DESIGN OF A WEB-ENABLED ROBOTIC SYSTEM FOR QUALITY CONTROL LABORATORY

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Abstract

This paper describes the development of an online inspection system for internet-based real-time product quality control integrated with a Web-controllable robot. The quality control course is an integral part of the undergraduate engineering program as well as the engineering technology program at Drexel University. The enhanced understanding of principles and theories of statistical process control can be attained through carefully designed lab experiments. Since the current manufacturing plants are widely distributed in different geographical locations around the world, the various production steps including design, manufacturing, quality, service and management have been dispersed as well. These circumstances require the remote collaboration of these manufacturing firms on the essential production equipment and tools, in addition to the efficient means of responding to a changing environment to counter process variations and diverse customer demands. A solution to this problem would be the Internet-controllable quality control laboratory that has been developed in the Department of Engineering Technology at Drexel University. With the use of the Internet, sensors, network cameras and various tools, students can test, control, monitor and study the operation of a robot for quality control and its underlying principles from anywhere, anytime.

Introduction

This paper presents an internet-based quality control system for real-time E-Quality for manufacturing, integrated with a Web-controllable robot. The current trends in industry depend on the framework of internet-based systems. The integration of information and knowledge based networks with a manufacturing system has opened the doors to a whole new world of collaboration among different firms. Production in this world would no longer reside locally, but would be part of a cooperative operation which includes monitoring of different products at different sites, remote quality control, and a wide range of error diagnosis possibilities. The result is the introduction of a new scheme in online inspection to the manufacturing industry, E-manufacturing or what is known as EQM (E-Quality for Manufacturing). The key feature of this new scheme is the possibility of integrating design, manufacturing, quality and business over the Internet in addition to being resilient with any rapidly changing environment. Moreover, with the enormous growth in Web-based technologies and networking, incorporating product quality control with the world-wide market is more feasible [1-3].

The constituents include a highly advanced form of production equipment and sensor networks connected to the Internet, all of which identified by the unique Internet Protocol (IP) addresses. The remote accessibility and the ability to control the equipment over the Internet present unprecedented benefits to the current manufacturing environment. Designers located remotely from the production facility can carry out the quality inspection as their design processes evolve. The quality control issues and the tolerance analysis of equipment can be monitored according to the manufacturing and assembly specifications. Any changes in the product specifications and associated quality control routines can be instantly updated and verified, which will enhance the overall production efficiency. The immediate benefit from this approach is the reduction of manufacturing costs, by preventing further processing of defective parts along the manufacturing stages [4-6]. Our approach would help protect the environment by reducing the production of off-goods.

The automated quality control system has been developed to monitor part quality status in an environment with real-time industry type settings. Figure 1 displays the remote quality diagnosis system that has been created. The system uses Visual Basic 6 to integrate machine vision technologies with robotics in a Web-based fashion. It includes features which allow the recording of control-related real-time measurements on sample work products that are passed around on a conveyor belt. A machine vision system is used to perform non-contact measurements on the key dimensions and position the objects and detect their quality. This data is fed back to a Web-based application server and thus is monitored and diagnosed automatically according to the algorithms embedded in the machine vision camera and the ones chosen by the quality inspector at the server side. Based on the final assessment of the product and the required specifications, the robot will make the necessary decision of picking up the product and placing it in the stack of objects according to their quality category. The fundamental functionality of this system is to provide users who are at remote locations with a live analysis on the quality of the products that pass on the conveyor belt in the production line [7-11].

Web-based Control Architecture

Figure 1 describes the detailed architecture of the system. The system is mainly composed of a Yamaha YK-250X SCARA (selective compliance assembly robot arm) robot, a Cognex DVT 540 machine vision camera (for remote inspection and measurement), a variable speed Dorner 6100 series conveyor system, a D-link web-camera (used for inspection purposes), and a Visual Basic coded Web application. The Yamaha robot is specifically configured to have high rigidity along the vertical axis, while being compliant in the horizontal direction in the form of swing arm motions. This renders the robot particularly suitable for pick and place or assembly operations with a high degree of accuracy and speed, having the repeatability along horizontal planes of +/- 0.01 mm (+/- 0.0004 in.). The robot's RCX 40 controller is

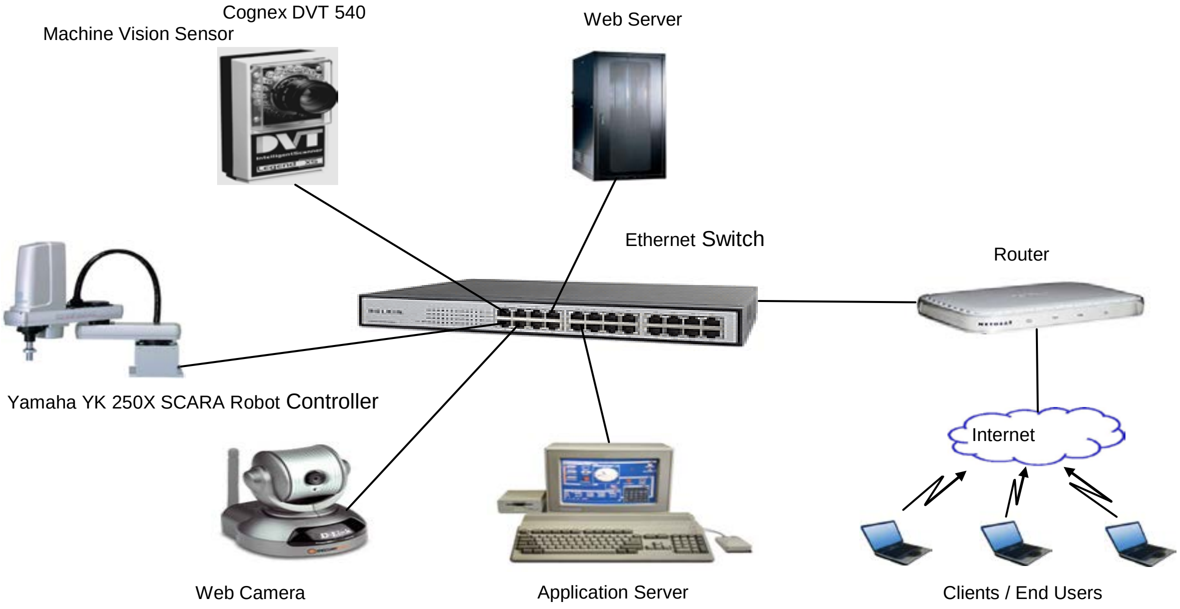

Figure 1: Internet-Based Integration of
E-Manufacturing with Vision and Robotics.

equipped with an Ethernet port and can be accessed through Port 23 (Telnet). This enables exchange of textual commands based on the operation of the robot over the Internet [12].

The machine vision camera is self-contained with optics and illumination LEDs to form an image of the object, an image acquisition circuit board to transform the image information into a computer format, and specialized image processing software to inspect parts, make measurements, and extract spatial feature information. The image resolution is 640 x 480 pixels with an exposure time set to 4 ms and a frequency of 2 Hz for taking snapshots on a moving conveyor. The camera is also equipped with an Ethernet port which allows communication to it using TCP (Transmission Control Protocol). Since the camera is equipped with an internal processor, it is able to send the extracted measurements to the Visual Basic application server after a proper TCP handshake. As for the conveyor system, it is connected to the robot's I/O device port so that it can be synchronized with the robot's motion. The D-Link network camera is Ethernet-based and can be accessed through a Web browser that is integrated within the Visual Basic interface.

The Visual Basic interface acts as a server that directs the different components of the system. As described in Figure 2, the interface contains the essential modules for robot communication and machine vision. It utilizes the necessary Internet and camera libraries to communicate with the internet-based components. Communication to the robot is done through the Telnet Daemon while TCP/IP is used for exchanging data with the machine vision and Web-cameras. The system control and decision making algorithms are coded into the interface to synchronize the whole system. After the data is collected, it is prepared for quality analysis.

Web-Based Quality Analysis System

Machine vision packages for the Cognex DVT 540 computer vision system are configured as a set of tools for inspections and measurements.SoftSensors are the working class inside Smart Image Sensors. Every type of SoftSensor serves a specific purpose, and the combination of the SoftSensor results represents the overall result of the inspection. The main groups of SoftSensors include Presence/ Absence SoftSensors, Positioning SoftSensors, and Specific Inspection SoftSensors.

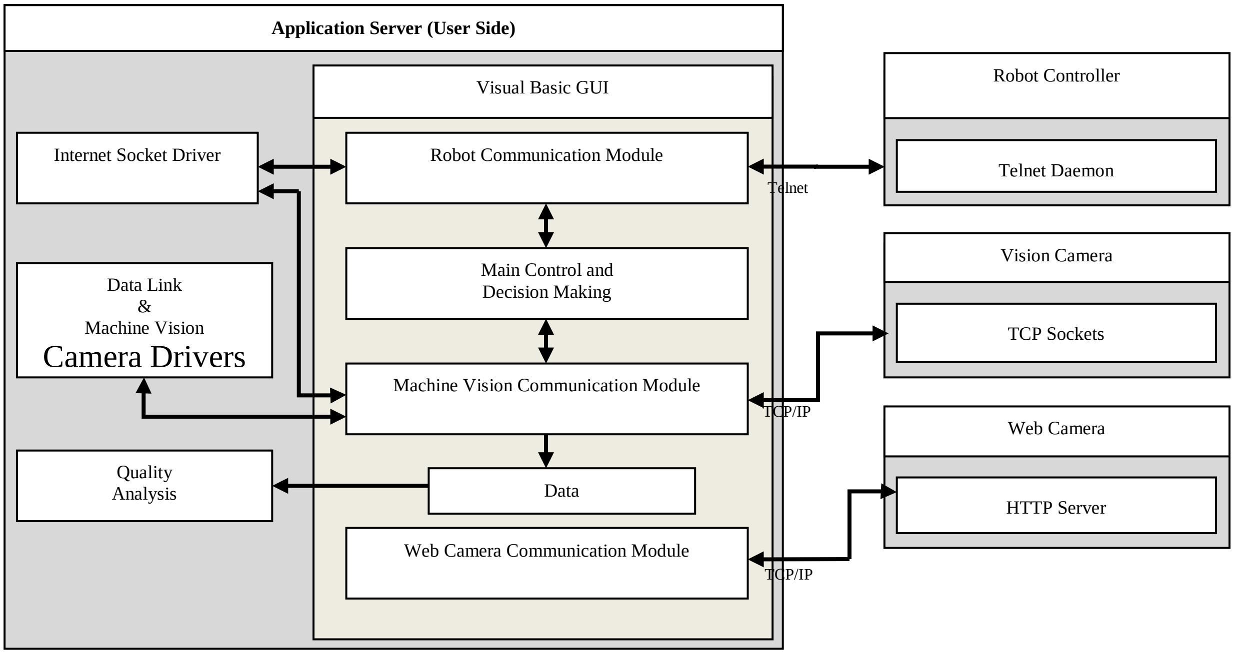

Figure 2: Web-based Vision & Robotic System.

In most applications, the type of Positioning SoftSensor becomes the key to a successful setup, because they locate the part to be inspected and pass an internal reference to the remaining SoftSensors indicating the location of the part. The SoftSensors perform basic checks for detection of features and edges or analyze the intensity level of the pixels in a certain area or linear path. All the SoftSensors perform many tasks from very specific inspections to a user defined task (programmable). They include: Measurement, Math Tools, Readers, Blob Tools, Template Match, ObjectFind, Pixel Counting, Segmentation, SmartLink, Script, and Spectrograph [13-14].

Along with the machine vision camera, a special piece of software called “FrameWork” has to be used for configuration and teaching the camera about the product. While teaching the camera about the specified product, the correct Softsensors should be used for each of the necessary tasks. Each inspection and measurement task is defined through several Softsensors. Figure 3 displays a typical view of the configuration of the machine vision camera for measurement purposes. For any machined part, a number of metrics (dimensions, angles, or other geometric features) can be measured as an indicator of function, conformance, or quality.

Automatic Inspection System by Visual Basic Programming

Visual Basic 6 (VB6) is an event-driven programming language and an integrated development environment which is convenient for rapid application development and programs which require fast responses to random events. As such, VB6 is considered to be suitable for applications that involve internet-based robotic control. It has a graphical user interface that can be used to perform sophisticated Web-based robotics. Moreover, VB6 has a packaging option which easily allows the developed program to be distributed and shared among any users in remote locations.

The remote robotic application enables streaming of video images from Webcams installed in the robot work cell. Most of the Webcams are provided with the Web-based interface for its control. The images from this camera can be viewed using a Web browser by entering the IP address in the browser. For a complete control package, it is necessary to have a video feedback embedded with it. For most Webcams, ActiveX component is used as

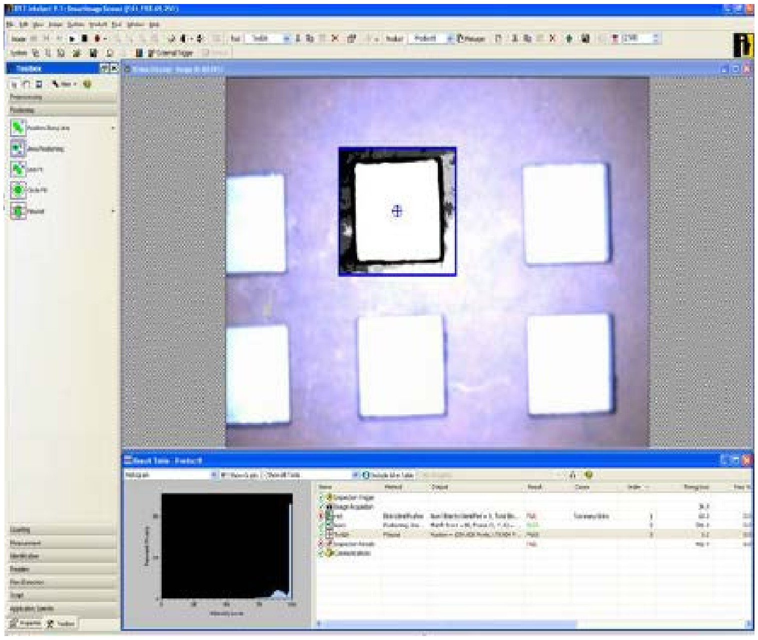

Figure 3: Captured image processing of features for machine vision configuration.

the control mechanism. This can be incorporated into a VB application for displaying the image by using the browser library Microsoft Internet Control component. This website consists of commands that load the ActiveX component by providing the object ID and, class ID, IP address, port address, username, and password.

To provide the TCP/IP functionality, the Winsock library (winsck.dll) of the VB programming language was used. This library simplifies the different tasks in network programming such as performing the TCP handshake. The availability of all of these libraries makes it possible to achieve an Internet-based integrated and synchronized system that can perform the automatic tasks portrayed in Figure 4. The first step in the VB program is to choose the product type that will be inspected. After that, the user has to establish the connection with the different components of the system (robot controller, conveyor belt, machine vision camera and Web-camera).

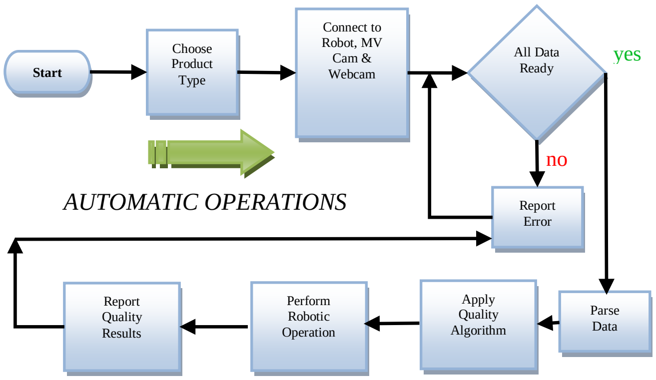

Figure 4: Quality Inspection Process via Internet.

It is to be noted that authentication is required to acquire access to any of these components. The user would have to enter the required username and password to be granted access to use the system. Once the user has enabled all the components, the system would be ready to run automatically. The system would keep checking on the TCP port, waiting for the data to be sent from the tool in the machine vision camera. When the machine vision camera detects an object, it will send the dimensions to the application server based on its configuration. The data gets captured by the VB program and is then parsed into separate chunks on which quality analysis algorithms are applied. When the analysis is complete, the robot is signaled to perform the necessary robotic operations on the test pieces.

Figure 5 shows the developed VB6 Web interface for the quality measurement integrated with robotic operations and Web cameras. There are seven dimensions which are being recorded, including the lengths of L_1, L_2, L_3, V_1, V_2, and V_3, and a diameter of ϕ_1. The different functions are executed due to internal and external events. The external events can be similar to playing the machine vision camera or the Web-camera. An example of an internal event is detecting a string of bytes on the TCP/IP port. Once the data arrives, the quality analysis automatically runs and provides the user with results in addition to performing the necessary robotic operations.

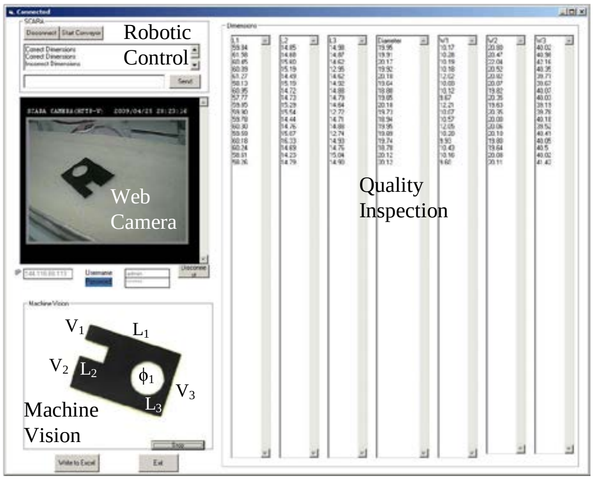

Figure 5: Graphical User Interface for Web-based Quality Control System.

The remote quality inspection of the test pieces is shown where the SCARA robot is monitored and its RCX40 controller is directed via the Internet. A separate console has also been established to send commands to the robot in case of slight modifications or emergencies.

The GUI also provides an access for users to view the quality information of the test specimens and the operations at the robot area through both, the machine vision camera and the Web-camera.

Statistics Process Control Integrated with a Web-controllable Robot

Figure 6 shows the real-time statistics process control experimental setup that is performed for error detection and fault tolerance. The quality control and robotic operations are performed remotely over the internet. In the left portion of the figure, the machine vision camera detects the object and a signal is sent to stop the conveyor belt. After the Visual Basic program performs the necessary quality analysis, it is decided automatically whether the object passes the required specification or not. The robot picks and places the specimen into either a good or bad stack of parts depending on the result of the analysis. The conveyor is then restarted and the process loops again until the user decides to log out and exit the program.

Internet-based Statistical Process Control

Upon the collection of measurements for all dimensions of the parts in the automatic quality control process, the part dimensions are statistically analyzed according to the preset specifications. The main categories for the statistical analysis are mean, median, range, variance, and standard deviation. The statistical quality tools used include: histograms to examine the distribution of the product sizes, Pareto diagrams to find the primary cause of failure, control charts to see if the process is stable and process capability analysis to determine the effectiveness of the current process.

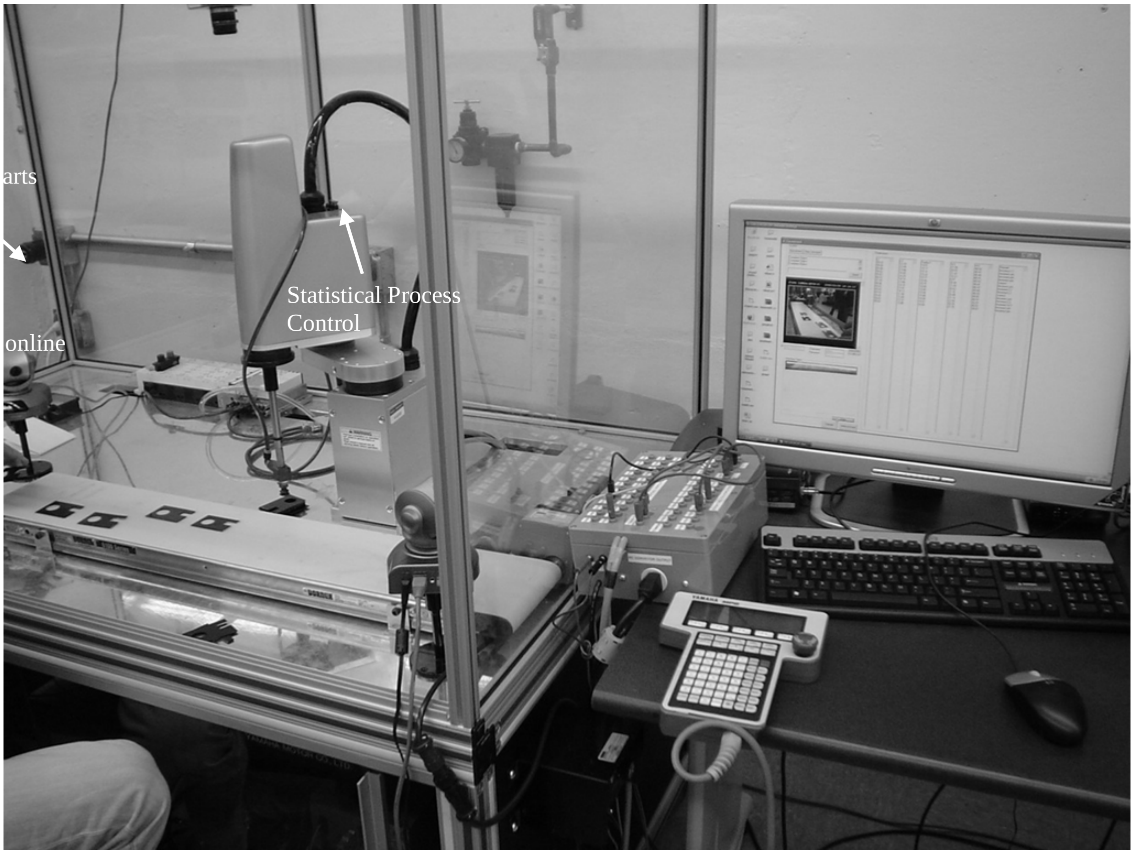

Figure 6: Internet-based statistical process quality control experimental setup.

The measurement data for this process can be calculated and checked if it is less or greater than the tolerance limit with the lower specification limit (LSL) – the upper specification limit (USL) as shown in Figure 7. All the data was saved in Microsoft Excel, from which a quality inspection system was developed. The main display screen for each feature included control charts of the part dimensions. Features of the system included robotic rejections for "out of control" points and real-time data collection of assignable causes that lead to special-cause variations. The real-time recording of "corrective actions" for rejections of "out of control" samples was part of the system. Histograms were created from the raw measurement data used for control charts and were used to display the distribution and frequency of the collected data. Pareto charts were used to display the distribution and to graphically present the number of occurrences of special-cause variation.

Hands-on Learning with Online Quality Control Experiments

This particular set-up served as laboratory activity for an undergraduate 3-credit course in Applied Quality Control in the ET curricula. This course has been offered consistently during past 8 academic years. The online quality control experiments are conducted by thosestudents enrolled in MET 204 Applied Quality Control at Drexel University. Students are first brought into the lab where the setup resides, to get acquainted with the working principles of the equipment. Later, they are given a lab handout that describes the online quality control experiments. In a nutshell, the online experiment result shows that the Web-based statistical process control is useful for real-time automation. During the experiment, statistical data are captured through the Visual Basic program and the various part parameter deviations are observed (see Figure 8).

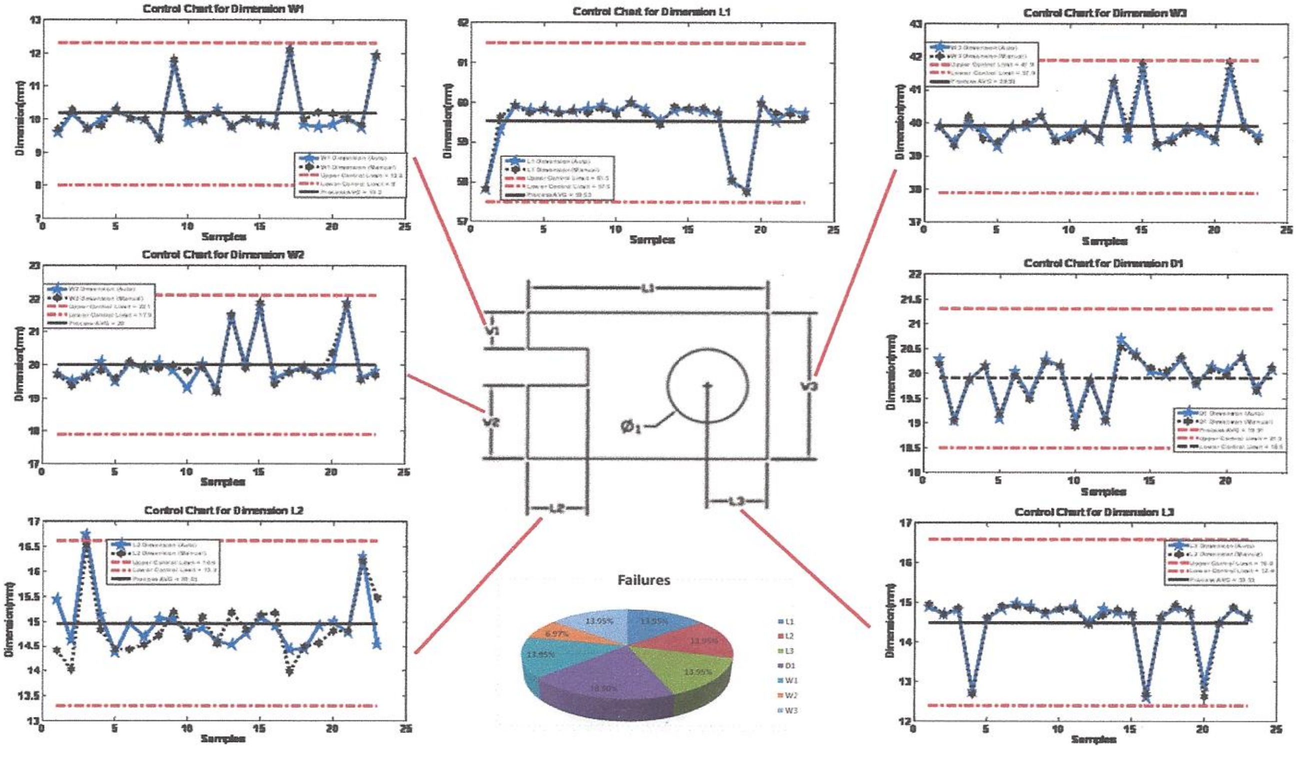

Figure 7: Measurement Data Diagrams.

Figure 8: Students performing Internet-based statistical process quality control experiments.

Overall, the online experiments provided interesting insights as to how to offer an effective laboratory course over the Internet. Even though the technologically advanced systems present seamless web accessibility, the specifics in tele-operations in line with the accompanying instructions multiply the complexity in creating a pedagogically effective online lab course. It is conceivable that the Internet-based educational tools are becoming more and more prevalent in mechanical engineering and technology education, due to the convenience and flexibility.

Course Learning Outcomes

The main student learning outcomes of undergraduate course MET 204 Applied Quality Control are focused on (1) learning through real-time product quality control; (2) manufacturing process inspection and evaluation; (3) real data analysis; (4) development by the students of real-like quality control projects based on experimental data; and (5) validation of the e-quality control laboratory model through several student projects. Topics cover theory and methods for design and analysis of quality control systems, including solutions to problems of product specifications, process control, acceptance inspection, and other means of quality assurance.

We also continuously improved the experimental activities as well as the teaching modules based on student project evaluations. This course improvement aims at investigating the different methods and possibilities of establishing an effective quality system that could be used by manufacturing firms for automatic and high speed quality inspection purposes. Since the implementation of these experimental activities, as a basis for teaching quality control methods, the online student evaluations have been consistently high with an average of 4.25 out of 5.00 for both the overall course and instructor. Overall the feedback received at the end of the term from the participating students was largely positive with regards to the experiments involving e-quality control systems.

Students were exposed tremendously to new theories, applications and technologies that are still considered emerging technologies and are not in a textbook or course notes. In this way we stimulated students further to seek research activities based on their personal or career interests through open-ended problem solving, interdisciplinary projects, offering them a great opportunity to “try-out” at a smaller scale a “capstone type” project. Students constantly enriched their knowledge and they improved critical thinking and creativity.

Students were able to define quality and understand the broad perspective of quality control, quality management and quality improvement. They were also able to analyze and evaluate statistical data related to quality. They also learned a real life industry-like setting experience through their laboratory classes and team projects using MiniTab. The students demonstrated in depth proficiency of Six Sigma concepts, purpose and philosophy, and its application in both manufacturing and service industries. The students gained understanding of management-level quality problems and solutions using Six Sigma process methods in terms of variation and defects. They demonstrated an understanding of the tools and techniques used to measure and monitor manufacturing, service and management processes.

Conclusion

In conclusion, a valuable Web-enabled robotic system has been developed for online quality control instruction. Remote quality control has been proven to be beneficial and as accurate as any other traditional method, preparing students for the emerging future in the manufacturing industry, and by giving them the necessary skills for the industry of the future. This result provides a great impact in production since engineers can access and control the equipment and quality anytime, from anywhere. Furthermore, the project will reinforce the ongoing initiatives to revitalize the regional manufacturing sector by providing highly skilled graduates to meet the demands of new advanced technologies.

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Biographical Information

Dr. Richard Chiou is Associate Professor within the Engineering Technology Department at Drexel University, Philadelphia, USA. His educational background is in mechanical engineering with an emphasis on manufacturing. In addition to his many years of industrial experience, he has taught many engineering and technology courses at undergraduate and graduate levels. He has tremendous teaching and research experience in sensor monitoring and control techniques, including Internet-based robotics and mechatronics, Web-based quality, remote control, etc.

Dr. Irina Ciobanescu Husanu is Assistant Professor within the Engineering Technology Department at Drexel University, Philadelphia, USA. She has prior industrial experience in aerospace engineering. She has experience in instruction for mechanical engineering and engineering technology courses in both quality control and quality assurance areas as well as energy conversion and mechanical areas from various levels of instruction and addressed to a broad spectrum of students, from freshmen to seniors, from high school graduates to adult learners. She also has extended experience in curriculum development.