Measurement of Circular Saw Blade Tooth Dimensions based on Machine Vision

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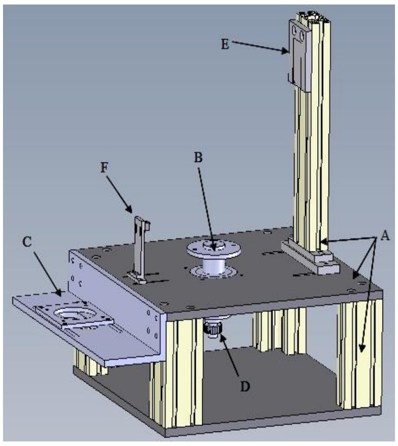
ABSTRACT
Machine vision is a non-contact sensing technology, which has been widely used in various applications, e.g. automatic inspection and robot guidance, in recent years. A basic machine vision system consists of a camera, a frame grabber, a computer, an illuminant source and image processing software. This research studies the application of machine vision for the measurement of tooth dimensions of a circular saw blade. Through backlit illumination, a CCD camera captured the image of the saw blade tooth. The image is then processed and analyzed for the tooth radius and depth. The results are compared with those obtained by an automatic precision measuring instrument (M-V Vertex 410) to verify the accuracy and precision of the machine vision system.

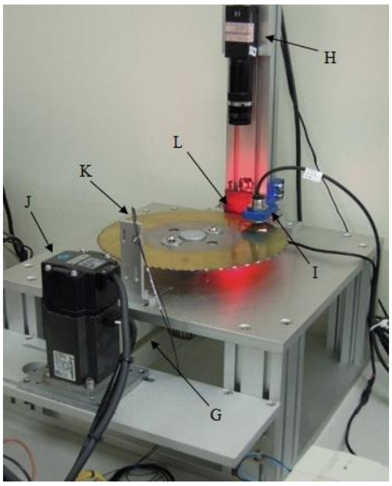
Keywords
Machine vision, Tool inspection, Circular saw blade, Tooth dimension

1. INTRODUCTION
Saw cutting is an important method of machining. Tooth profiles, outer and inner diameters, flatness and concentricity, along with other saw blade parameters, affect saw cutting performance. Hence, it is essential to inspect the saw blade dimensions to ensure the saw is fit for cutting. Machine vision is a non-contact sensing technology able to rapidly collect and analyze a large amount of image data automatically. Consequently, machine vision technology has been implemented in various industries for production line monitoring, work piece inspection and robot guidance, etc. [1]-[3]. Reference [4] proposed a method for micro-milling tool wear inspection using machine vision. Computer vision algorithms for measurement and inspection of external screw threads are developed in [5]. For saw blade inspection, [6] placed several eddy current sensors beneath the saw blade and analyzed the collected data to determine the flatness. Reference [7] developed a machine vision system to measure the outer and inner diameters, roundness error, and angles of the saw blade. Reference [8] evaluated the saw blade dimensional parameters based on image processing techniques. Different tooth profiles are designed for cutting different material and work pieces. If any tooth does not conform to its dimension standards, abnormal noise and vibration will occur and cutting ability will be compromised. Other teeth or the saw blade itself will be damaged or even rupture. Therefore, it is important to inspect the teeth for any dimension variation. In this research, a measuring system is developed based on machine vision technology. The saw blade is illuminated by a backlit panel and its images are captured by a CCD camera. The images are then processed and analyzed for the tooth radius and depth. The results are compared with those collected through a commercial automatic precision measuring instrument (M-V Vertex 410) to check the precision and accuracy of the developed system.

2. HARDWARE SETUP
Typical machine vision system hardware includes a camera, an image capture card, a computer and an illuminant source. Combined with other mechanical and electrical components, an inspection mechanism is constructed for the saw blades. Fig. 1 illustrates the hardware configuration the system besides the computer and frame grabber. Table 1 lists the components shown in the configuration.



(a) A CAD model of the mechanism



(b)The integrated system

Fig. 1: Hardware setup of the inspection system

Table 1 Components of the inspection mechanism

Item	A	B	C	D
Component	Main Frame	Saw Blade Mount	Motor Fixture	Timing Belt Gear
Item	E	F	G	H
Component	CCD Camera Fixture	Optical Fiber Fixture	Timing Belt	CCD Camera
Item	I	J	K	L
Component	Analog Switch	Servo Motor	Optical Fiber Sensor	Red Light Backlit Panel

The saw blade is mounted on the saw blade mount. The end of the mount is connected to the servo motor shaft through a timing belt. The saw blade can be rotated and positioned according to the resolution ratio between the servomotor and timing belt gear. The optical fiber sensor helps positioning the teeth accurately. A red LED backlit panel illuminates the saw blade while a CCD camera captures the tooth images from above.

3. IMAGE PROCESSING

The original image captured by the CCD camera is shown in Fig. 2. It is then transformed by threshholding [9] to the binary, black and white, image in Fig. 3. The black and white colors of the binary image are switched to represent the blade teeth in black. The teeth can then be observed in greater contrast to the background.

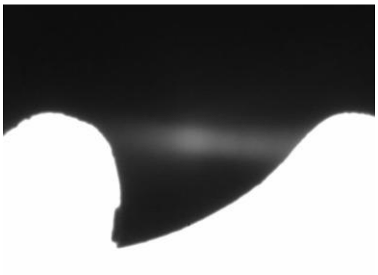


Fig. 2: The image captured by the CCD

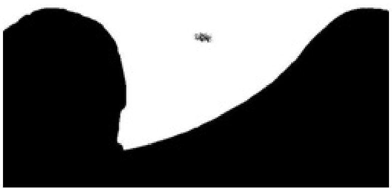


Fig. 3: The binary image

As seen in Fig. 3, the binary image has a small black spot outside the teeth. It corresponds to the blurry area, which reflects more light, in the image of Fig. 2. The spot is eliminated by a hole-filling algorithm [10]. The image after hole-filling is shown in Fig. 4. Because the edges of the teeth reflect light differently, the contours of the teeth are zigzagged. A median filter is applied to the image to produce smoother contours while preserving the integrity of the tooth outlines.

Fig. 4: The binary image after hole-filling

Fig. 5: The median filtered binary image

To locate the specific area for measuring the tooth dimension, a standard template of tooth image is created beforehand. The template is than compared to the image by a process called pattern matching [11]. The matched area is shown in Fig. 6. A proper coordinate is essential in machine vision measurement [12]. A coordinate system is then placed on the image in reference to the template, as shown in Fig. 7.

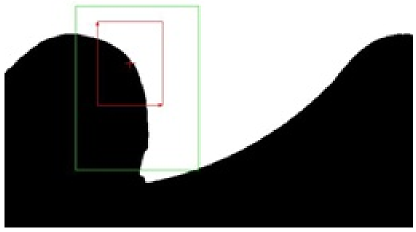


Fig. 6: Pattern Matching

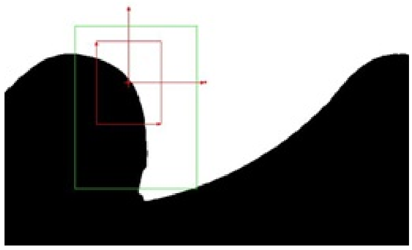


Fig. 7: An image coordinate system

4. DIMENSION MEASURING

The image is calibrated by importing a scale image and placing it on top, as illustrated in Fig. 8. Fig. 9 shows that a circular arc feature is extracted from the image and 25 points are located on the edge of the arc for measuring the radius.

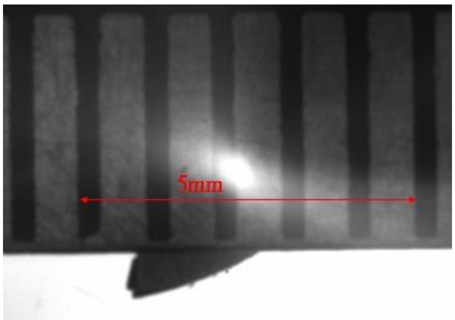


Fig. 8: The calibrated image

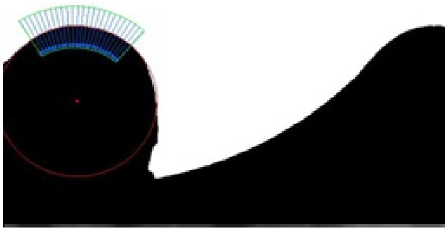


Fig. 9: Extracted circular arcs

The coordinates of the i^{th} point are designated as xi and yi. The center coordinates of the arc are x0 and y0. The tooth radius r is calculated based on (1) with number of points m=25. The estimated tooth radius is pictured in Fig. 10. For the height of the tooth, the inspected area is equally divided into 65 portions, as illustrated in Fig. 11. The y coordinate of the edge in each portion of the tooth image is measured. The highest and lowest y coordinates, ymax and ymin in Fig.11, can be found. The tooth height h is then estimated from (2).

$$r = \arg\min \sum_{i=1}^{m} \left(\sqrt{(x_i - x_0)^2 + (y_i - y_0)^2} - r \right)^2 \quad (1)$$

$$h = y_{\max} - y_{\min} \quad (2)$$

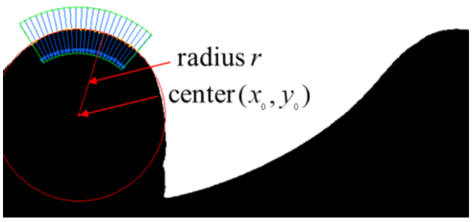


Fig. 10: Estimated tooth radius

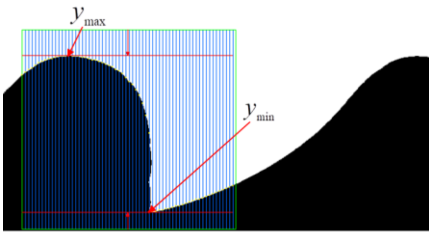


Fig. 11: Estimated tooth height

5. RESULTS AND DISCUSSION

80 measurements are conducted and the results are summarized in Table 2. Table 2 also includes the data collected by an automatic precision measuring instrument (M-V Vertex 410). The results indicate that the developed system has accuracy comparable to the commercial one and even higher precision as demonstrated by its smaller standard deviations.

Table 2 Measuring results of the developed system and M-V Vertex 410

System → Tooth dim. ↓	Developed System		M-V Vertex 410		$\frac{A-B}{B}\times 100\%$
	Mean (A)	standard dev.	Mean (B)	standard dev.	
Radius *r* (mm)	1.190	0.018	1.188	0.031	1.69%
Height *h* (mm)	2.397	0.015	2.388	0.023	0.37%

Nevertheless, it should be noted that the measured areas of two systems may not be the same. Each tooth of the same blade varies slightly. Lighting and mechanical vibration may also contribute to the measurement errors. However, the results demonstrate the effectiveness of the developed system. It can be incorporated into an automatic production line to perform accurate and fast inspection of the cutting tools. Human inspection errors can be reduced.

6. CONCLUSION

A circular saw blade tooth dimension measuring system based on machine vision is developed. The system is shown to produce accurate and precise measurement results. Fast and consistent measurement can be achieved without too much human effort and cost. Human error can be avoided. Some conclusions are made in the following:

(i) A backlit LED red light source is used. The CCD camera has a good response to red light illumination. LED lights have high luminous efficacy and long lifetime. The backlit panel clearly shows the profiles of the blade tooth. Proper setup of hardware increases the quality of the captured images and decreases the complexity of image processing.

(ii) Image processing by median filtering and hole filling reduce the image disturbance on the edges without compromise the profile integrity. The interference of the reflected light is eliminated. Possible measurement error is avoided by image processing.

(iii) The measurement results can be shown on a computer user interface. An inspector can easily observe the results and decide whether or not the saw blade teeth are up to standard.

(iv) The measuring results of the developed system are accurate and precise as verified by a commercial automatic precision measuring instrument (M-V Vertex 410).

(v) The dimension measuring time for each tooth is about 0.060 seconds. The positioning time is 0.8 seconds. For a saw blade of 140 teeth, it takes only around 2 minutes to finish the inspection.

7. REFERENCES

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