International Journal of Mechanical and Aeronautical Engineering Vol.1, No. 1,September, 2017

Visual Inspection System for the Spur Gears

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Abstract. In industry, gears are mostly measured by the direct contact between the stylus and gears. However, the measuring device is expensive and difficult to be applied in the measurement of the small gears. The main objective of this paper is to develop a measurement system for the spur gears by the image processing technology. In present, most of the commercial image measurement systems could only measure the point, line, and fillet of a work-piece. If the systems are applied in the gear measurement, it can only measure the outside and root diameters. The profile deviation and pitch error cannot be obtained due to the gears complicated geometry. In this paper, a new method of comparison edge detection is applied to measure the spur gear. It can have a better quality of the boundary curve to improve the precision of measurement. Thus, the developed system can be applied in the measurement of the important parameters and determine the precision of gear tooth profile, etc. In order to validate the developed system, the direct contact measurement is also preceded. This developed system provides a reliable and powerful method to measure the spur gears and the results can also be applied to the other types of planar gears such as non-circular gears.

Keywords: *Image Processing; Measurement; Profile Deviation; Pitch Error; Non-circular Gear.*

I. Introduction

Involute gears are the most commonly used components in the power transmission system. The reasons are: (1) It still maintains a certain rotational speed ratio with center distance deviation. (2) Involute gears could be manufactured by the straight-edged cutting tool with high accuracy. For higher production efficiency and quality demands, gears inspection technology must be improved. Conventionally, the diameter, tooth thickness and other basic data of small gears (module<0.5 mm) are measured by manual. The projection is used to evaluate the precision of tooth profile by comparing the manufactured gear with the drawing of gears. However, the results are not reliable and cannot obtain the level of precision. If the precision level of gears needs to be evaluated, high accuracy measurements instrument is required. Although the development of automated measurement instruments, for example, 3D CMM (Coordinate Measuring Machine) and stylus profiler are widely applied in industry, the application is still limited in the field of the measurement of small gears due to the limit of probe diameter.

In the references of applying image system to be the tool of the non-contact measurement, Zhang and Wei [1] developed a method to detect the contact region of the hypoid gears by the image processing. Jalili et al. [2] introduced the problems of visual dimensional inspection and some solutions to improve the systems performance. Nayar and Nakagawa [3] applied the sum-modified-laplacian to calculate image focus in the microscopic image and reconstruction the 3D profile of the article in the microscopic image. Pentland [4] proposed a way of focal gradient to calculate everyone pixel depth in the image by measuring image fuzzy. Subbarao and Choi [5] proposed a way of getting the article contour in the focused image surface, and reconstruct the 3D profile data by the image focus in the block plane.

Recently, some companies begin to develop the commercial system for the small gears measurement. However, the high price limits the

Manuscript received July 1, 2016; revised August 1, 2016 accepted February 1, 2017

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application of the device. And the algorithm is not well known to the engineers. In this paper, a visual inspection system is developed for the measurement of spur gear based on the image processing.

II. A NEW COMPARISON EDGE DETECTION METHOD

Sobel edge detection method is frequently applied for the detection along the horizontal and vertical directions. The other directions detection will have larger error. The 8-neighbor edge filter method shown in Fig.1 can compensate the mentioned disadvantages. It improves Sobel edge detection along the top, down, left, and right directions. Filtering and the masks can be designed to detect lines (edges) along a specific direction. The accuracy of the edge has then been improved. However, the extraction edge attained by Sobel or 8-neighbor detections has wider width. In this study, a new edge detection method is introduced by defining a new image threshold and applied in the profile detection of spur gears. The threshold has a 5 x 1 horizontal and 1 x 5 vertical matrices shown in Fig. 2. When y is defined as the vertical coordinates of the image, type 1 is the matching pattern for the looking of the bottom boundary point. When the detected line matched with the type 1 of pixel arrangement, y_i is set to be dark spot and saved to another new image. When the detected line matched with the type 2 of pixel arrangement, the up boundary is found by setting y_i as the dark spot. The types 3 and 4 are then applied to search the horizontal boundaries. By applying the proposed method, only two computing processes (horizontal and vertical) are needed, and the line of the edge can be specified precisely. Comparing with Canny edge detection method, half computing time of the proposed method is required. The method can improve the accuracy of the boundary and reduce the computation time. The results obtained by 8-neighbor edge filter and the proposed method are shown in Fig.3.

-1	-1	0	1	1	1	0	-1	-1
-1	0	1	0	0	0	1	0	-1
0	1	1	-1	-1	-1	1	1	0
1	0	-1				-1	0	1
1	0	-1				-1	0	1
1	0	-1				-1	0	1
0	1	1	-1	-1	-1	1	1	0
-1	0	1	0	0	0	1	0	-1
-1	-1	0	1	1	1	0	-1	-1

Figure 1. 8-neighbor edge filter.

Type 1		Type 2
0	y_{i-2}	255
0	y_{i-1}	255
255	y_i	255
255	y_{i+1}	0
255	y_{i+2}	0

	x_{i-2}	x_{i-1}	x_i	x_{i+1}	x_{i+2}
Type 4	255	255	255	0	0
Type 3	0	0	255	255	255

Figure 2. Edge detection

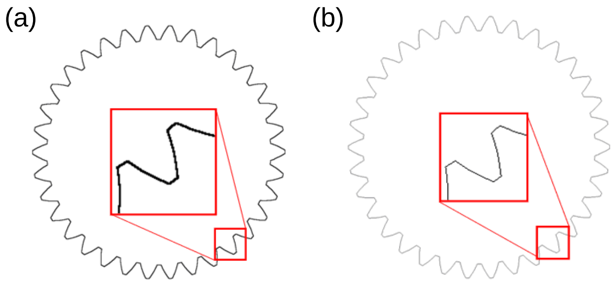

Figure 3. Comparison of two edge detection methods
(a) Boundary obtained by 8-neighbor edge filter;
(b) Boundary obtained by the proposed method.

III. DEVELOPMENT SYSTEM FOR SPUR GEAR

This paper aims to develop an image processing system for the spur gears. The important data and precision level of the gears can be determined by the developed system which contains image capture and image processing modules. The image processing module contains the algorithms for the detection of main parameters of spur gears. The image capture module relies on the precision setting, hardware control, and pixel adjustment.

A. Structure of the Measurement System

The developed machine vision measurement system can be divided into image capture and image computing module while the image capture module contains the CCD (Charge-coupled Device) camera, lens, CCD bracket, image capture card and the integrated light source. In the system, the CCD is adopted to capture the images of gears and transmits the image data to the PC through the video capture card. The proposed measurement system applies the image processing techniques and numerical methods to develop an automated measurement system for the spur gear. The developed system architecture is shown in Fig. 4, where the software features are mainly composed with image reading, image processing, determination of important dimensions, and the output of measured results.

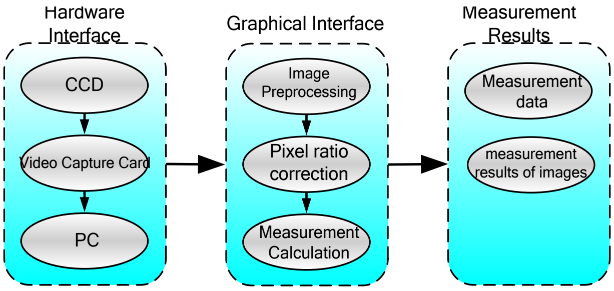

Figure 4. Architecture of the Machine Vision System

B. The measurement of the spur gear

The developed automated gear image measurement system contains the measurements of tooth thickness, the whole depth, circular pitch, pressure angle, and the error of tooth profile.

In present, there are few image processing systems developed for the precision level evaluation of the gears. In this study, the system is developed to measure the spur gears. After the pitch points are obtained by checking the intersection of tooth profile and pitch circle, an arbitrary pitch point can be selected as the starting point for the search of the tooth profile and pitch errors. The stored pitch points can be applied to evaluate the single pitch error, adjacent pitch error, and cumulative pitch error. The profile's searching direction is defined by the quadrant of the tooth profile located as Fig. 5 shows. If the upper region of the left side of tooth profile needed to be searched, the searching direction is along directions 1, 2, or 3 shown in Figs. 5 and 6. If the lower region of the left side of tooth profile needed to be searched, the searching direction is along directions 5, 6, or 7 shown in Figs. 5 and 6. Follow the mentioned process and choose a pitch point P, the tooth profile and the tangent points T_1, T_2 of the base circle can be obtained. The pressure angle α_1, α_2 shown in Fig. 6 can be computed. Comparing with the theoretical involute tooth profile, the deviation of the left-sided tooth profile is obtained. The deviations of right-sided tooth profile and another chosen three teeth can be calculated. When N is the number of teeth of the measured gear, D is set to be the integer part of N/4. Another three measured teeth are the number D+1, 2D+1, and 3D+1.

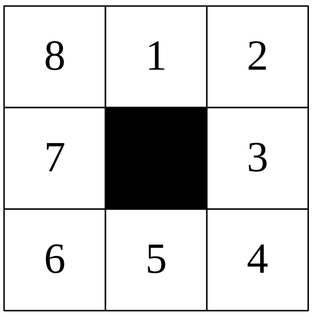

Figure 5. Edge detection direction

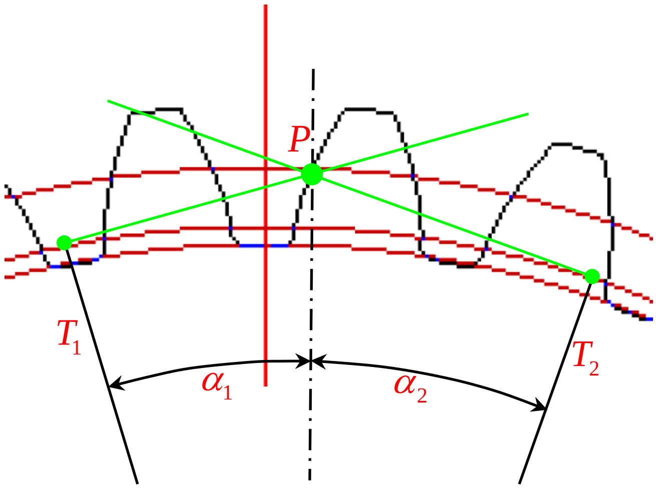

Figure 6. Measurement of Tooth Profile Deviation

IV. RESEARCH RESULTS

The window interface of the developed system is shown in Fig. 7. The interface has "Loading image file", "Image processing", "Instant coordinates", "Pixel adjust", "Determination of the gear center", and "Image processing of gears". The image processing function contains the gray level, threshold, and search of edge. The gear image processing function can be used to measure the gear thickness, pitch, whole depth, pressure angle, and misalignment of the gear, tooth profile deviation, and outputs the measured data. In order to verify the reliability of the developed system, a module 0.5 mm spur gear with 34 teeth drawn by CAD and shown in Fig. 8 is used to measure the important indices. The measured results are shown in Figs. 9 to 15. The errors highly depend on the resolution of the pixel of the image.

Then, a standard spur gear shown in Fig. 16 which is manufactured by KHK CO. is adopted as the test sample whose accuracy is JIS B 1702-1 N8. The pressure angle is 20°, module is 0.5 mm, and numbers of tooth is 15(BSS0.5-15A). Tables I to III show the results of tooth thickness, single pitch error, adjacent pitch error, and cumulative pitch error got by the developed system and the device of Mitutoyo CNC Coordinate Measuring Machine (Crystal Apex C Series). It reveals that the developed image processing system can be successfully applied in the measurement of spur gears. However, the device of Mitutoyo is not suitable to evaluate the error of the tooth profile. Fig. 17 shows the error of the tooth profile obtained by the developed system in this research.

The developed system can also be applied in the fundamental measurement of the non-circular gears. Fig. 18 shows a noncircular gear with module 2.5 mm and 47 teeth for the measurement. Because the size limit of the image, two teeth are measured and shown. Tables IV to VII show the measured results of tooth thickness, pitch, addendum, and dedendum, respectively. However, due to the different curvatures of the teeth, the tooth profile measurement of the non-circular gear is still a challenging work.

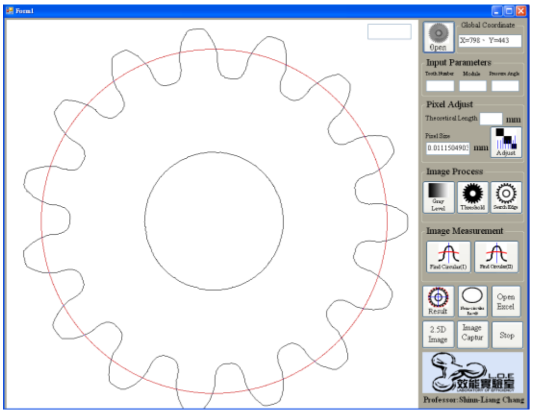

Figure 7. Main interface of the measurement system

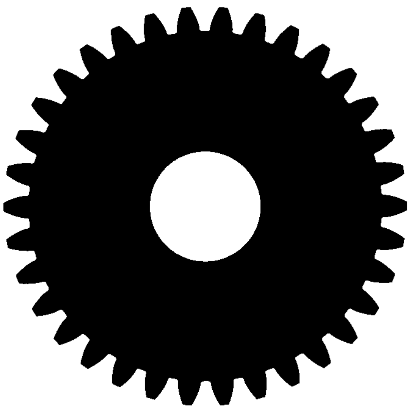

Figure 8. Theoretical spur gear

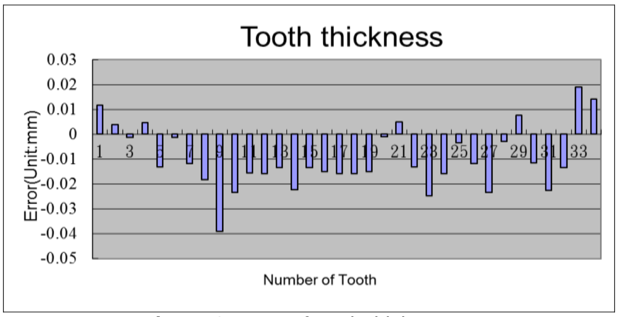

Figure 9. Error of tooth thickness

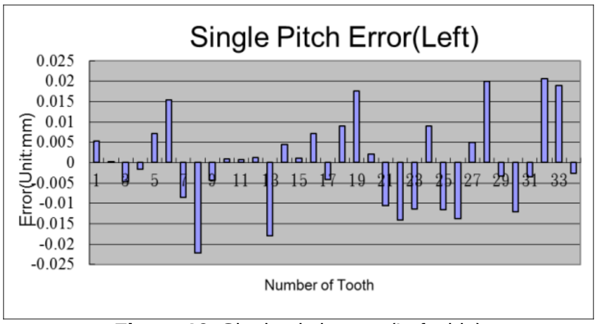

Figure 10. Single pitch error (Left side)

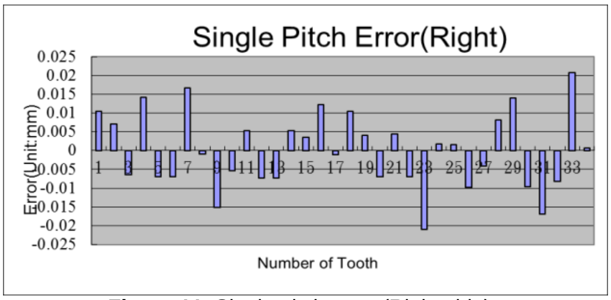

Figure 11. Single pitch error (Right side)

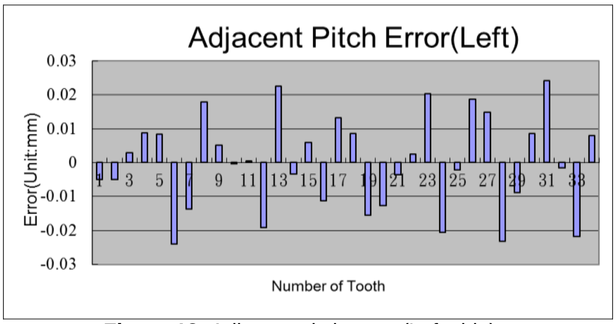

Figure 12. Adjacent pitch error (Left side)

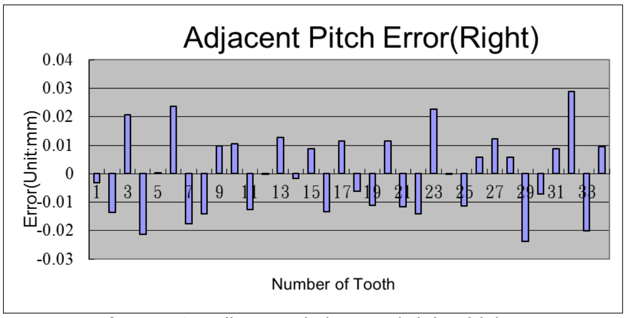

Figure 13. Adjacent pitch error (Right side)

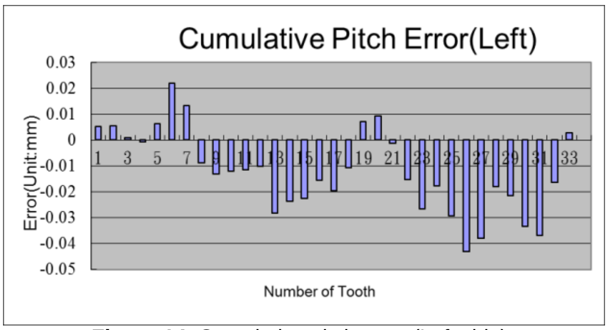

Figure 14. Cumulative pitch error (Left side)

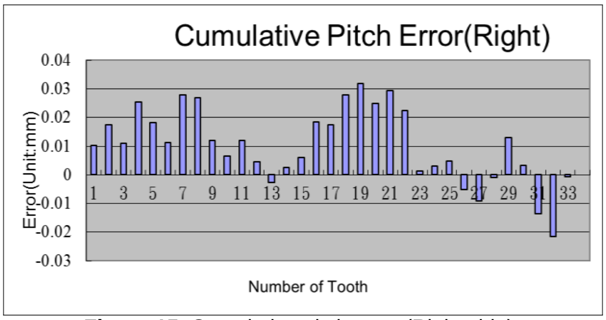

Figure 15. Cumulative pitch error (Right side)

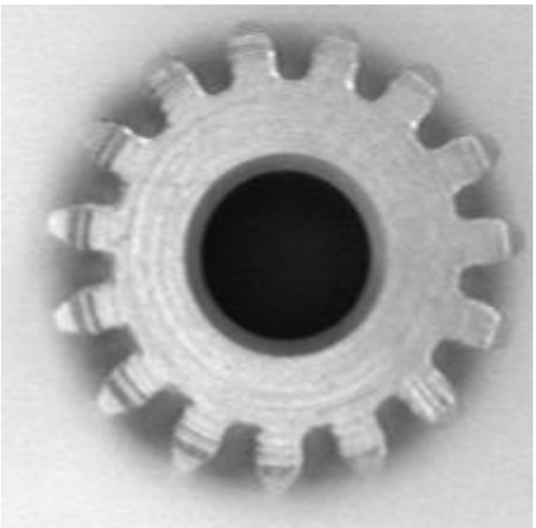

Figure 16. Spur gear BSS0.5-15A

Table I. Measurement of tooth thickness unit: mm

Theoretical tooth thickness	0.785398		
	Average	Average error	Error percent
This research	0.782591	0.002807	0.35%
Mitutoyo	0.760098	0.0253	3.22%

Table II. Measurement of left pitch unit: mm

	Single pitch error	Adjacent pitch error	Cumulative pitch error
This research	0.007629	0.007487	0.015052
Mitutoyo	0.007493	0.004846	0.013006

Table III. Measurement of right pitch unit: mm

	Single pitch error	Adjacent pitch error	Cumulative pitch error
This research	0.00799	0.008278	0.020468
Mitutoyo	0.00588	0.0039	0.004706

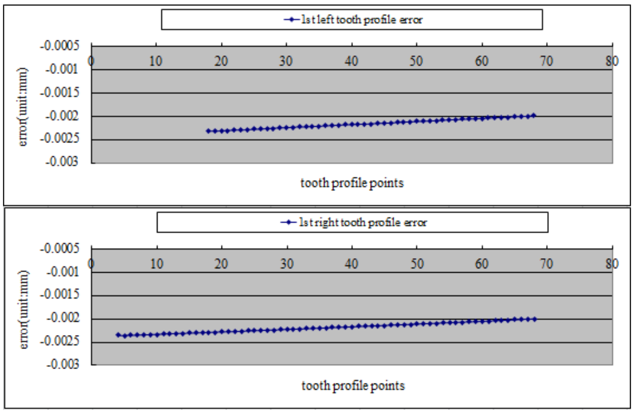

Figure 17. SS0.5-15A Tooth profile error comparison

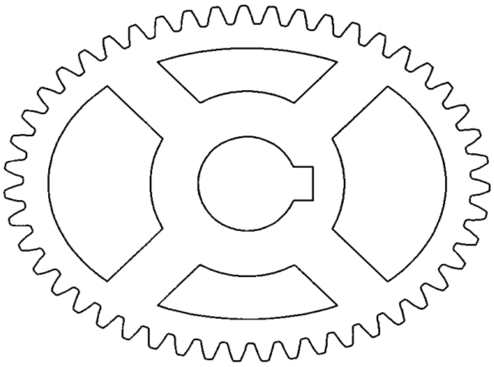

Figure 18. A non-circular gear

Table IV. Measurement of tooth thickness for the non-circular gear unit: mm

Theoretical tooth thickness	3.926991	
	Measured length	Error percent
1st tooth	3.959538	0.82%
2nd tooth	3.901734	0.64%

Table V. Measurement of pitch for the non-circular gear unit: mm

Theoretical pitch	7.853982	
	Measured length	Error percent
Left 1st pitch	7.890173	0.46%
Left 2nd pitch	7.832370	0.27%

Table VI. Measurement of addendum for the non-circular gear unit: mm

Theoretical addendum	2.41	
	Measured length	Error percent
1st addendum	2.426110	0.67%
2nd addendum	2.427786	0.74%

Table VII. Measurement of dedendum for the non-circular gear
unit: mm

Theoretical dedendum	2.91	
	Measured length	Error percent
1st dedendum	2.875759	1.18%
2nd dedendum	2.857400	1.81%

V. CONCLUSION

In industry, gears are mostly measured by the direct contact between the stylus and gears. The method is not suitable for the measurement of soft (plastic) and small gears, especially, the measurement of the small gears with the module less than 0.5 mm. Now, there are some companies try to develop the commercial module for the small gears measurements. However, the algorithm is not released in literature. In this paper, an image processing system is developed to measure the parameters and precision level of spur gears. The experimental results and comparisons show that the developed system is feasible and useful to measure the spur gears with small module.

The developed system can also be applied in the measurement of non-circular gear. The boundaries of non-circular can be obtained by the proposed comparison edge detection method. However, the tooth profile error needs to compare the theoretical tooth profile with the measured profile. Due to the different curvatures of the teeth, the measurement of profile errors is still a challenging work in the industry.

VI. ACKNOWLEDGEMENTS

The authors wish to thank MOST 104-2218-E-010-004 project for the financial support.

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