AC 2010-1936: ON-LINE SURFACE ROUGHNESS MEASUREMENT USING LABVIEW AND VISION METHOD FOR E-QUALITY CONTROL

Richard Chiou, Drexel University

Michael Mauk, Drexel University

Yueh-Ting Yang , Drexel University

Robin Kizirian , Drexel University

Yongjin Kwon, Ajou University

On-line Surface Roughness Measurement using LabVIEW and Vision Method for E-Quality Control

Abstract

The annual results of laboratory development under an NSF, CCLI sponsored project, "CCLI Phase II: E-Quality for Manufacturing (EQM) Integrated with Web-enabled Production Systems for Engineering Technology Education" (NSF Award # 0618665) is presented. This paper discusses an E-quality learning system developed to automatically measure and monitor the surface roughness of products by utilizing vision technology. Several methods have been developed to measure surface roughness in industry. These methods utilize a contact-based approach to perform the necessary measurements. Our system is developed based on a non-contact method that uses a smart machine vision camera and LabVIEW-based programming. The method for determining the roughness is based on the correlation of optical roughness parameters and the average surface roughness. After the surface roughness monitoring system has been built, it can be applied as an automated quality control system used for educational purposes. Students are able to inspect the pieces cut by CNC machines right after the lab. In addition, they are able to simulate the automatic quality control process which is utilized in the industry. All of the data that is fed back by the machine vision camera can be real-time monitored and recorded for statistical calculations and quality control. In order to introduce students to this emerging technology, the procedural steps are currently being worked out to introduce one or more undergraduate projects at sophomore and junior level engineering courses with a new system consisting of Digital Camera for Microscopes, LabVIEW, MATLAB and standard surface finish comparators.

Introduction

The Applied Engineering Technology (AET) program at Drexel University offers three concentrations: mechanical, industrial, and electrical. The degree program contains the traditional engineering science classes associated with the degree and/or concentrations, along with a large world-class engineering technology lab experience. These curricula also include a Computer Numerical Control (CNC) machining course. Manufacturing-related knowledge is also included in the Applied Engineering Technology program objectives and outcomes (thus important to the program's ABET accreditation).

Students in the Applied Engineering Technology programs are required to complete a machining course MET 316 Computer Numerical Control that increases the student's design-for-manufacturability (DFM) knowledge. Providing students with a hands-on approach when teaching machining classes in the ET curriculum enables students to become aware of how their design, dimensioning and tolerance calculating, and quality can drastically influence the downstream manufacturing processes. This is especially helpful for students in the mechanical and industrial concentrations as they have a high probability of designing parts that will require machining processes during their manufacture. In industry, having mechanical and industrial engineers "cross-train" is not a new concept.

This paper describes the NSF E-quality project implemented in the CNC course offered within the Applied Engineering Technology Program and describes how surface roughness experiments have led to successfully designing and building projects in the development of course, curriculum, and laboratory[1-4]. In the globally competitive market, the ability to produce cost-effective products under strict time frame and quality control dictates the survival of the manufacturing industry. This kind of external pressure from the customers has created the need to re-look at the way manufacturing process is conducted in typical factory setup. Furthermore, major manufacturing industries like carmakers have evolved rapidly by establishing manufacturing branches at different geographical locations to capture the global market. In such a scattered setup of human resource personnel and manufacturing equipment, the ability for the different manufacturing nodes to collaborate on a product design and development would undoubtedly lead to a streamlined operation of that industry[5-7].

This project built E-quality experiments on the HAAS CNC milling machine, developed at the AET Program, by adding a web-based interface to allow students to remotely access and inspect the milled part surface via the Internet. The proposed methodology is different from others in that instead of developing customized client-server architecture, it will focus on development of LabVIEW to be served by time tested web server over HTTP (hypertext transfer protocol).

Roughness is a parameter that signifies the measure of the texture of a surface[8-9]. This kind of inspection is normally performed through the use of stylus type instruments, which correlates the motion of a diamond-tipped stylus to the roughness of the investigated surface. The stylus techniques have both, advantages and disadvantages. A sample disadvantage is the fragility of the instruments, which increases the risk of surface scratching. However, the non-contact based roughness measurement technique is able to find guaranteed ways to permit rapid surface roughness measurements with accepted accuracy[10-14].

The ideal environment for roughness measurement that can be applied within the industry must contain several features. The most important of these features are the real-time quality control processing, the Ethernet communication and monitoring, and the automatic robot integration. The synchronization of these processes should be optimized to maximize the efficiency of the production. Among all of the methods that have been introduced, the white light scattering is the one with minimum environmental restriction. We adopt this algorithm along with some surface profile parameters definition introduced in ISO 4287 to build an automatic surface quality control system. With the integration of the machine vision camera in this system, feedback quality control would be the strongest feature of this system. It has been noted that LabVIEW has been more widely used than any other development platform. The reasons are highlighted in amongst which are that LabVIEW provides object-oriented and platform independent development environment. While some researches have developed their own client-server architecture for communication, others have opted to use the software to remotely control and monitor a given manufacturing process.

Remote Surface Roughness Measurement

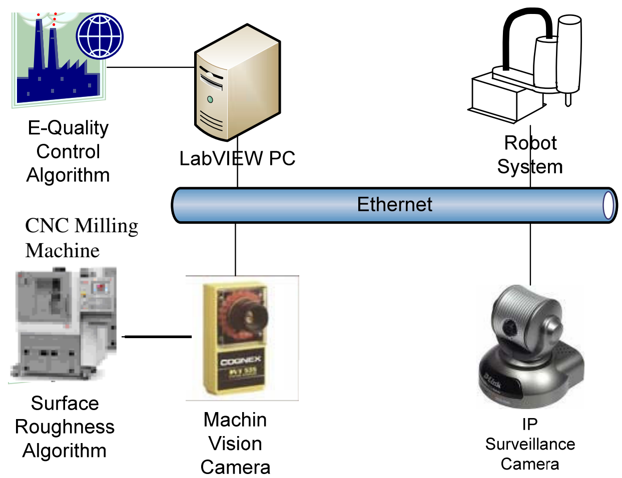

Figure 1: System Configuration

Figure 1 describes the top-level architecture of the system. The system is composed of a Scara 4-axis robot, a conveyor belt, a machine vision smart camera, an IP Surveillance camera, and a PC-based remote inspection system. The machine vision camera has a built-in processor which allows it to handle real-time algorithms and perform live-time monitoring. The whole process is designed to be Ethernet based using TCP-IP communication. After a successful TCP handshake, images and extracted measurements can be sent back and forth remotely between the servers and clients. The machine vision camera is properly programmed with necessary algorithms to calculate the various surface roughness parameters.

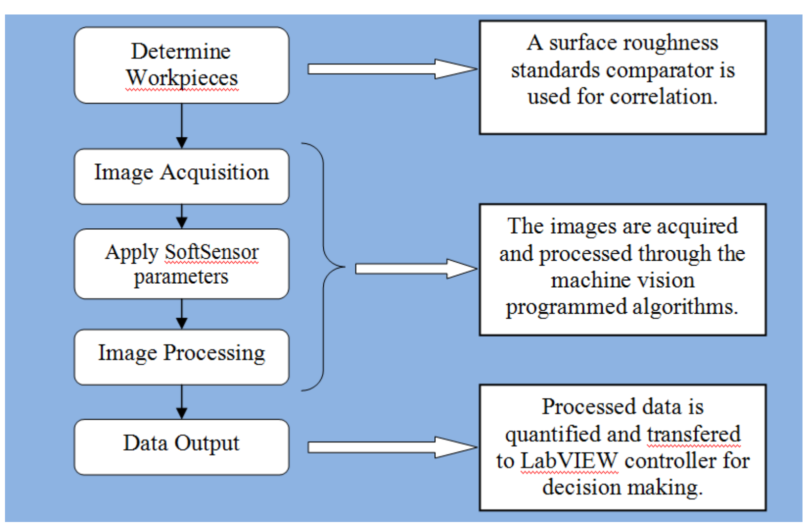

Figure 2: Vision module construction flow chart

In the LabVIEW based controller, E-Quality algorithms are applied to this data, and statistical quality control results are calculated. Based on these results, the LabVIEW controller will communicate with the robot to instruct it to perform the required operations. Moreover, monitoring the system is done through the IP surveillance camera displaying the products that are being analyzed. The most significant part of the whole automation system is the vision module. The flow chart in Figure 2 portrays the construction of the vision module.

Standard Workpieces:
Prior to collecting the surface roughness parameters, it is essential to identify the workpieces and have the theoretical values of the available parameters. The experimental and the theoretical values will be correlated to measure the quality of the experiment. The test pieces are obtained from surface roughness standard comparators with several different calibrated finished surfaces. The comparator contains several different specimens, each built according to a unique machining process and a specific average surface roughness parameter. The comparator is shown in Figure 3.

Figure 3: Surface roughness comparator

Image acquisition:
Image acquisition is a crucial step for the non-contact roughness analysis. Several factors can influence the quality of the images. The most important factor is building an environment with adequate illumination. An extremely bright or dim environment will result in ineffective and impracticable data. Several other affecting factors include the dust on the surface, micro chips, and so forth. The images in the system are captured via a smart machine vision camera. It has the function of digitizing the images and processing them in a real-time manner. The acquired image has the dimensions of 640 by 480 pixels and is in grayscale mode. Every pixel provides a numerical value from 0 to 255 to demonstrate the gray intensity level.

For the purpose of this experiment, a certain illumination environment has been built as shown in Figure 4. In order to stay consistent, a fixed lighting source is utilized in a certain angle and intensity directed to the test pieces. The exposure time is also set to be fixed. In general, machine vision is recommended as a solution due to the popularity for quality inspection in industrial applications.

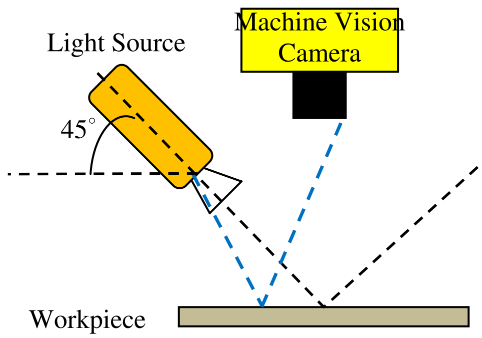

Figure 4: Illumination environment for machine vision camera

Vision SoftSensor parameters:
The machine vision camera has built-in processors and soft sensors. Each soft sensor is specialized for analyzing a certain shape or dimension. These soft sensors can be applied in an intuitive way by the end users in the accompanying machine vision camera software. The software is graphical based and allows users to pick and use the soft sensors of their choices. In addition to that, the programmer can write custom scripts to program the machine vision camera to perform custom needs. The analysis of the data is executed within the soft sensors and is made available for the user to utilize.

Figure 5 highlights the intensity soft sensor to define the Region of Interest. It computes image properties such as pixel count, mean intensity, threshold, and so on. All of these features are very useful for surface roughness inspection.

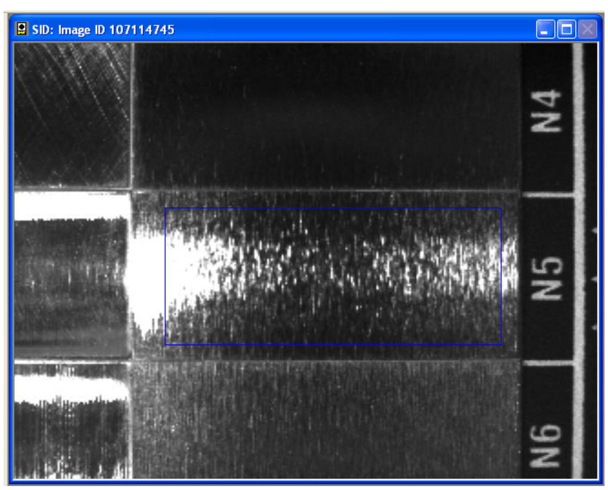

Figure 5: Region of interest analyzed by Intensity Softsensor

Image Processing:
For machine vision camera, the built-in soft sensors are usually applied for pattern recognition and item positioning. To correlate the surface roughness parameter using optical method, the front script soft sensor needs to be further implemented. After the Region of Interest is determined by intensity soft sensor, we apply an algorithm into the front script sensor program. The algorithm can be summarized with the following equation.

$$R_a = \frac{1}{n}\sum_{i=1}^{n}\left|y_i - \overline{y}\right| \tag{1}$$

where R_a = Average surface roughness parameter (micrometer), n = Number of sampling data, y_i = Height of roughness irregularities, and $\overline{y}$ = Mean height of profile elements.

According to the definition of surface roughness standard, we can express the average surface roughness R_a as in equation (1). It is one dimensional profile data and it articulates the surface profile with digitizing method. However, to correlate R_a using optical method, intensity level is widely used to be the first nomenclature in image processing method. We express the grey level intensity as X_i in equation (2),

$$X = \frac{1}{N}\sum_{i=0}^{255} F_i X_i \tag{2}$$

$$N = \sum_{i=0}^{255} F_i \tag{3}$$

where X = Mean intensity of the pixels, N = Total number of pixels in the distribution. F_i = Number of pixels at grey level X_i, and X_i = Grey intensity level coordinate (i = 0, 1,…, 255).

After expressing physical height as intensity level, we can calculate the mean intensity level based on equation (2). The mean intensity value of the image is expressed as X. Differing from $\overline{y}$, X is the average intensity of a two dimensional image. With this method, images can be analyzed in a very short cycle time instead of using traditional one dimensional profiling method.

To express the characteristics of a surface, more parameters are included in the experiment. The variance of a surface can be derived from the histogram of an image. To calculate the standard deviation of the grey level distribution, equation (4) shows the method to determine the value of the standard deviation of the distribution (SD).

$$SD = \left(\frac{1}{N-1} \sum_{i=0}^{255} F_i \left(X_i - X \right)^2 \right)^{1/2} \tag{4}$$

In addition to standard deviation, root mean square value is derived based on height of the grey-level distribution. The mathematical formula of the root mean square height of the distribution (RMS) is expressed in equation (5).

$$RMS = \left(\frac{1}{N} \sum_{i=0}^{255} F_i^2 \right)^{1/2} \tag{5}$$

In the project, the correlation of surface roughness R_a and these parameters will be further analyzed and discussed.

Data Analysis:
The parameter values obtained from the image processing algorithm will be sent to the system controller through TCP/IP connection. The machine vision has the feature to customize and broadcast output data to Ethernet. The feature is called DataLink connection. By utilizing DataLink, users can access online image and data in a real-time manner. Furthermore, the output data can be manipulated and interpreted in the system controller for automation adjustment.

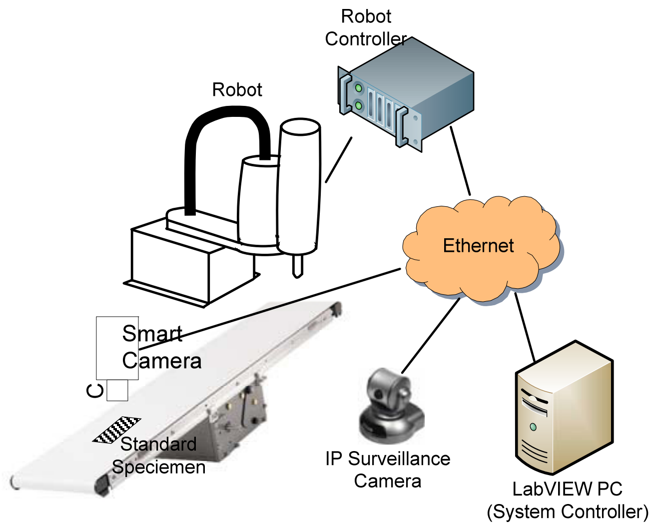

Figure 6: Automatic Surface Roughness Quality Inspection System

After organizing the vision module, we extract the surface roughness automation system to the following configurations. In Figure 6, the machine vision camera is applied to inspect standard roughness specimens. Quantified data will be directed through Ethernet to the system controller. To make the system work efficiently, different programs were used in the system. For machine vision camera, the program handles the measurement of surface roughness. For the robot, program in the robot controller is prepared in advance and will be executed with a command from the system controller. The IP surveillance camera is utilized to send surveillance images to the system controller. To integrate the whole system with multi-sensors, the system controller has LabVIEW software installed. A PC based controller has the advantage of higher compatibility of Ethernet functional sensors. Accompanied with the LabVIEW platform, GUIs (graphic user interface) were designed to develop a fully functional automatic surface roughness quality inspection system.

For any machined part, a number of histograms can be measured as an indicator of function, conformance, or quality. The surface roughness can be measured by machine vision as shown in Figure 7. The students, working in groups, collected data for some assigned subset of the workpieces. Data was then entered into LabVIEW for analysis.

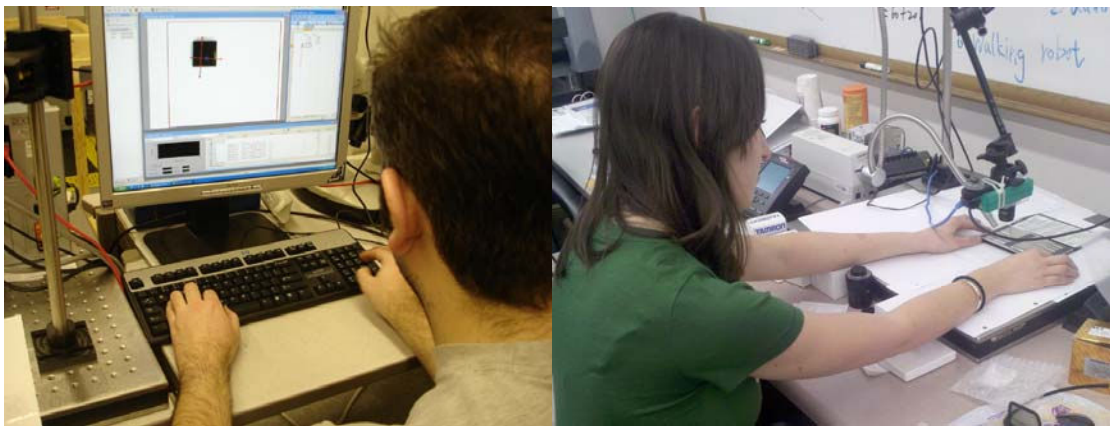

Figure 7: Students capturing images of CNC-machined test part features with machine vision setup.

Experimental Results

From the utilization of machine vision, images of the workpieces are shown on the programming software. Six different surface roughness pieces are discussed here. Their average surface roughness is 0.05, 0.1, 0.2, 0.4, 0.8, and 1.6 micro meters. The machining process is milling. The real-time images of these specimens are shown in Figure 8.

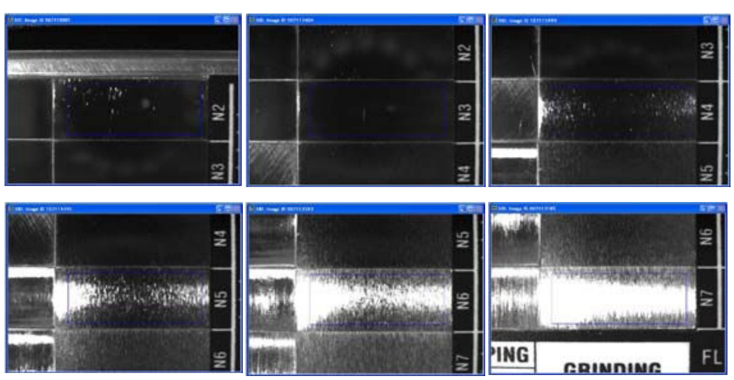

Figure 8: RGB images for six different surface roughness specimens

Figure 9 show the properties and the intensity distributions of these image histograms corresponding to six different surface roughness parameters in Figure 8. It can be seen that the histogram tends to move rightward and the standard deviation of Percent Pixels increases as the average of surface roughness increases. The rougher surfaces seem to reflect more of the projected light which consequently increases the intensity level captured by the machine vision camera. This can be supported by the fact that rougher surfaces contain rougher edges that tend to scatter the light in the direction of the camera. For this reason, the percentage of bright area is higher in rough surfaces compared to the smoother ones.

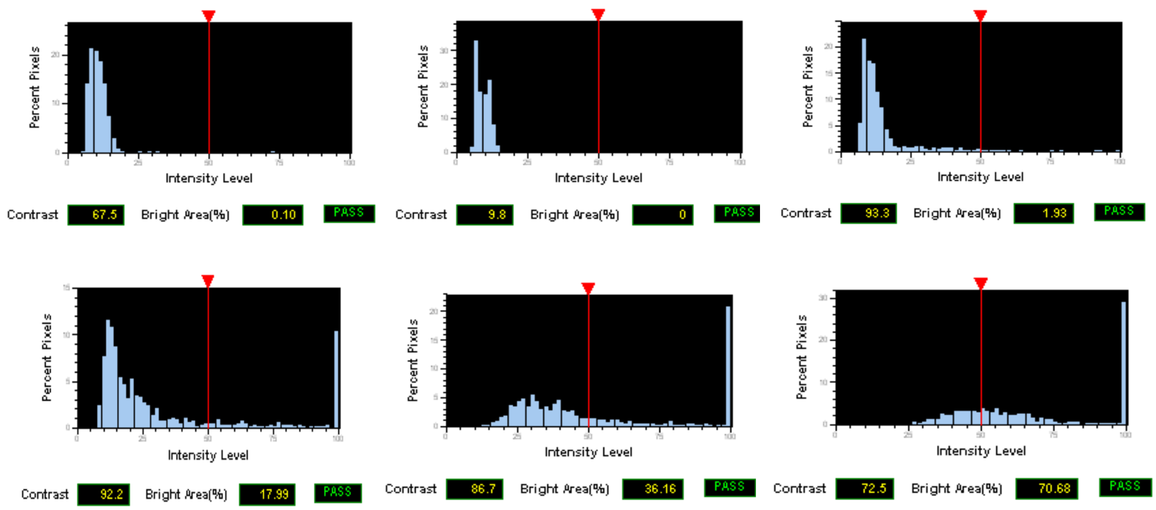

Figure 9: Histograms of the six milled surface roughness specimens

For the accomplishment of Internet based automation, the LabVIEW program is applied for monitoring and collecting the data results. Moreover, the quality inspection algorithm is also integrated. It will determine the fail pieces and send commands to the robot controller through Ethernet via this program. The robot will then remove the bad part from conveyor belt. The graphical user interface for this LabVIEW program is designed as Figure 10.

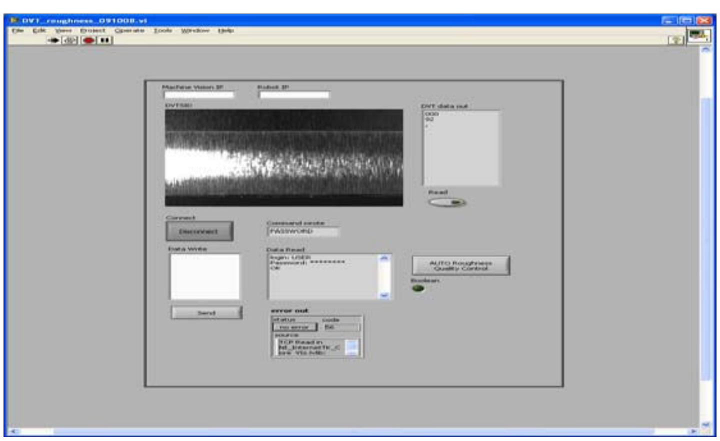

Figure 10: Graphic User Interface of the LabVIEW program.

The results were collected through the LabVIEW program. There are six different work pieces utilized in this experiment. Table shows the results of their mean intensity, standard deviation, and root mean square value.

Table 1. Experimental Results

Average Surface Roughness (um) R_a	Mean Intensity X	Standard Deviation SD	Root Mean Square RMS
0.05	27	8.80	6.77
0.1	23	5.76	7.67
0.2	36	27.46	5.89
0.4	78	71.71	5.01
0.8	131	72.39	7.03
1.6	171	61.07	9.52

The results of Table 1 are plotted in Figures 11 and 12.

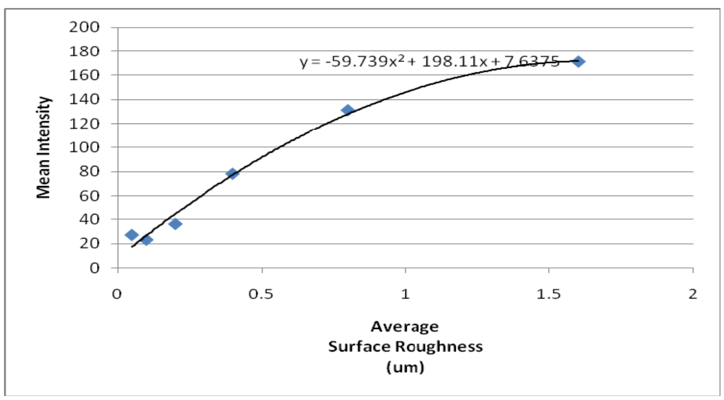

Figure 11: Mean Intensity V.S. Average Surface Roughness

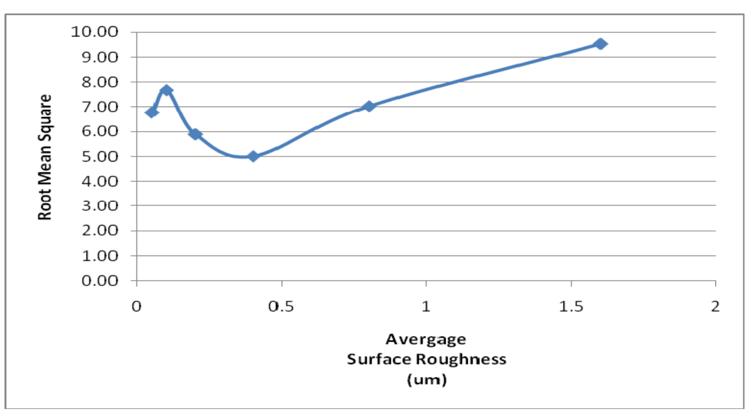

Figure 12: Root-mean-Square V.S. Average Surface Roughness

Conclusion

The study of CNC-machining surface quality for application with internet based non-contact diagnostics devices provides an instructive case study of E-quality concepts and methods. The manufacturing quality issues are conceptually straightforward with the CNC machining. The CMM or machine vision inspection laboratories can each be performed in a CNC laboratory session. From the experimental results, the algorithms for statistical process inspection are in good agreement with basic vision-based roughness characterization results. In addition to CNC code programming and CAD/CAM skills, the course MET 316 CNC has successfully provided the students with the skills in specifying geometry and surface roughness of a part and learning GD&T (Geometric Dimensioning & Tolerancing) for quality control.

Acknowledgement

The authors would like to thank the National Science Foundation (Grant No. NSF-DUE-CCLI- 0618665) for its financial support of the project.

Bibliography

1. Richard Chiou, Yongjin Kwon, Bill Tseng, Yueh-Ting Yang, and Robin Kizirian, "Enhancement of Online Robotics Learning Using 3-D Visualization Technology," International Symposium on Engineering Education and Educational Technologies (EEET), Orlando, Florida, USA, July 10th-13th, 2009.
2. Richard Chiou, Yongjin (James) Kwon, Tzu-Liang (Bill) Tseng, Robin Kizirian, and Yueh-Ting Yang, "An Internet-based Online 100% Inspection System for Real-Time Robot-Integrated Quality Control," International Conference on Manufacturing and Engineering Systems (MES 2009), National Formosa University, Taiwan, December 17-19, 2009.
3. Richard Chiou, Michael Mauk, Sweety Agarwal, and Yueh-Ting Yang, "Development of E-quality Laboratory Modules for use in Engineering Quality Control Courses," ASEE Annual Conference & Exposition, Austin, TX, June 14-17, 2009.
4. Richard Chiou, Michael Mauk, William Danley, Yueh-Ting Yang, Robin Kizirian, and James Kwon, "Innovative Engineering Technology Curriculum Integrated with Web-based Technology in Robotics, Mechatronics, and E-quality," International Mechanical Engineering Conference and Exposition (IMECE), Lake Buena, Florida, USA, November 13-November 19, 2009.
5. G. Al-Kindi, B. Shirinzadeh, Y. Zhong, "A Vision-based Approach for Surface Roughness Assessment at Micro and Nano scales," ICARCV 2008, p. 1903-1908, 2008.
6. K. Rajneesh, P. Kulashekar, B. Dhanasekar, and B. Ramamoorthy, "Application of digital image magnification for surface roughness evaluation using machine vision," International Journal of Machine Tools and Manufacture, v 45, n 2, p. 228-234, 2003.

7. V. Elango and L. Karunamoorthy, “Effect of lighting conditions in the study of surface roughness by machine vision - an experimental design approach”, Int J Adv Manuf Technol, v 37, p. 92-103, 2008.
8. X. Li, L. Wang, and N. Cai, “Machine-vision-based surface finish inspection for cutting tool replacement in production,” Int. J. Prod. Res., v 42, n 11, p. 2279-2287, 2004.
9. E. Alegre, J. Barreiro, M. Castejón, and S. Suarez, “Computer Vision and Classification Techniques on the Surface Finish Control in Machining Processes,” ICIAR 2008, LNCS 5112, pp. 1101-1110, 2008.
10. F. Luk, V. Huynh, and W North, “Measurement of surface roughness by a machine vision system,” J. Phys. E: Sci. Instrum., v 22, p. 977-980, 1989.
11. D-M Tsai and C-F Tseng, “Surface roughness classification for castings,” Pattern Recognition, v 32, n 3, p. 389-405, 1999.
12. Z. Hu, L Zhu, J. Teng, X. Ma, and X Shi, “Evaluation of three-dimensional surface roughness parameters based on digital image processing,” Int J Adv Manuf Technol, v 40, p. 342-348, 2009.
13. M. A. Younis, “On line surface roughness measurements using image processing towards an adaptive control,” Computers & Ind. Engineering, v 35, n 1-2, p. 49-52, 1998.
14. “Geometrical Product Specifications (GPS) -- Surface texture: Profile method -- Terms, definitions and surface texture parameters,” ISO 4287, p. 10-18, 1997.