ON-LINE MEASUREMENT & EMBEDDED INSTRUMENTATION PROJECTS IN ENGINEERING EDUCATION

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Abstract:

This paper presents an experimental approach for intelligent monitoring of a Computer Controlled Machining Process using embedded instrumentation. The article reviews the ongoing development in the field of embedded systems. This is followed by presentation of the hardware and software scheme adopted to implement on-line inspection procedures for surface roughness and geometrical data measurement of the machined part. The surface finish data is obtained using a newly designed laser based technique; where as geometrical data is obtained using a specially designed optical digitizer. These measurement techniques will be implemented in the form of embedded systems. The paper concludes by giving examples of how these instruments are adopted for an on-line monitoring process in an aerospace industry.

1 Embedded Microcontrollers

An embedded microcontroller is a small but complete computer system implemented on a single silicon chip. It often includes memory, Input/Output, communications, and Analog / Digital conversion capabilities. The principal difference between this device and a general-purpose microprocessor is that it integrates memory and I/O capabilities onto a single silicon chip, whereas the general-purpose device requires external memory and I/O circuitry. The primary components of a microcontroller are: CPU, Data Memory, Program Memory, Digital I/O, Time/Counters, A/D Converter, Communications and Interrupts. Among its many capabilities is the ability to do Digital Signal Processing (DSP) functions such as thresholding, linearization and filtering of signals.

Low-cost microcontrollers embedded into sensor products add end-user value to those products. Many new applications become cost effective when the cost of incorporating a microprocessor into a sensor compares to that of adding an op amp and several resistors. A microcontroller can be used either to replace existing analog-/discrete-logic functions, or, to add enhanced functionality.

One of the major differences between programming microcontrollers vs. desktop PCs is the user interface environment. A typical programming and implementation scheme for a microcontroller is shown in *Figure 1*. Getting a program to function on one of these devices can be a trying experience requiring specialized programming tools such as simulators and emulators. Many simulators provide a code generation function that allows the designer to create C code that can be downloaded to the target system of choice. The designer then compiles the C code for use in the actual hardware controller. In most cases, the target system is an embedded microprocessor that does not support a graphical user interface or GUI, and as such, testing the control system becomes more difficult.

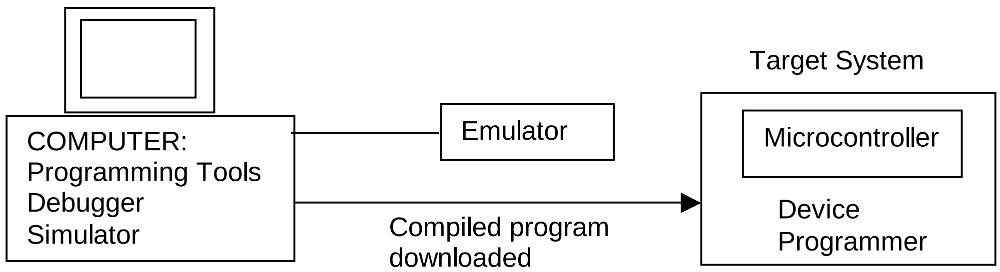

Fig. 1 Microcontroller programming environment

An alternative programming environment, which supports GUI and allows for Hardware in the Loop Simulation is discussed in the next section.

2 Embedded Systems Using Microcomputer Devices

In a typical mechatronics system design process [1], software tools are available to aid the designer in creating and debugging the mathematical system models. Some tools that are particularly useful allow the designer to represent the system by creating a system block diagram from simple building blocks such as integrators, gain stages, summing junctions, and non-linear switches. Such software programs are VisSim from Visual Solutions and Lab View from National Instruments. With these programs, the designer can create a plant model, and then validate it against real-world measurements. Once the plant model has been validated, the designer can then design the control system and optimize it until the correct response is achieved. These simulation tools also allow the designer to interface to actual sensors and actuators through one or more data acquisition cards contained on the PC compatible platform. This Hardware-in-the-Loop Simulation testing provides the designer reassurance that any assumptions made on the plant model were correct. If any assumptions were incorrect, however, the designer does have the opportunity to optimize the design before committing to the real target hardware platform. Such capability is provided by these simulation programs by graphically showing "real-time" data plots on the PC compatible monitor as well as providing the ability to stream data to a disk file for later analysis. Data plotting on the monitor is done through the PC's GUI.

One major drawback that these simulation tools and other PC based simulation systems suffer from is the inability to work in systems where loop responses need to be fast (less than 100ms). This shortcoming is the result of non-optimized software code running through an interpreter which then interfaces to a Window operating system that was not designed for "real-time" processing. This creates "realtime" simulation results that vary depending on what other programs are running on the PC platform such as network connections, printing utilities, virus scanning software, disk accesses, etc.

As a result of these shortcomings, the use of a microcomputer device is proposed as an intermediate target system between the simulation PC and the intended real hardware target in order to address the GUI and “Real Time” capabilities of an embedded system’s programming environment. *Figure 2* shows the proposed programming environment.

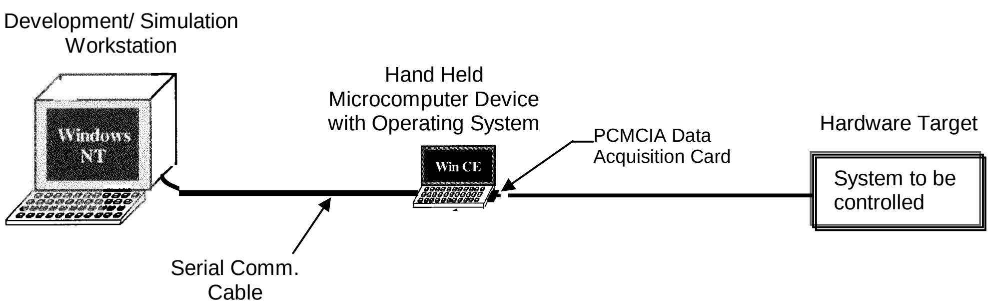

Fig. 2 Microcomputer based simulation environment

Microcomputer based devices commonly known as PDA (Personal Digital Assistant) or "Palm-top" computer have been developed with operating systems, which reside in a limited memory space. One such system is called Window CE, a scaled down version of Windows. This operating system makes use of the standard device driver interfaces for such devices as memory cards, modems, printers, network communication cards, mass storage devices and a LCD Graphical User Interface.

The use of such a simulation environment will provide the designer the tools and steps to port the Simulation software generated C code to a PDA running Windows" CE. This PDA will contain a type II PCMCIA slot so that a data acquisition card can be inserted and allow a "real-time" Hardware in-the-Loop test. The benefits of using a PDA as the intermediate target system are various. Among them being that with the scaled down Windows operating system, the operating system response characteristics will be more representative of an embedded microprocessor system. Also, the GUI interface of the PDA will provide the designer a level of interaction with the control system that is not possible when the code is directly ported to the final target platform.

3 On-Line Measurement

During the development cycle of a product, quality control is typically done either at the design stage or at the inspection stage. Normally at the design stage, robust design methods are used to select the proper alternatives and ensure that quality is incorporated into the product. At the inspection stage, statistical process control (SPC) procedures are used to check the quality of the manufactured part. As manufacturing processes become more automated, there is a stronger demand for on-line coordination of multiple process issues. [2]. Studies have shown that On-line process control of manufacturing operations is beneficial in modern production systems. As an example, on-line surface roughness and on-line geometry evaluators are discussed.

4 Surface Roughness Measurement: Background And Theory

For roughness evaluation, the most widely used instrument is the surface profilometer with contact stylus. This technique requires contact with the surface of the sample. As such, if surface roughness measurement of a critical component is required, a non-contact approach is preferred. Many researchers have contributed to the development of reliable non-contact techniques using optical methods. Among these, Marx and Vorburger [3] have developed a non-contact method of measuring the specular and scattered reflection of a laser beam off the surface of a workpiece. This research was further enhanced by Shetty and Neault [4] by developing a non-contact surface roughness analyzer. The method developed by Shetty and Neault takes advantage of the fact that a light source reflected off the surface of a workpiece provides a signature pattern based on the roughness of the surface. The basic light scattering as a result of light reflected off a surface is shown in *Figure3*. An electromagnetic wave of known wavelength is incident upon the rough surface at an angle θ. This methodology has been implemented in the form of a compact tool which can be mounted on the spindle of a CNC machine as shown in *Figure 4*.

Machined surfaces tend to exhibit a grating structure on account of tool marks made during the machining process. In the case of periodic roughness, the scattering is made up of a specular component, at an angle predicted by ray tracing optics, and discrete components at angles predicted by the grating equation as shown in Eq. 1.

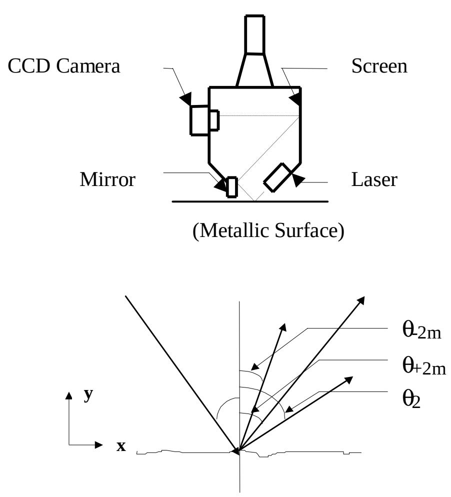

Fig. 3: Basic light scattering

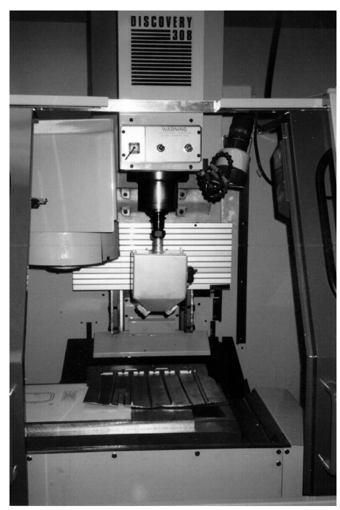

Fig. 4: Miniaturized Surface Roughness Probe

$$\theta_{2m} = \mathrm{Sin}^{-1}(\mathrm{Sin}\,\theta_1 + m\,{}^{\lambda}/_{T}) \quad \text{where, } m = 0, \pm1, \pm2 \text{ and } T = \text{Surface period} \qquad (1)$$

The angle of diffuse scatter, $\theta_{2m,}$ is related to the period of the roughness. Since surfaces produced by various processes exhibit distinct differences in texture, the specimens of the machined surfaces can easily be identified by looking at the diffraction pattern - such as ground, shaped, milled or turned workpieces. This probe is implemented in an On-Line Inspection system and consists of the following major components:

- A supervisory computer, that contains the algorithmic interface used to carry out the inspection process.
- CNC vertical machining center is used for machining as well as inspecting the workpiece.
- The non-contact laser based probe is the inspection tool, which is housed on the carousel of the CNC machine.

After the machining is done, the CNC machine picks up the inspection tool stored in the carousel and places it to a specified point near the machined workpiece for measurement to take place. The basic operation of the system consists of initial system set-up, calibration, positioning of the instrument and measurement of the part [5].

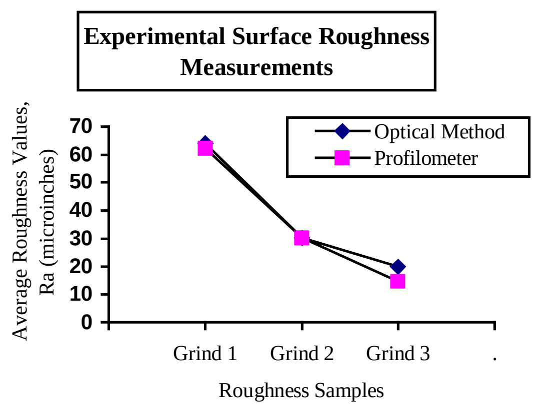

Fig. 5: Comparison of Surface Roughness Measurements

In this setup, a video system grabs the image of the diffracted light and the computer algorithm executes the necessary functions. The surface roughness value is recorded and then displayed to provide the information to the operator. The results of *Figure 5* shows experimental data of the measured average roughness value obtained by non-contact method in comparison with contact type instruments.

5 On-Line Dimensional Measurement

On-line geometric inspection is done using a different optical probe. For on-line implementation, the probe works like a small digitizer to be mounted on the spindle of the CNC machining center. The probe consists of a laser and a one dimensional PSD (position sensitive detector) as shown in *Figure 6*. The operation of the instrument is managed by a computer-based procedure that provides the operator interaction in the form of a menu-driven graphical interface.

Principle of Operation

Dimension measurement using this digitizer probe is based on the method of triangulation as shown in *Figure 7*. A laser beam is emitted from a source at an angle to the centerline of the instrument, which is parallel to one of the axis of the CNC. The PSD mounted at an angle on the other side of the instrument centerline senses the reflected light off the part being measured. As such, changing the distance of an object from the measurement probe results in a displacement of the spot projected onto the photodetector. This sensor consists of a silicon device which provides position signals on a light spot traveling over its surface. The photoelectric current produced at each terminal is proportional to the resistance between the electrode and the point of incidence.

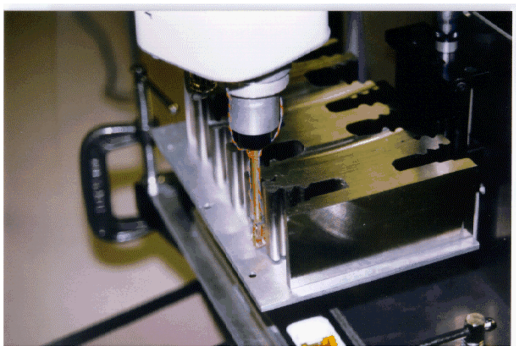

Fig. 6: Geometric Inspection Probe

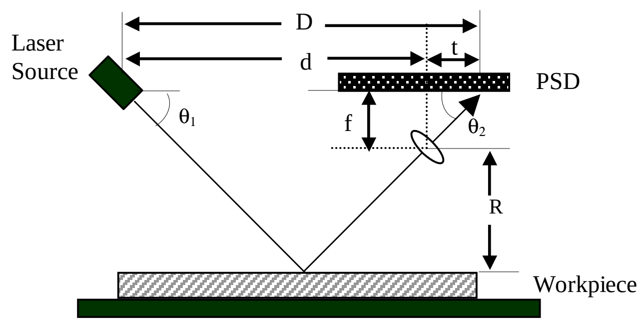

Fig. 7: Principle of Triangulation

Operation of the On-line Geometric Measurement System

In the measurement phase, the data acquired in the measurement procedure is compared to the data acquired in the calibration procedure. Positional X,Y,Z information of the points to be measured is determined by the operator. The CNC part program is initiated to traverse the instrument from one point to another. As soon as predetermined point is reached, a signal is sent to switch the operation to inspection mode. The measurement of the X, Y and Z location of the measured point are recorded and then displayed on the computer screen to provide the information to the operator. The described sequences are repeated until all the selected positions have been inspected.

6 In-Process Monitoring System For Aerospace Industry

The following section discusses the application of optical based embedded instrumentation for surface roughness and dimensional measurement that can enable both on-line and off-line accurate, quick and multiple measurements in hard to reach areas. It is also an object of this system to provide a methodology, which allows the operator to interact in the form of a menu driven procedure. *Figure 8* shows the experimental setup of the surface roughness/ dimensional measurement instrument designed to inspect integrated turbine rotor blades. It consists of four major parts: a laser probe; an educational robot; a networked simulation workstation; and a Hardware in-the-Loop test simulation environment to program the laser probe. The setup simulates the real shop-floor environment at Pratt & Whitney. After the aircraft blades are initially polished, the robot changes the polishing tool to the surface roughness measurement probe. The robot is programmed in such a way that the movement of the laser probe will follow the surface profile of a workpiece.

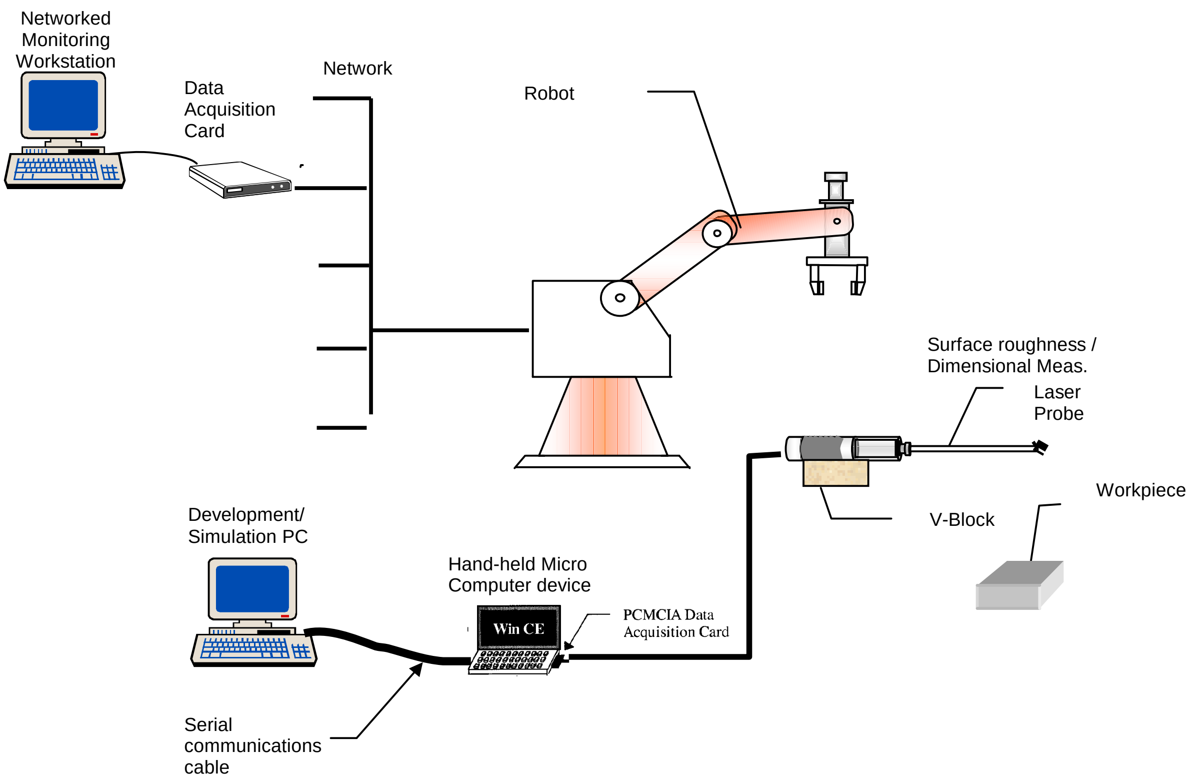

Fig. 8: Layout for On-line Measurement Using Industrial Robot

7 Conclusion

The research has been intended to devise an on-line quality control system which is industry affordable and shop floor compatible utilizing inexpensive embedded instrumentation components. The use of embedded systems will allow further miniaturization of the sensors, elimination of the personal computer for calibration and measurement, real time processing capability and provide the user a level of interaction with the control system to simulate the implementation of changes in methods of measurement. Using the above-mentioned instruments, further research efforts are in progress to fully implement a supervisory control system.

Acknowledgments

The authors are grateful to Mr. Robert Roark and James Campbell, Pratt & Whitney Co., for their continued interest in this work.

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