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Design and Performance Analysis of Developed Computer Vision Measurement Application for End Mill Cutting Tool

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Abstract

Quality control department of end mill cutting tool manufacturer always deal large quantity of products daily and faced capacity, errors, and machine limitation issues. Precision computer vision measurement application overcome those issues. In this paper, multi features computer vision measurement application had been developed to determine diameter, runout, and corner radius of end mill cutting tool and radius for ball nose cutting tool. The accuracy of developed application had been verified and compare with commercial unit. The result outcome had obtained ±0.002 mm or less than 0.20% differences accuracy for all measurement modules from cutting diameter range of 1 mm to 8 mm.

Keywords: Image Processing, Computer Vision, OpenCV, Node Red, Python

I. INTRODUCTION

Quality control (QC) is the most important process in a production line as it represents the reputation and brand of a company's product. In end mill cutting tool manufacture production line, QC department deal up to thousand pieces of products daily to ensure that the quality within specification in term of dimension and appearance. Currently, QC department faced few issues, which were capacity of equipment, human error, and machine limitation. One of the major causes is the fabrication tolerance of end mill cutting tool become tighter in micrometer and this cause human unable to tackle the rejected item precisely. As technology growth, precision measurement equipment's common available in market in order to overcome those issues stated. Unfortunately, those commercialize measurement equipment have their own limitations such as less configuration flexibility. For example, some of them unable to measure some parameters such as corner radius, diameter, point angle, and run out of a cutting tool at the same time. This may increase the department's lead-time and decrease in productivity. Some of the equipment able to get all parameters of a cutting tool, but flexibility and cost were the major concern during selection. Hence, develop a flexible, affordable and high efficiency of computer vision measurement equipment was required in order to overcome those issues. This measurement application developed with open source image processing libraries by Python programming language in order to determine the diameter, runout, corner radius of end mill cutting tool and radius of ballnose cutting tool between cutting diameter of 1 mm to 8 mm. The performance of developed computer vision measurement application was compare with commercial unit, named Zoller Venturion for accuracy verification.

II. LITERATURE REVIEW

Machining is a process that shape the workpiece into desired dimension, surface and size by removal unwanted material [1-2].

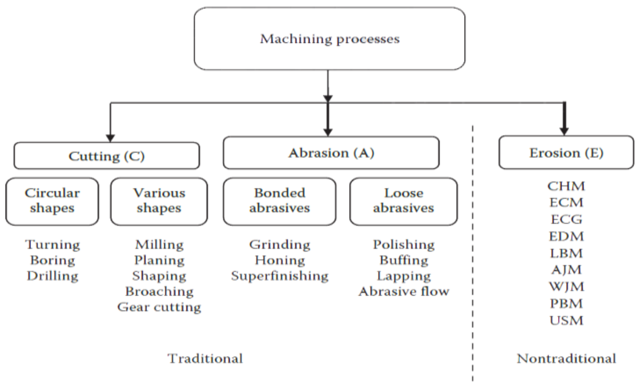

Fig. 1. Categories of Machining Process

Non-conventional machining process such as electrical discharge machining (EDM) and wire cut able to overcome most of the situation in machining process [3] but it was not cost effective. Therefore, conventional machining process still had high demand in machining process [4]. Fig.1 show the

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categories of machining process.

End mill cutting tool is the main tool of conventional machining process. The parameters on geometry such as diameter, run out, surface roughness of an end-mill cutting tool are extremely important as it affect the tool life directly during machining process [5]. Hence, the function of end mill cutting tool and demand on precision measurement application increasing [6] as the tolerance required become tighter [7].

Many researches carried out to determine the condition of targeted product [8-14]. For end mill cutting tool, Lee had been carried out a development on image processing application in order to determine the fracture in ceramic cutting tool from the profile of workpiece after cutting process [15]. A high-resolution digital single-lens reflex (DSLR) camera had been used to discover the workpiece in real time. Fast Fourier transform (FFT) algorithm was used in this research to interpret the data outcome in order to determine the condition of ceramic cutting tool.

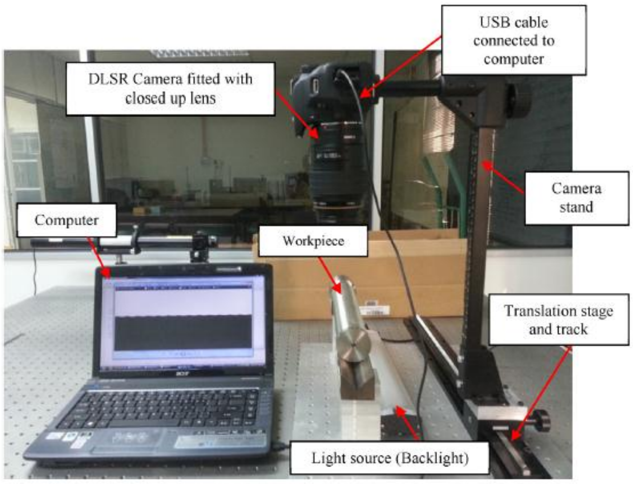

Fig. 2. Setup of ceramic cutting tool research

Chen et al. [16] developed a simple machine with two axes movement in order to measure geometric parameters of end mills cutting tool. Charge-coupled device (CCD) camera and illuminations used to determine diameter, ball-nose radius, helix angle, axial relief angle, and axial clearance angle of end mill cutting tool. The movement system used servo mechanism due to servo provided precision movement up to 1 µm [17].

Cutting tool detection system by image processing had been introduced by Weng and Wang to perform measurement on end mill cutting tool [7]. Low image processing methods such as threshold, noise filtering, and edge contour detecting were used to produce better and clearer image output and diddle image processing method used in order to measure the external diameter, angles, and the attributes of the tool.

Surface defect inspection of end mill cutting tool by image processing method had been proposed by Inoue by simple setup [18]. Discrete Fourier Transform (DFT) mathematic algorithm was used to create the attributes of the image after some low level image processing for the input of neural network.

III. METHODOLOGY

Precision computer vision measurement application required to develop in this project. Few components and tools for both hardware and software used were crucial in order to achieve the desired result and objectives. Basler acA1920-150 µm USB 3.0 camera, Opto Engineering Bi-telecentric lens TC23009, Opto Engineering telecentric illuminator LTCLHP023G, ZhengKe DC motor, and Cytron MD10C DC motor driver were the main hardware components for this measurement application. Global shutter mode of digital camera had been selected instead of rolling shutter to avoid the distortion created on image output as global shutter captures the light simultaneously for all pixels at the same time. Fig.3 shows the comparison of light capture method between rolling shutter and global shutter.

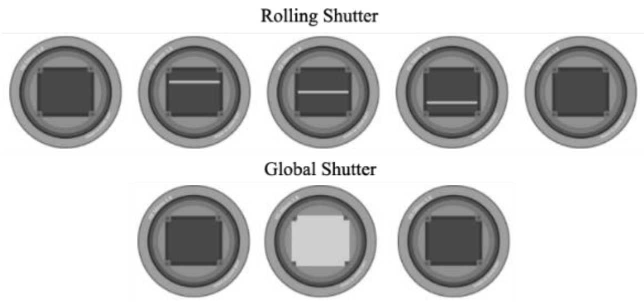

Fig. 3. Light capture method comparison

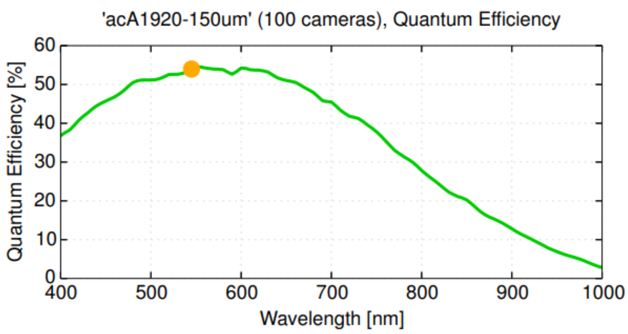

Fig. 4. Graph of quantum efficiency against wavelength of Basler acA1920-150um camera

Green color illumination had been selected for the telecentric collimated back illumination as the European Machine Vision Association (EMVA) data sheet of selected camera had provided which showed the relationship between quantum efficiency and light wavelength. Fig.4 shows the graph of quantum efficiency against light wavelength that provide in the EMVA data sheet of selected camera.

Software that used to configure the camera is Basler pylon camera software suit while Opto Engineering TCLIB suite used on calibration of alignment for both telecentric lens and telecentric illumination. Python language was used to develop the image processing algorithm. OpenCV open source image processing library was included in the algorithm for low level image processing and other mathematical algorithm libraries also used for geometrical processing. Mechanical design by using Solidworks for jig and fixture 3D drawing. For graphic user interface (GUI), Node-Red had been used as GUI development platform to create a simplified control environment between user and devices. Commercial measurement unit act as the result comparison benchmark of the developed measurement application in this project. The designed and developed mechanism shown in Fig.5.

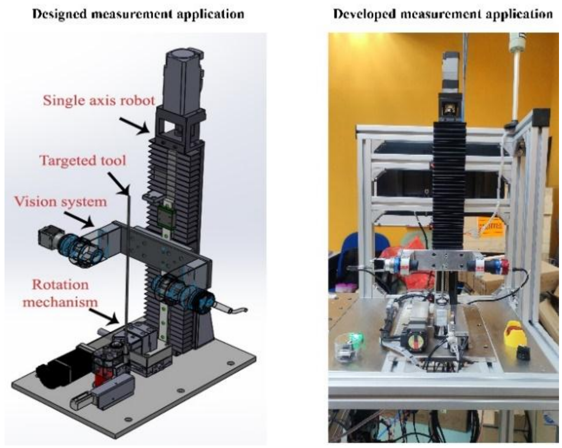

Fig. 5. Designed and developed mechanism

The developed application was the environment for the vision system to perform measurement on end mill cutting tool in order to determine the required parameters. The end mill cutting tool was place on the roller jig that rotate by DC motor and the vision system discover the tip of targeted cutting tool. The single axis robot bring the vision system to the tip of the cutting tool by moving vertically. The supported size of shank diameter was below 8 mm. The vision system continuous captured the targeted cutting tool and processed the images in real-time. The nominal parameters of end mill cutting tool provided by user through GUI that act as the input for measurement.

Calibration in term of mechanical and pixel size had been carried out before proceed to measurement to increase the accuracy of the vision system. Mitutoyo blank rod used to determine the pixel size in millimeter by using self-developed algorithm. Calibration in term of mechanical alignment had been carried out with assist of TCLIB suite that shows in Fig.6.

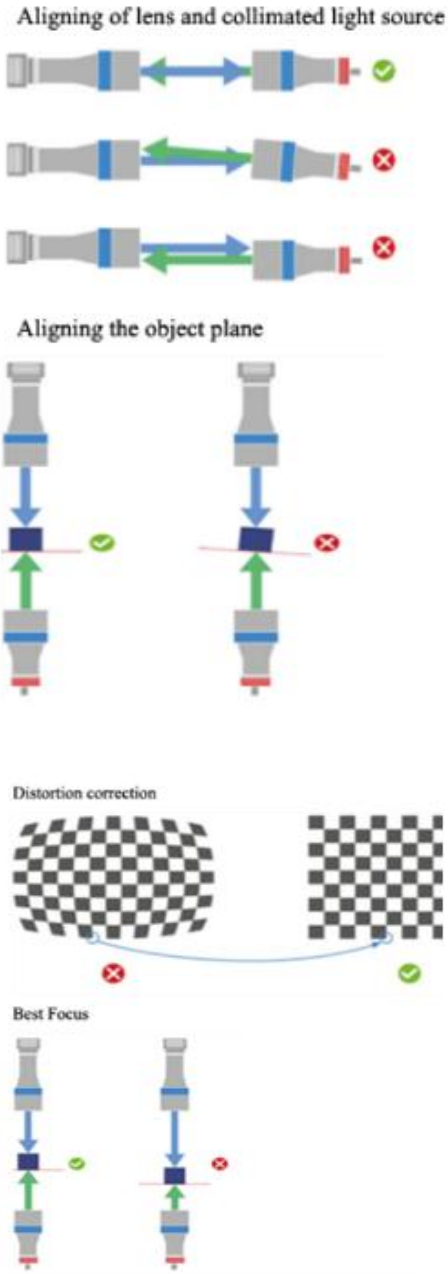

Fig. 6. Mechanical calibration

TCLIB suite able to assist for the alignment of telecentric lens and collimated illumination by provide visual color feedback in order to obtain homogeneous illumination. Beside that, alignment about object plane also able to perform by using this software to provide parallel vision system axis and targeted object plane to avoid errors. Also, TCLIB suite provide visual feedback of the best focus of optics toward targeted object by using the chessboard calibration plate in order to tune the distance between plane of chessboard and the edge of optics.

The targeted end-mill cutting tool that gripped on the measurement mechanism underwent the self-developed measurement algorithm in order to determine the required parameters.

IV. RESULT AND DISCUSSION

Four parameters of end mill cutting tool had been determined during this project, which were diameter, runout, corner radius, and radius of ball nose cutting tool. Following section discussed each parameter accordingly. The nominal configuration values input on the self developed NodeRed GUI which able to plug the value to the measurement module. Fig.7 show the GUI with some explanation.

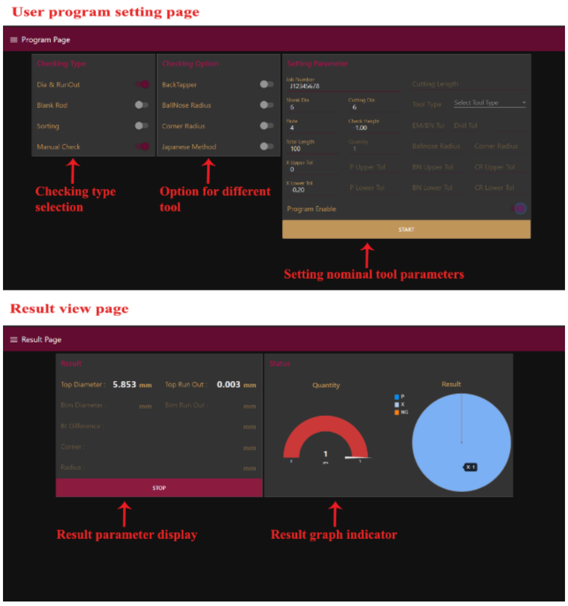

Fig. 7. NodeRed GUI

Fig. 8. Effective diameter of tool

A. Diameter & Run out

Diameter of end mill cutting tool had been determined by minus between effective diameter with run out of tool. The effective diameter determined from the stack image of the tool with the outer contour. Fig.8 shows the effective diameter coverage of end mill cutting tool.

During stacking cutting tool image, pixel data at certain point was continuous captured and store in a variable. These data were used for determine the parameter of each flutes of end mil cutting tool and different between flutes was the run out of the end mill cutting tool. Fig.9 shows show graph of x-axis coordinate against number of flutes.

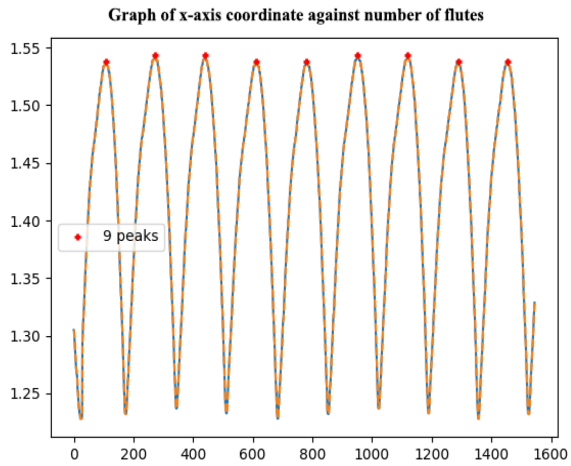

Fig. 9. Effective diameter of tool

Table 1. Diameter and run out compared result

Commercial Unit		**Self-developed Unit**	
Diameter (mm)	**Run out (mm)**	**Diameter (mm)**	**Run out (mm)**
0.996	0.003	0.995	0.003
1.950	0.001	1.952	0.001
2.999	0.004	2.998	0.003
3.980	0.005	3.981	0.004
5.000	0.002	4.999	0.002
5.998	0.002	5.999	0.002
7.999	0.003	7.998	0.003

The peak of every flute had been determined and minus between the maximum with the minimum point to calculate the run out of end mill cutting tool. Few data sets had been determine in order to determine the most frequency value to create more result that is reliable. The measurement had been repeat and compare with commercial unit. Table I below shows the results of diameter and run out measurement that compare with commercial unit.

All the value had been repeated 5 times and average results was taken. The different between self-developed and commercial unit was about 0.10% or 0.002 mm in maximum. This able to proved that the results were reliable.

B. Corner Radius

The corner radius of end mill cutting tool had been determined by using Japanese method. Fig.10 shows the method description and the parameter labeling.

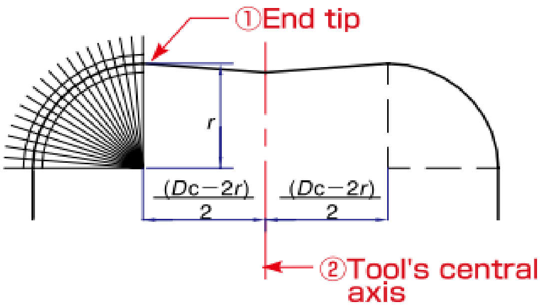

Fig. 10. Corner radius Japanese method schematically diagram

The center of corner radius had been define by two parameters which were end tip and tool's center axis. The nominal cutting diameter of targeted tool had been minus by radius and divided by two which act as x coordinate. Nominal radius act as y coordinate for center of corner radius. Table II below shot the compared result of corner radius.

Table 2. Corner radius compared result

Diameter (mm)	Corner radius(mm)	
	Commercial unit	Self-developed unit
1	0.199	0.198
2	0.397	0.399
3	0.480	0.483
4	0.595	0.596
5	0.798	0.800
6	0.998	0.996
8	1.190	1.188

Same with diameter and run out result, the value had been repeated 5 times and average results was taken. Also, the different between self developed and commercial unit was about 0.15% or 0.003 mm in maximum.

C. Ballnose Radius

The ball nose radius had been conducted by using Hyper least square method that able to generate the best fit of circle from the ball nose contour. The more data input, the more accurate the center and radius of the circle drawn. Fig. 11 shows the drawn circle by hyper least method and the center of the circle had been labeled.

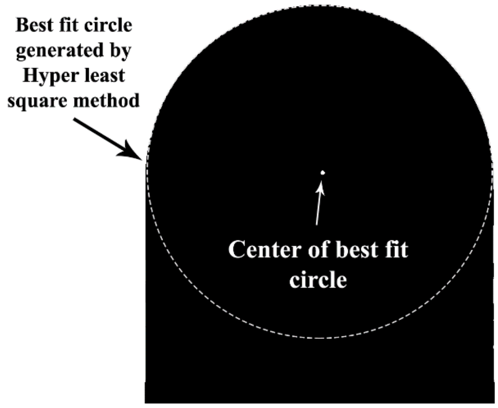

Fig. 11. Circle drawn by Hyper least square method

This method regardless with the nominal input value which it determine by the contour coordinate. The returns of the algorithm were the coordinate of best fit circle center and the radius of the circle. The radius return was the ball nose radius that required to determine. The result had been determined and recorded that shows in Table III below.

Table 3. Ballnose radius compared result

Diameter (mm)	Ballnose radius(mm)	
	Commercial unit	Self-developed unit
1	0.499	0.497
2	0.996	0.996
3	1.496	1.498
4	1.997	1.995
5	2.490	2.493
6	2.987	2.990
8	3.993	3.995

The values had been repeated 5 times and average result was taken. The different between the self-developed and the commercial unit was about 0.15% or 0.003 mm in maximum.

VI. CONCLUSIONS

In conclusion, the results obtained of self-developed computer vision measurement application was reliable and stable which able to compare with commercial unit. The error or different was below 0.20% which consider minor in vision measurement. Also, those implemented methods produced reliable and stable result outcomes during repeat measurement. The NodeRed user interface provided a simple graphic user interface to perform designed measurement module easily even for untrained user. Measurement mechanism was portable and easy access for both measurement and maintainance.

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