WEB BASED SUPERVISORY SYSTEM FOR PLUNGE GRINDING OPERATION

Eraldo Jannone da Silva
Rafael Caram Abujamra
André Del Bianco Giuffrida
Vinicius Ricco Alves Reis

Abstract. *The current demand for quality and reliability in the manufacturing processes has a direct impact on the process automation level. Besides, the faster is the detection of non-conformities or deviations from the production targets; the lower is the impact on the part production costs. Considering that the grinding operation is in most of the cases the last step in the manufacturing chain, the statement above become even more critical. The popularization of PC-based open-architecture numeric control in machine tools enabled the easier implementation of end-user application and also the acquisition of machine information with minimum requirement of external sensors. Information such as: actual axis position, feed rate, and spindle RPM, among others, is available to be gathered from the numeric control using standard interfaces. By intranet or Ethernet, information can be disseminated among all enterprise levels. The current scenario allows the implementation of monitoring and supervisory systems for data acquisition of the machining processes. The aim of this paper is the development of a web based supervisory system for plunge grinding operation. The MTConnect standard was used to acquire CNC data, increasing the flexibility in adding further machines to the system, regardless the CNC manufacturer. The data collected directly from the CNC using Ethernet can be divided in three main categories: machine, process and production. The most suitable CNC parameters to be monitored were selected. Particular combinations of those parameters were determined to define current machine status. For measuring the start diameter and eccentricity of the workpieces, a strategy based on the acoustic emission and capture of the machine coordinates when a skip signal is detected was used. The proposed web based system interface allowed local and remote client stations (Ethernet/Internet). Finally, the key features of the system were presented.*

Keywords: *grinding; supervisory system; open architecture; numeric control.*

1. INTRODUCTION

The increase of the automation level for manufacturing process is directly related to the current high demands for quality and reliability. The management level in organizations is trying to have access to relevant information directly related with production performance. Manual feedback systems are not suitable for reaching this goal because they are slow and don't have the required time resolution to serve as a base for management decisions.

The Internet popularization provided new technologies to integrate the different automation levels in an enterprise environment (Figure 1). Supervisory systems using advanced network technologies and industrial automation tools become a market reality. That fact enabled the easy share of information among all automation levels with the required time resolution.

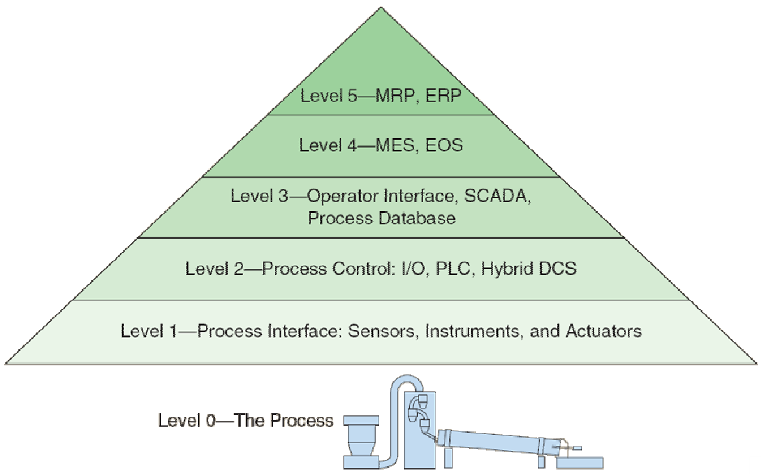

Figure 1 – Automation Pyramid (Difrank, 2008)

Basically, the information acquired from the shop-floor can be grouped in two main automation systems: production supervisory and monitoring of the machining process. According to each functionalities and information to be collected, each system has a particular level of time resolution for data collection. Supervisory systems are in the range of day/hour/minutes and the information is uploaded to the Enterprise Resource Planning (ERP) systems with time bases varying from one day until one month; for production management systems, as Manufacturing Execution Systems (MES) the information is updated in time intervals from 1 to 10 minutes. Moreover, monitoring systems have normally time resolution determined in fractions of seconds, once its resolution relies on direct process evaluation. Those systems can be on-line (during the process) or off-line (periodically), in the case of acquiring during machining intervals. The aim is to monitor the machining process, the machine or the cutting tool.

Each monitoring application requires its own special architecture to achieve its features, such as time resolution and purpose of the data collection. In Figure 1 both architectures are presented.

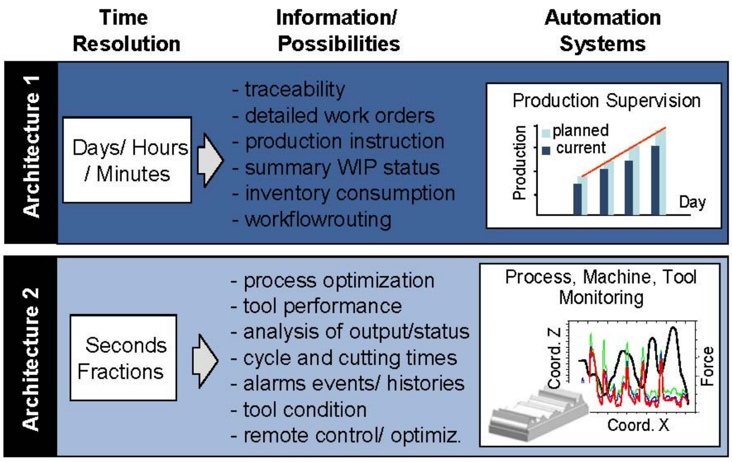

Figure 1 – Shop-floor data acquisition architectures (Ferraz Júnior 2007, Ferraz Júnior e Coelho, 2004).

The data collection represents the core of monitoring applications, once all decisions and process evaluation will be based in the acquired information. It can help the determination of new ways to enhance the operation and to increase the productivity (Michaloski *et al.*, 2008). To achieve a more flexible manufacturing, Supervisory Control and Data Acquisition system (SCADA) is been developed by CNC manufactures for CNC remote data collection. Cimplicity (GE-FANUC) and MDA (Siemens) are two examples of SCADA systems. These proprietary applications represents an advance for monitoring CNC machine tools remotely, but the communication can be stabilized only with machines and SCADA systems from the same manufacturer and are also limited to some parameters, such as: alarms, cycle times, workpiece counters etc.

According to Vijayaraghavan *et al.* (2008) and Ferraz Junior (2002), the integration between Information Technology (IT) systems and all automation levels (Figure 1) is desirable and has resulted in improvements of efficiency and production.

A bottleneck for the implementation of supervisory systems in machining industry is the heterogeneity of the machine inventory. Identical machines with different CNC types together with legacy machines with or without numerical control can be grouped together in a given industry shop-floor, exponentially increasing the required automation costs for data collection in the ground levels of the automation pyramid.

Standard interfaces or neutral communication languages for machine tools and other production equipment are sought to overcome the issues mentioned above. Web-based systems using intranet or Ethernet can expand the application field of those systems. Supervisory systems currently developed for continuous process can be applied to discrete processes (like machining) increasing the integration among automation levels, eliminating the manual data collection. Data related to production (production rate, total of produced workpieces, etc.), to process (cycle time, speeds, etc.) to the cutting tool (number of produced parts per dressing, etc.) and to the machine events (alarms, types, descriptions, etc.) can be collected with adequate temporal resolution (Oliveira *et al.*, 2008).

1.1 Objective

The aim of this paper is the development of a web-based supervisory system for plunge grinding operation The MTConnect standard was used to acquire CNC data, increasing the flexibility in adding further machines to the system, regardless the CNC manufacturer. The system will allow data collection related to production, process, tool performance and machine events, providing the important information about the process in the required time resolution.

2. Supervisory systems for grinding

According to Oliveira *et. al* (2000), information related to the production can be acquired in a supervisory system, including, but not limited: time, quantity and costs and comparison between current and target indicators, being directly related to the Production Planning and Control (PP). Thus, integration between supervisory systems and ERP's software can be performed. The basic components of a supervisory system may include sensors, fieldbus to interconnect machines, supervisory software and a database for storing relevant information.

One example of a supervisory system for grinding is the one proposed by Medalha (2001). Acoustic emission was used to measure the workpiece diameter in the beginning of the grinding cycle in addition to the workpiece eccentricity associated with the clamping system and the geometrical errors from the previous process (turning). A circuitry was developed to read the encoder position of the grinding machine X-axis when the acoustic emission level had reached a threshold value. That approach was used to measure the workpiece initial diameter. Furthermore, the eccentricity from the previous operation (turning) was measured by acquiring the workpiece diameter (X-axis position) at two particular situations: right after the first contact between the grinding wheel and the workpiece (crossing limit 1 for acoustic emission) and when the workpiece is finally round during the rough phase of the grinding cycle (crossing limit 2 and staying above that limit during the rest of the grinding cycle – see Figure 2). The proposed system was able to determine the workpiece initial diameter and the eccentricity under the typical grinding and turning tolerances.

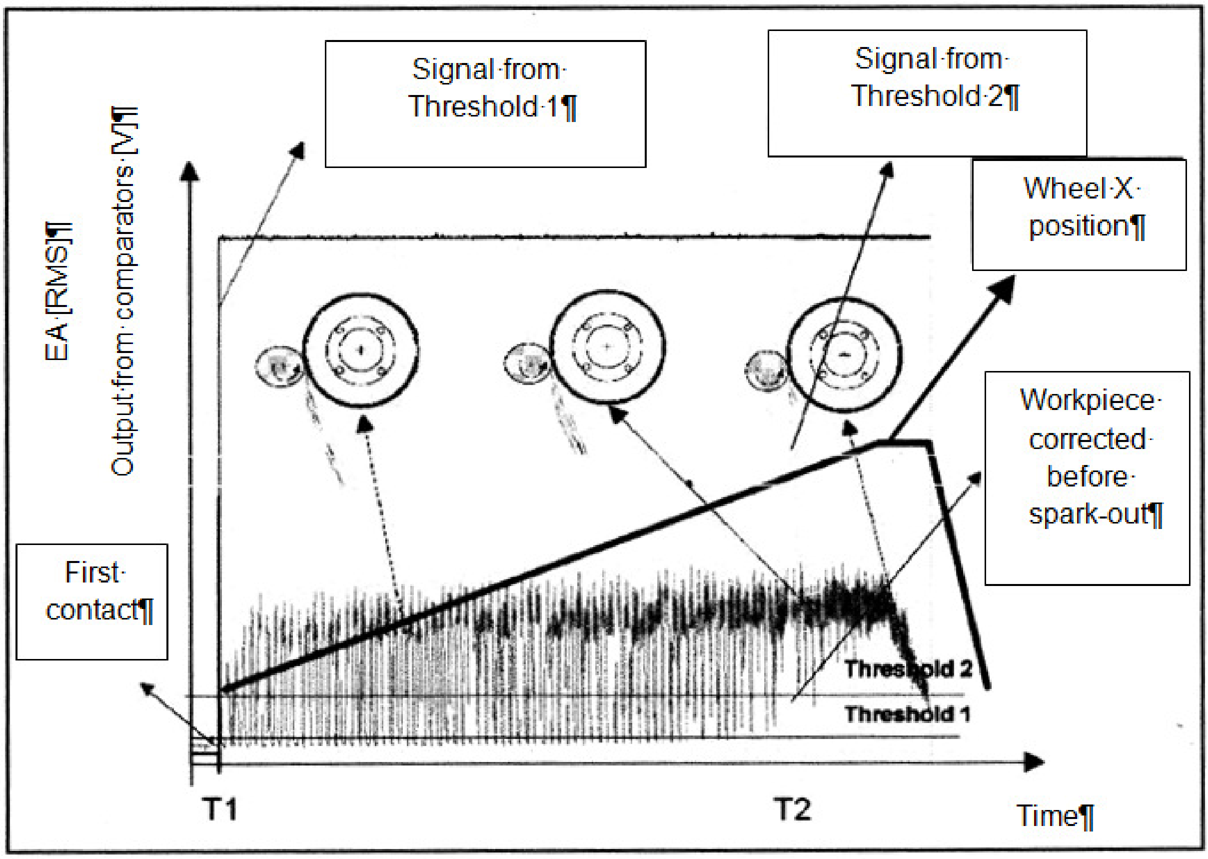

Figure 2 – Methodology to determine the workpiece diameter during the grinding cycle (Medalha, 2001)

.

The advantage of the proposed system by Medalha (2001) is that it uses an acoustic emission sensor already presented in the machine to perform the measurements. No additional sensor was required. The drawbacks are the required initial fine tuning of the acoustic emission unit and the additional circuitry to gather the actual wheel position by manipulation encoder pulses to determine the workpiece diameter. Nowadays, that issue is easily overcome when considering the current generation of CNC controllers which allows the capture of the current machine coordinates and other CNC related data without the need of additional circuitries using Ethernet connections to the CNC, as will be discussed in the next section.

2.1 MTConnect™ Standard

2.2.1 What is the MTConnect™?

On a normal day at a manufacture plant, hundreds or millions of machines and independent systems operate in union to guarantee that the product can be produced quickly, with quality and at a low cost (Warndorf *et al.*, 2007). Each of these machines and systems accumulates information about operations and, normally, cannot share this information with other systems.

The MTConnect™ was designed based on the most relevant points of production lines and software used in industry, expanding the number of available tools for settling and providing high levels of inner-operativeness through use of already existing technology (Vijayaraghavan *et al.*, 2008).

The standard, MTConnect^{TM}, is based on XML (Extensible Markup Language), which offers a flexible representation for semi-structured data exchanging. The open standard is free of royalties to guarantee that it can be used to the maximum potential. The inter-operability from the standard stimulates the development of software and hardware from others to make the process of manufacturing more productive.

Figure 1. Representation of the MTConnect^{TM}

2.2.2 Standard Components

The main components of the MTConnect Standard are described below:

- ***Adapter*** – With the standard still under-development, most of the CNCs are incompatible. To allow such scenario, it is necessary to add an adapter. Optional software that connects an external agent to a dispositive.
- ***Agent*** – A software that gathers data sent from compatible dispositive (if not, an adapter is used) with the MTConnect standard, organizing them into a database from XML.
- ***Alarm*** – Indicates an event that calls for attention, an alteration from the normal operation behavior.
- ***Sample*** – An exact data from a series of continuous data. An example is the position of an axis at a given moment.
- ***Component*** – Part of a device that may contain sub-components or data items. The components are blocks that compose the devices.
- ***Current*** – Requisition made for the agent to factual values from all the data items specified. If no item is specified the agent returns the values of all available components.
- ***Device*** – Part of the equipment capable of performing any operation. A device is defined as a group of components capable of providing data for the application. A device is an entity with at least one controller conducting its operation.
- ***Event*** – Represents an alteration on the state that occurs on a certain given moment. Note: an event does not occur under pre-defined frequency.
- ***Data Item*** **–** Represents a description or value from any information that can be gathered from the agent.
- ***Probe*** – A requisition that results on configuration description and Device composition.
- ***Stream*** – Collection of Events and Samples organized by Devices and Components.

2.2.3 Architecture

MTConnect^{TM} is a standard constructed under the most relevant manufacturing and industrial software patterns, maximizing the number of available tools for its implementation and providing high levels of cooperation with other standards and tools on these industries (Sobel, 2010).

Seeking to solve problems in a simple way, like standards incompatibility or being handled by API providers, the MTConnect^{TM} was developed from a modular architecture which allows the use of tools to connect these devices.

According to Rondon (2010), four different architectures for installing the standard can be observed (Figure 4). By considering the first architecture (a), considered ideal, the device is completely compatible with the MTConnect^{TM} which contains an agent inside the controller requiring no modifications. Architecture (b) shows a device with an adapter attached, but the development of an agent is necessary in order to collect data from the device and make it available. The architecture (c) and (d) illustrate a device that is not compatible, or a legacy device. In this case it is necessary to program the adapter and the agent. It may require a different adapter for each CNC model, due to the proprietary communication protocol.

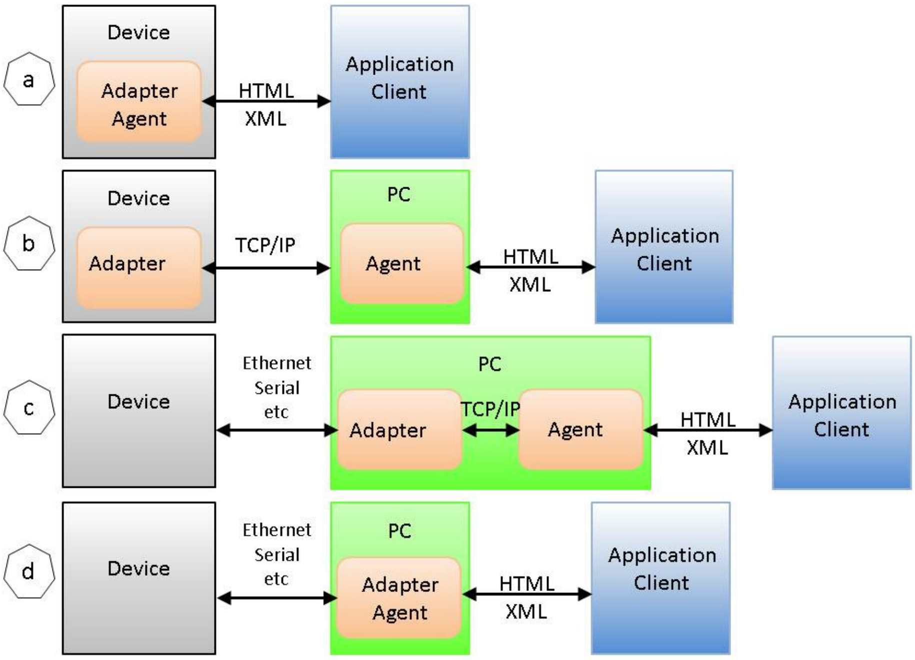

Figure 2. Possible architectures for MTConnect^{TM} standard installing (Rondon, 2010)

3. TEST METHODOLOGY

The development of a web-based supervisory system for plunge grinding operation was divided in two phases. The first one included the programming of piece of software using the MTConnect standard for collecting relevant information from the CNC of the grinding machine to be monitored. The definition of those parameters was also part of the phase one. In the second phase, a remote web application was developed using JavaFx, creating the front-end of the supervisory system. The system functionalities were testing by acquiring grinding data during the machine operation.

3.1 Phase 1 – Development of the MTConnect software application for CNC data collection

3.1.1 Defining the topology, implementing the adapter and the agent and selected the revelant information from the grinding process

The grinding machine ZEMA G-800HS (Fanuc 180i CNC controller), equipped with a acoustic emission monitoring system (SENSIS-DM42) was connected to laboratory Ethernet. The machine was not MTConnect compliant (Architecture a – Figure 4), requiring the development of an adapted and an agent to enabled the data collection and the data output. Architecture c was then selected.

The grinding machine to be monitored was connected in the laboratory Ethernet. A server with two network interfaces was used. The first was connected to the local network allowing access to the grinding machine and other machine tools. The second network adapter was connected to the main router, with a real IP to Internet access. The implementation of a server with an interface to the Ethernet allows the implementation of security tools, like a firewall, protecting the CNC of the machine tools from an unauthorized access, deploying only the necessary information requested by the system (Rondon, 2010). The proposed topology is present in Figure 3.

Figure 3. Network topology

The agent software used was provided by MTConnectTM Institute (MTCONNECT INSTITUTE, 2010), along with its C++ source-code, being freely modified. This software was used without modifications, connecting to the configured adapter (developed in C++) and providing the output files in MTConnectTM format in a HTTP host.

All collected data were provided by the agent in XML format, and then analyzed by an application developed in JavaFX platforms.

Adapter

The adapter CNC GE-FANUC used, available from *MTConnect™ Institute* was added on C++. It has an embedded FOCAS 2 library required to enable the communication with the Fanuc CNC controller. That library provides a full list of parameters that can be read or write from or to the PMC. The adapter sampling rate was 100 samples/second.

As the adapter does not have a possibility to externally configure which data will be read from the device, it was necessary to add that feature directly in the program source-code. In the developed JavaFX application, only two parameters were not available in the original adapter: machine power and a particular range of "custom macro" variables, which can be externally configured. To acquire the spindle power, the 8-bit output reference signal from the frequency inverted was read and converted to the grinding power.

A range of custom macro variables was assigned to particular parameters of the grinding process, as indicated in Table 1. Those variables were also included in the CNC program used to grinding the workpieces in an external plunge grinding operation.

Table 1. Reserved custom macro variables used during the tests

Custom Macro variables	Parameters
580	Initial workpiece diameter
582	Stock removed
584	Round workpiece diameter
585	Piece counter (final)
586	Approved workpieces
587	Rejected Pieces

Agent

The agent used was the official *MTConnect™* without additional modifications.

As shown in Figure 6, the agent is a software that must be executed in text mode, in the Windows prompt, and must be informed by the parameter "-c <name_file>" to indicate the file configuration filename from the adapter (or adapters). That file indicates the address for the connection of agent with each system adapter. Each file line must be on the following format:

<name_device>:<address_ip>:<door>

Figure 4. Indication of adapter address and agent initializing

In order to avoid compatibility problems, the device name must be the same name used in one of the other devices described on the XML document that was previously created. In this case, the created XML file must have the name "probe.xml". The IP address and doors are addresses for the TCP/IP server adapter. In this case, due to the fact that either agent or adapter must be in the same server, the address is local and the defined door in the adapted code. This configuration was made in the file "adapters.txt" containing the address of the added device.

The execution line for the agent software is:

agent –c <name_file_adapters>

Once the agent and the adapter were developed, an automatic instruction was developed in the server to automatic start the adapter and the agent. That procedure allows the data polling from the machine. The agent will deploy periodically an output file in a XML format, which will be reached by the client application through a HTTP request to a public IP address. The parse of the XML file will be performed by the client application.

Relevant Grinding information

In precision grinding, one of the most important output parameter to be controlled is the workpiece diameter. The dimensional problems presented by the cylindrical grind process are related to the deflections generated in the system machine-workpiece-fixture during the grinding cycle. The deflections must be released during the spark-out time, correcting workpiece final dimension and roundness.

The proposed supervisory system must monitor the workpiece diameter and also other relevant information from the grinding process, which can be grouped in the following main classes: production, process and machine. A fundamental research was also performed in order to understand the particularities of CNC controller of the grinding machine to be monitored.

Using the parameter classification provided by the MTConnect Institute, the relevant information was grouped as presented in Table 2.

Table 2. Information to be included in the supervisory system

<table>
<tr><td colspan="2" rowspan="4">Initial Screen (Start)</td><td>Machine Status</td></tr>
<tr><td>Control Modes</td></tr>
<tr><td>Estop Situation</td></tr>
<tr><td>Piece counting</td></tr>
<tr><td rowspan="21">Menu – Details</td><td rowspan="3">Production</td><td>Piece Counting</td></tr>
<tr><td>Approved pieces</td></tr>
<tr><td>Reproved pieces</td></tr>
<tr><td rowspan="8">Process</td><td>Initial Diameter</td></tr>
<tr><td>Final Dimension</td></tr>
<tr><td>Removed Material</td></tr>
<tr><td>Cycle timing</td></tr>
<tr><td>Cutting timing</td></tr>
<tr><td>Load on X axis</td></tr>
<tr><td>Load on Z axis</td></tr>
<tr><td>Graphic of Final Dimension</td></tr>
<tr><td rowspan="10">Machine</td><td>Program identification</td></tr>
<tr><td>Executing Line</td></tr>
<tr><td>Load on X axis</td></tr>
<tr><td>Load on Z axis</td></tr>
<tr><td>Load on Spindle</td></tr>
<tr><td>Axis position (Z, X and C)</td></tr>
<tr><td>Advance</td></tr>
<tr><td>Axis Override</td></tr>
<tr><td>Graphic – Load on a axis Z, X an spindle)</td></tr>
<tr><td>Progressive bar – Power</td></tr>
</table>

From Table 2, all parameters were collected directly from the CNC using particular functions from the *FOCAS 2* library, except power and workpiece diameter, which required additional manipulation to be read.

Power was collected by reading a 8-bit output from the frequency inverter which drives the wheel spindle. There was no particular FOCAS 2 function to read that value, so a particular byte from the CNC input address were read and manipulated. The strategy for reading the workpiece diameter is described below.

The DM42 acoustic emission (AE) unit is wired to the CNC skip signal inputs (I/O rack). Acoustic emission is used to detect the start point of contact between wheel and workpiece. By setting particular threshold limits for the acoustic emission signals, the AE unit send a 24V output signal to a physical CNC input with high-priority processing hierarchy, when the AE value cross that limit. Then, by reading a particular CNC parameter (for the FANUC 180i – parameter #5061), it is possible to determine the current X position when the skip signal was received. That machine coordinate is used to determine the workpiece initial position in the grinding cycle (initial diameter).

3.2 Phase 2 - Supervision System definitions

The developed supervision system has a simple and friendly interface. The main idea is to provide a fast overview of the current machine status, by using a color code box around the machine picture. The following classification was defined:

- Green (Active): The machine is executing a CNC. Machine in MEM mode;
- Yellow (Ready): The machine automatic operation was interrupted by a specific instruction, for example, a M0;
- Red (Stopped): Machine is not executing a CNC program or instruction. This situation involves all non-production machine states (manual jogging, editing of programs, machine setup);
- Gray (Unavailable): communication lost with the CNC. All other machine information grouped into machine, production and process would be displayed in different screens accessed by the main screen.

The main requirements for the supervisory system were: being a web application, accessed from Ethernet or Internet, with minimum or no requirements of additional software installation.

4. RESULTS AND DISCUSSION

The main screen of the developed supervisory system is present in Figure 7.

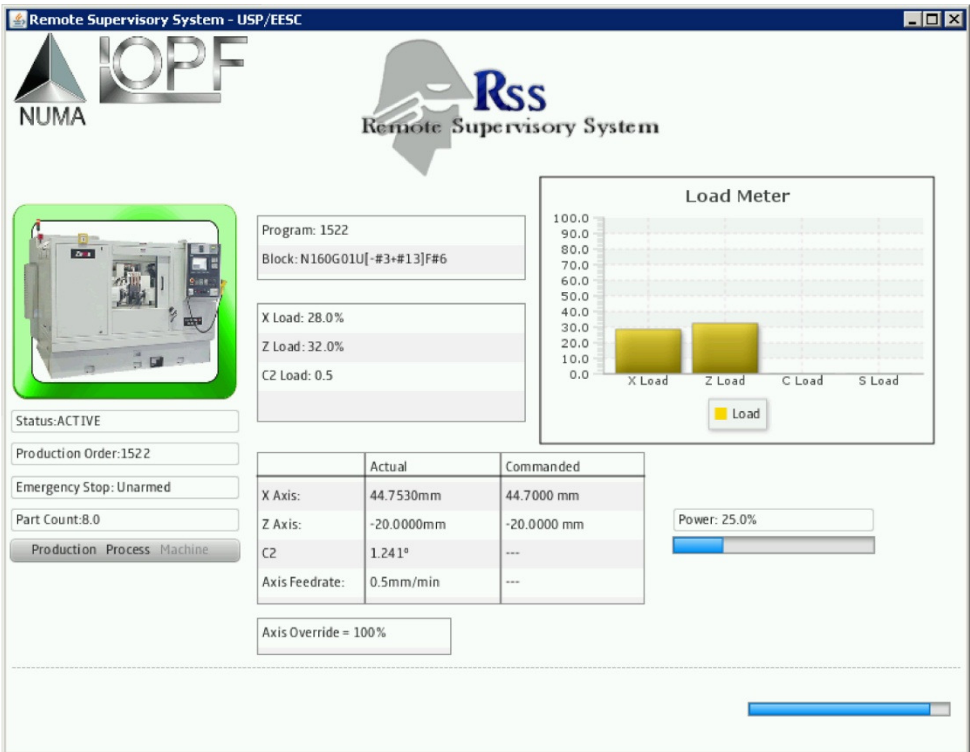

Figure7. Remote Supervisory System Machine Screen

The RSS application (Remote Supervisory System) was developed using Netbeans 6.9.1 IDE (Integrated Development Environment) and some java libraries. The RSS has a function added that recognizes connection to the machine. This means if the agent and adapter were not started or if there is any physical problem (disconnected cable or hardware problems) in the connection, the application will exhibit a message “It was not possible to connect to Server” and shall close automatically. The application screen is updated every 10 milliseconds.

In the left top corner of the main screen the color code related to the machine status is presented along with a summary of the more relevant information among the groups, including machine status (in the example “active”), production order, emergency stop status and part count. Additionally, information regarding the machine parameters are presented, such as axis position, a load meter for all axis, power consumption, feed rate, feed override and spindle power consumption, among others. All collected information is already available in the CNC, not requiring the installation of additional sensors.

Details about the production information are available in Figure 8. Considering that the machine was no in-process gauging system, the definition of bad or good parts in the proposed systems are related with the initial eccentricity of workpiece calculated by acoustic emission using the methodology proposed by Medalha (2001). In that situation, the eccentricity calculated by the differences between the “initial” and “round” workpiece diameters is compared with the maximum allowed initial eccentricity of the workpiece. If greater than the reference value, the available stock might not be sufficient enough to reach the required workpiece roundness, rejecting the workpiece.

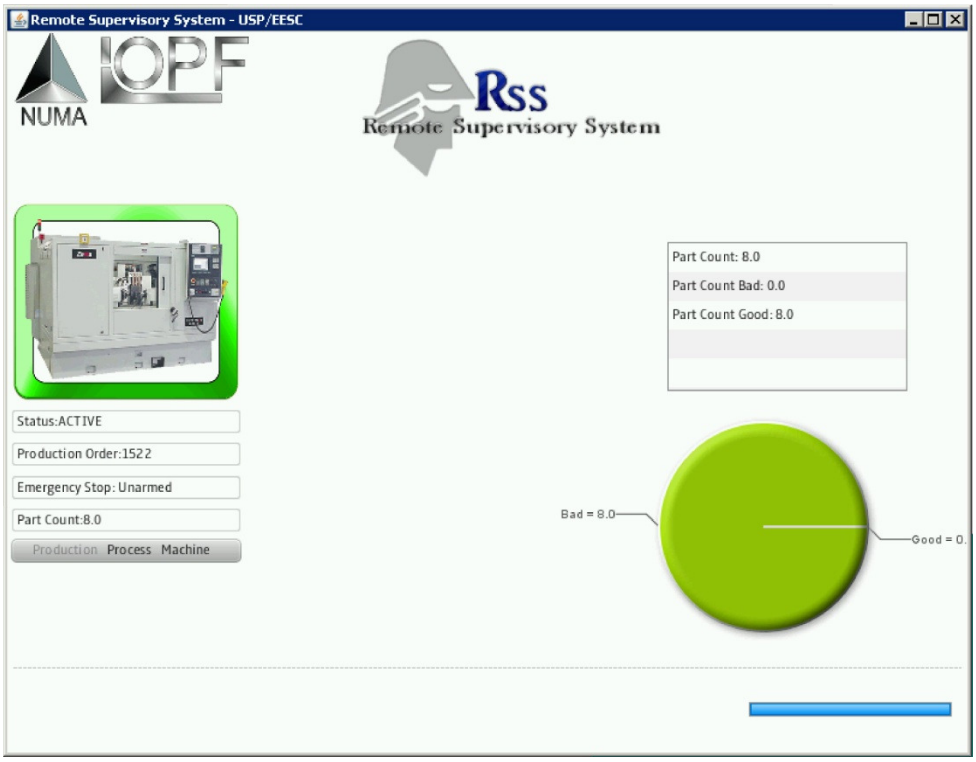

Figure 8: Remote Supervisory System – Production Screen

Process information is now presented in Figure 9. The initial workpiece diameter is calculated by acquiring the machine X coordinate when receiving a skip signal from the acoustic emission sensor. The round diameter and the eccentricity are calculated according to the methodology proposed by Medalha (2001) (section 2), differing on the approach to capture the machine X coordinate, not requiring the development or installation of additional hardware.

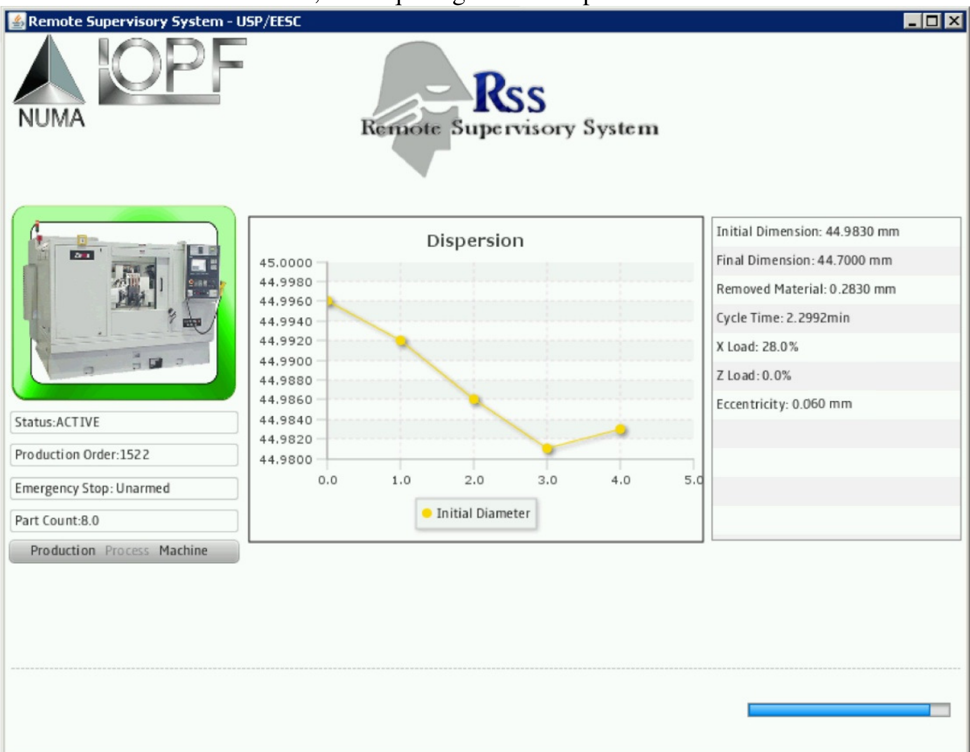

Figure 9: Remote Supervisory System – Production Screen

In the initial version of the system, historical data can be acquired from the XML output file of the agent using *sample* requisition. The result is a documentation called *MTConnectStreams*, containing the last 100,000 items. A database will be implemented in the server to increase the historical view of the process.

5. CONCLUSION

Through the introduction of the standard MTConnect and proposed architecture, it was possible to collect data from the grinder Zema Numerika G-800 – HS and the development of a supervisory system for grinding with the required time resolution.

Relevant information from the machine, production and processes could be acquired with the proposed system through client applications in the Ethernet or Internet. The majority of the information is already available in the CNC, not requiring the installation of additional sensors. Acoustic emission was used to determine the workpiece diameter.

The adoption of the MTConnect will enable the ease of integration of additional machines, regardless the CNC type.

6. ACKNOWLEDGEMENTS

The authors wish to tanks the support of the FIPAI (Fundação para o Incremento da Pesquisa e do Aperfeiçoamento Industrial), Sensoft Indústria e Automação Ltda. and the MTConnect Institute.

7. REFERENCES

Difrank, G. (2008) Power of automation: An overview, technology, and implementation. IEEE INDUSTRY APPLICATIONS MAGAZINE, Mar/Apr: www.ieee.org/ias, p. 49-57.

Ferraz Jr, F. (2007). “Arquiteturas para monitoramento e supervisão integrados de processos de usinagem em máquinas com controle numérico aberto”. Engineering School of São Carlos, University of São Paulo, PhD Thesis.

Ferraz Jr, F. and Coelho, R. T. (2004). “Data Acquisition and Monitoring in Machine Tools with CNC of Open Architecture using Internet”, The International Journal of Advanced Manufacturing and Technology, http://www.springerlink.com, DOI: 10.1007/s00170-003-1977-3.

Ferraz Júnior, F. Desenvolvimento de um sistema de monitoramento e supervisão para o processo de torneamento. São Carlos, 2002. 94 p. Dissertação (Mestrado) – Escola de Engenharia de São Carlos, Universidade de São Paulo.

Gomes, J. J. F. Implementação de sistema automático de calibração dimensional em retificadoras CNC utilizando emissão acústica. São Carlos, 1997. 80 p. Dissertação (Mestrado) - Escola de Engenharia de São Carlos, Universidade de São Paulo.

Konig, W.; Klumpen, T. Process monitoring in grinding, dressing and sharpening processes. Precision Engineering, 1993, v.I/1 p.27-30.

Konig, W.; Meyen, H.P. AE in grinding and dressing: accuracy and process reliability. In: 4th International Grinding Conference, Deaborn, Michigan, 1990. Annals. P.526/1-526/20.

Medalha, G. C.; Oliveira, J. F. G.; Nova metodologia para monitoramento dimensional de peças, em processo, utilizando uma retificadora cilíndrica. In: XVI Congresso Brasileiro de Engenharia Mecânica, 2001, v.14, p. 408.

Oliveira, J. F. G.; Ferraz Júnior, F.; Coelho, R. T.; Silva, E. J. An Innovative architecture for machining process and production monitoring. Journal of Engineering Manufacture –Proceedings of the Institution of mechanical engineers Part B, v.222, 2008, p. 1605-1612.

Oliveira, J. F. G.; Soares, D. D. ; Meireles, G. S. C. ; Caetano, A. G. L. S.; Medalha, G. C. Sistema de supervisão para operações de retificação. In: 55º Congresso Anual da ABM, 2000, Rio de Janeiro v. 01. p. CD-CD.

Pollock, A. Acoustic emission inspection. Metals Handbook, 9th Edition – Nondestructive Evaluation and Quality Control, American Society for Metals, 1989, v. 17, p.278-294.

Rondon, L. C. Desenvolvimento de sistema de supervisão utilizando padrão MTConnect™, 2010. Monografia de conclusão de curso apresentada ao Instituto de Ciências Matemáticas e de Computação – ICMC-USP - para obtenção do título de Engenhario de Computação, 61p.

Sobel, W. MTConnect® Standard Part 1 - Overview and Protocol. 1.1.0., 2010. Disponível em: <http://www.mtconnect.org>. Acesso em: 6 Set. 2010.

Vijayaraghavan, A.; Sobel, W.; Fox, A.; Dornfeld, D.; Warndolf, P. Improving machine tool interoperability using standardized interface protocols: MT Connect, 2008.

Warndorf, P.; Fox, A.; Sobel, W. MTConnect Technology White Paper. 2007.

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.