is milling cutter clamping equipment.

![Overall structure diagram of system hardware.](image1.png)

![3D diagram of system hardware.](image2.png)

**Figure 1.** Overall structure diagram of system hardware. **Figure 2.** 3D diagram of system hardware.

Overall structure diagram of the system hardware is shown in Fig. 1, in which an industrial camera, telocentric lens, and lighting sources are included to constitute the machine vision experiment bench. Milling cutter fixture and moving platform are included in milling cutter clamping equipment. It is necessary to configure the appropriate lighting source to ensure the clear and bright field of view for image acquisition. The image of milling cutter with defect is collected by the industrial camera, which is zoomed through the telocentric lens. The digitized image is then transmitted to the computer, in which the image processing is carried out. At the same time, the computer is also used to control the movement of the platform and the milling cutter clamping equipment, completing the wear measurement of different areas of the milling cutter.

The design of milling cutter gripping equipment includes milling fixture and motion control platform. By controlling movement of the platform and grasping of the milling fixture, the precise positioning of measured milling cutter is realized. In this way, and the milling cutter is guaranteed to be in an ideal position of the camera vision. As shown in Fig. 2 is the three-dimensional diagram of the hardware of the machine vision detection system. A stepping motor is precisely controlled by STM32 single chip microcomputer to realize the movement of each mechanical structure, so as to complete the precise positioning of the milling cutter and ensure the normal operation of the detection system.

In this paper, camera and lens are fixed and the measured milling cutter is controlled to move accordingly. Therefore, it is necessary to pick up the measured milling cutter by milling cutter fixture. When it moves to the designated position, the fixture will put the milling cutter 7 down and move it out of the camera field of vision. Milling cutter fixture mainly consists of milling cutter conveying device, main manipulator 1 and auxiliary manipulator 3. The batch inspection of milling cutter to be tested can be realized by milling cutter fixture. The detection process is compact, which can not only improve the detection efficiency but also ensure the stability of the system.
1. Manipulator   2. Transmission part   3. Auxiliary manipulator  4. Electromagnet  5. The Conveyor  6. Transmission part of the conveyor  7. Milling cutter to be tested  8. LED back-light

**Figure 3.** Top view of the platform.

The milling cutter fixture used in this paper is shown in Fig. 3. The milling cutter conveying device transports the milling cutter to the designated position through the conveyor belt, and then the main manipulator equipped with electromagnet adsorbs and grabs it and delivers it to the centre of the LED backlight source 8. After that, the secondary manipulator can also grasp and rotate the milling cutter to achieve different angles of shooting. To have milling cutter placed on the backlight smoothly, on the centre place of LED back light a permanent magnet 4 is equipped with in order to avoid milling cutter shaking in moving process of the platform because of its inertia and affecting the normal operation of the detection system.

In transmission of the auxiliary manipulator in the milling cutter, the gear transmission 6 with stable transmission and high accuracy are adopted in this paper. A conveyer belt 5 is used in the milling cutter conveying device. Through a set of gear transmission, the belt is driven in rotation and the milling cutter to be tested is moved to the direction of the LED backlight, to achieve the milling cutter conveying.

3. Detection and Discrimination of Wearing Defects

Through the Milling Cutter Detection System, a series of milling cutter images with good quality are obtained. Image processing experiments, including pre-processing and features extraction, are carried out. The image pre-processing process is as followings, filtering to remove noise, binary image and edge extraction. The pre-processing result is shown as Fig. 4.

After pre-processing, it can be clearly seen that the interference in the image is removed or decreased to some extent. And only interesting features and target object are increased. To correctly calculate the wearing area of cutting edge, accordingly solution is presented in this paper. The program is shown as Fig. 5.

(a) ![Figure 4. Image pre-processing results.](a)  
(b) ![Figure 4. Image pre-processing results.](b)  
(c) ![Figure 4. Image pre-processing results.](c)  
(d) ![Figure 4. Image pre-processing results.](d)

**Figure 5.** Image processing program.

In the edge extraction after the last pre-processing, the profile of the measured milling cutter can be determined ultimately. In practice, however, the circle centre of the milling cutter in image may not be the centre of whole image because of the moving error in the milling cutter fixture. The angle of cutting edge relative to horizontal direction is not concluded as well. Therefore, the image positioning is firstly needed to solve the measurement of the wear amount.

The positioning method includes a series of operation, determination of the optimum circumscribed circles of interesting area, calculation of the centre point coordinate and rotational angle of the...
measured milling cutter in image. In practice, different kinds of milling cutter are tested to complete the experiment of determining the circumscribed circles, in which the Hough transformation is used. The maximum relative error in diameter of the circle determined is controlled to less than 2%.

The angle of cutting edge relative to horizontal direction is used to rotate the image to fix the interesting area in a right direction. In method, any straight line of the cutting edge is firstly extracted. The deflection angle of the cutting edge to horizontal direction is then calculated accordingly. The experimental results in the positioning are shown as Fig.6.

Table 1. The final inspect result of the wear amount of milling cutter.

| No. | Diameter (mm) | Edge number | Average (mm) | Maximum (mm) | Wear Area (mm²) |
|-----|--------------|-------------|--------------|--------------|-----------------|
| 1   | 12           | 4           | 0.1584       | 0.6400       | 0.8864          |
| 2   | 12           | 4           | 0.1294       | 0.4864       | 0.7259          |
| 3   | 12           | 3           | 0.1818       | 0.7872       | 0.7708          |

Table 2. The comparison of wear amount of two methods.

| Group | Cutter No. | Average(mm) | Maximum(mm) |
|-------|------------|-------------|-------------|
|       | Machine | Manual | Machine | Manual |
| First | 1 | 0.0430 | 0.0505 | 0.1010 | 0.0975 |
|       | 2 | 0.0488 | 0.0523 | 0.1451 | 0.1455 |
|       | 3 | 0.0748 | 0.0775 | 0.2019 | 0.1990 |
|       | 4 | 0.0261 | 0.0253 | 0.0505 | 0.0495 |
|       | 5 | 0.1150 | 0.1202 | 0.4733 | 0.4693 |
|       | 6 | 0.0346 | 0.0412 | 0.0568 | 0.0545 |
|       | 7 | 0.1047 | 0.0996 | 0.5237 | 0.5206 |
| Sec.  | 8 | 0.1452 | 0.1513 | 0.5868 | 0.5785 |
|       | 9 | 0.0861 | 0.0907 | 0.1199 | 0.1178 |
|       | 10 | 0.0652 | 0.0614 | 0.1514 | 0.1482 |
|       | 11 | 0.1345 | 0.1309 | 0.4922 | 0.4865 |
|       | 12 | 0.1288 | 0.1331 | 0.4102 | 0.4080 |
| Third | 13 | 0.0448 | 0.0493 | 0.1136 | 0.1120 |
|       | 14 | 0.0916 | 0.1012 | 0.1388 | 0.1359 |
|       | 15 | 0.0787 | 0.0816 | 0.1325 | 0.1285 |
|       | 16 | 0.1523 | 0.1605 | 0.5995 | 0.5960 |
|       | 17 | 0.1009 | 0.1112 | 0.3281 | 0.3242 |
| Forth | 18 | 0.0974 | 0.0898 | 0.1451 | 0.1420 |
|       | 19 | 0.0581 | 0.0625 | 0.1830 | 0.1795 |
|       | 20 | 0.0833 | 0.0792 | 0.2461 | 0.2385 |

Figure 6. Image clipping process and results.

Figure 7. A clockwise rotations of the image and its parameters inspection.
cutting edge. As shown in Fig. 6, (a) to (c) is the rectangular clipping area and the final extracted image. The wear amount of the measured cutting edge then can be calculated according to the image shown in Fig. 6 (c).

The parameters calculated above are only from one of the cutting edges. To estimate wear amount of a milling cutter, every one's parameters should be inspected. As shown in Fig. 7, a clockwise rotation of the image is carried out to obtain the parameters of each cutting edge. In this way, the maximum one among them finally is the wear amount of the milling cutter. Three milling cutters with different cutting edge are used in experiment respectively. The final results are shown as Table 1.

Following the above experimental steps, the wear amount of the cutting edges from 20 milling cutters are measured to compared with the result by manual measurement, in which tool microscope is used. The experimental results reveal that two methods are almost same in correction, as shown in Table 2.

### 4. Summary

The principle and installation of an experimental system for the wear amount measurement of milling cutter are introduced in detail, including the clamping equipment, measurement platform and system hardware structure. A series of image processing experiments have been completed for defects detection of worn cutter and related wear amount calculation, in which image pre-processing and features extraction are accomplished accordingly. The image positioning, wear amount calculation of the measured cutting edge are respectively carried out. The experiment shows a promise result, compared with manual inspection. The developed hardware system can be used to realize the image acquisition and wear defects measurement. The designed device can be used in wear amount measurement and the state recognition of milling cutter in practice.

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