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CNC MACHINE TOOL MONITORING USING MTCONNECT COMMUNICATION ARCHITECTURE

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Abstract. *The information acquired from the shop floor can be grouped in two main automation purposes: production supervisory systems and monitoring systems of the process, depending on what type of information will be presented, each one with its particular level of time resolution. To achieve a more flexible manufacturing, SCADA systems have been developed by CNC manufactures, which represents an advance for remote monitoring of CNC machine tools. However, proprietary applications limit the communication possibilities of the system and also minimize the type of information collected. A universal architecture is necessary in order to integrate all different levels of information required with low update times. Additionally, it is required that the proposed universal architecture attends different kinds of controllers. MTConnect presents a powerful option to achieve the objectives above and it was implemented in the monitoring framework presented in this paper. An application was developed using MTConnect architecture in order to download from machine the measurement results obtained during inspection routine of step gauge mounted on the machine's table. The architecture proposed can be very useful, reliable and robust for supervisory systems in general, and also for applications already developed for the traditional architecture.*

Keywords: *supervisory systems, monitoring, CNC*

1. INTRODUCTION

Basically, the information acquired from the shop floor can be grouped in two main automation purposes: production supervisory systems and monitoring systems of the machining process. According to each functionalities and information to be collected, each automation system has a particular level of time resolution for data collection. For Supervisory systems it is 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. Its objective aims on monitor 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.

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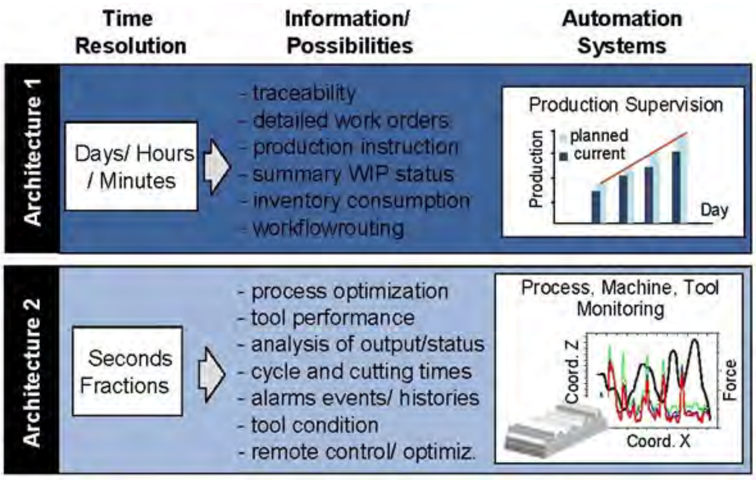

Figure 1. Shop-floor data acquisition architectures (Ferraz Jr., 2007 and Ferraz Jr. and Coelho, 2004).

The data collection represents the core of monitoring applications, once that all decisions and process evaluation will be based in the information acquired.

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.

It is still not available in the market an “open” SCADA system for machining process monitoring and communication with different brands/models of CNC, also focused on the acquisition and data analysis of the manufacturing process itself, including: true feed rate and spindle power, among others (Torrisi and Oliveira, 2011). The implementation of the new features will not only identify the process faults by historical alarms registry (currently done by actual systems) but also correlate such occurrences with the phenomenological aspect of the process and, consequently, their causes. This is the objective of the purposed OPF Monitoring Framework (Torrisi and Oliveira, 2011).

1.1 MTConnect monitoring scenario

It can be concluded that there are blanks to be fulfilled in the current monitoring and supervision system for discrete processes. An improved follow-up in the information related to the production process represents one important advance to be achieved. That information must be automatically collect, with a higher sampling rate and in an integrated way with all workstations that are included in the manufacturing system. Another advantage would be that the monitoring system would use only the resources already available in the CNC machine tools, without the necessity of installing additional equipments (sensors, conditioners, etc.). Finally, it can be noticed the necessity of a new standard communication architecture for both automation systems leading to the integration and simultaneously acquisition of two levels of time resolution (the supervision and monitoring ones) (Lödding and Oliveira, 2005). Figure 2 represents this architecture for data collection for different purpose: floor control, execution and planning.

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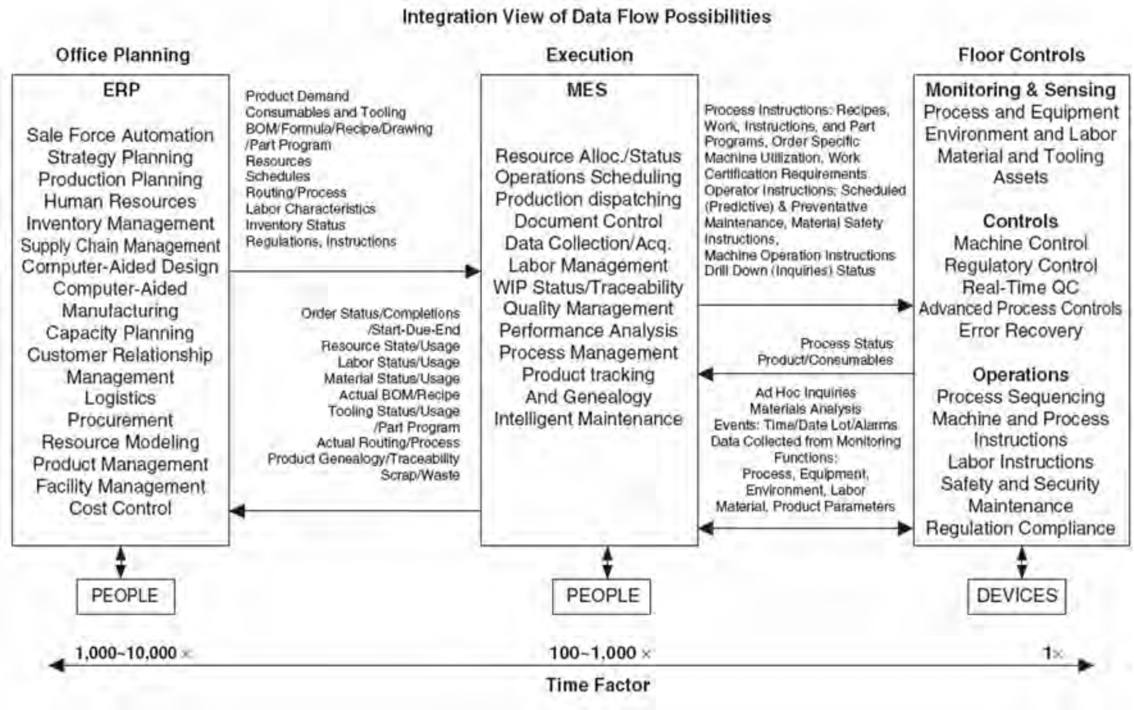

Figure 2. Information flow for MES integration – adapted from (Qiu and Zhou, 2004).

This scenario isn't fully achieved because there is no standardization for generic architectures. A universal architecture is required in order to integrate all levels of time resolution and information detailing to acquire data according to the necessary requirements and allows its automatic application in the manufacturing production with low update times. Additionally, it is required that the proposed universal architecture attends different kinds of controllers. The type, description and calling procedures of the data available as well as the communication interface must be standardized for all CNC manufacturers. Therefore, with all these requirements fulfilled, it will be possible to use the same architecture to different applications in different kinds of controller avoiding particular solutions.

MTConnect presents one powerful option to achieve the objectives for the ideal scenario of manufacturing integration. The proposed standard for CNC machine tools communication, based on XML, is been developed with the objective to allow the information from each workstation to flow to a common system for data collection and storage. Also, it's an open and free standard with will encore the adoption for several application for supervisory and monitoring systems. The architecture to be adopted based on three main platforms. The agent is responsible for the storage and orientation on the data collected by the adapter, responsible to connect the CNC machine tool to the agent. Once the information is collected and stored, is possible to develop applications, the last platform, to use and perform the desirable management of the data collected. Figure 3 presents the new scenario for monitoring and supervisory systems, using the MTConnect standard.

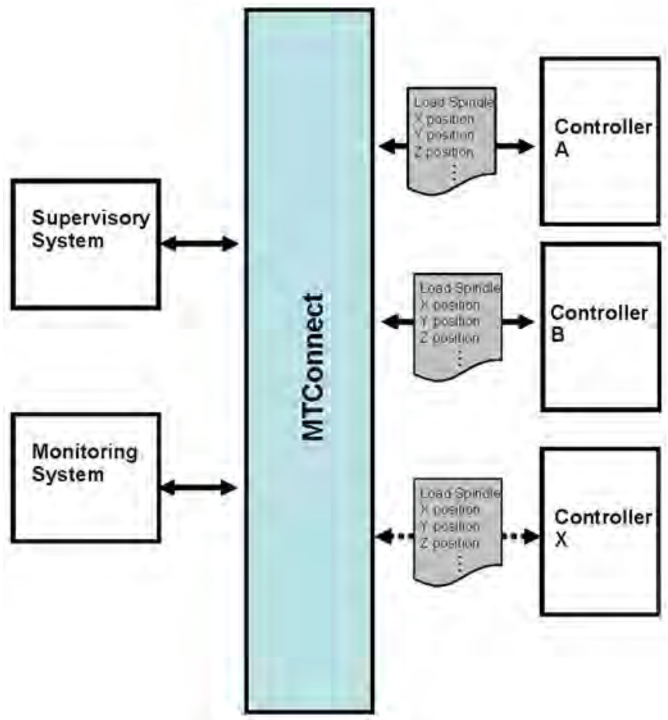

Figure 3. MTConnect monitoring scenario.

As other monitoring protocol like OPC-XML, MTConnect specification include a profile of use of HTTP as a transport protocol. The HTTP Protocol Transport Message consists of one header and one body as shown in Figure 4.

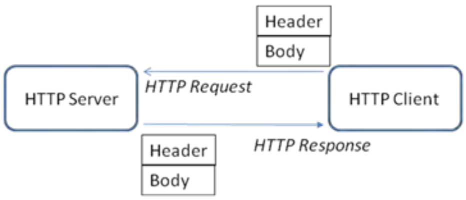

Figure 4. HTTP Protocol Communication Schema.

In order to send commands over this transport protocol, it is necessary to envelop the commands, whether inside the header or the body. OPC-XML and OPC-UA adopt the Web Services technology based on the SOAP Protocol, which means that the command related to the OPC Service is enveloped inside the HTTP headers. MTConnect adopts an XML processor directly applied to the HTTP body. MTConnect embeds the commands inside the HTTP bodies.

The next section presents the use of MTConnect standard in order to develop a framework for monitoring CNC machine tool from different manufactures. In addition, the methodology used to implement the standard is presented and also the results. It was created one adapter, OPF adapter and one application to prove the uses of the proposed architecture.

2. OPF MONITORING FRAMEWORK USING MTCONNECT STANDARD

The acquisition of information from machine tools using the technologies available today requires a specific software development for each application. As a result, the implementation of a monitoring system in machine tools is a complicated process and also not flexible.

Typical methods of data acquisition involve the development of individual interfaces for each model of machine tool control. Due to the fact that each CNC manufacturer uses its own communication standard several applications are necessary to implement monitoring systems in different machine tools.

The OPF Monitoring Framework is composed of Device (Machine Tool CNC), Adapter, Agent and User (Application) (Figure 5).

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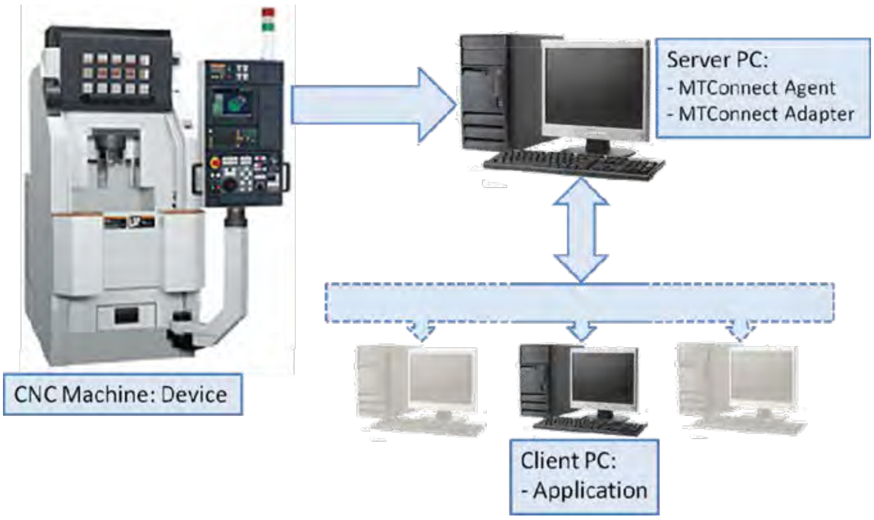

Figure 5. General OPF Monitoring Framework.

The Agent and the Adapter are embedded in the Server PC that receives the information from the Device and responds the requests from the running application of the Client PC. The information flow framework is detailed in figure 6.

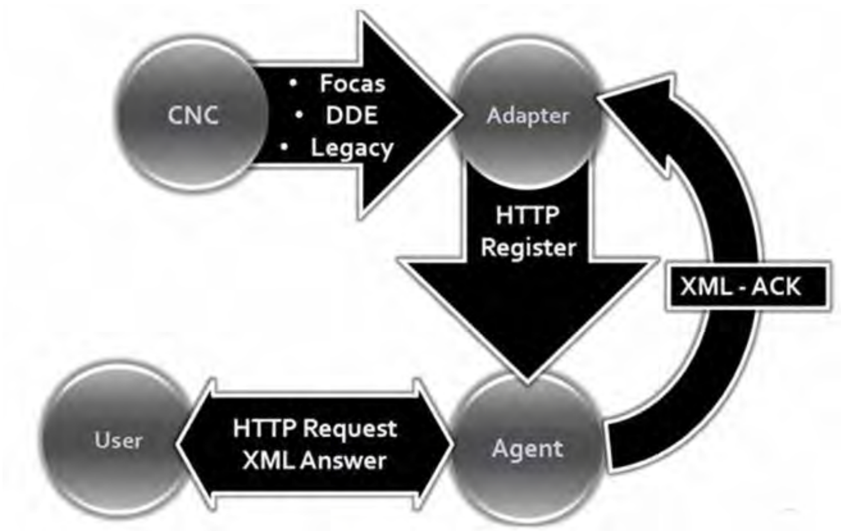

Figure 6. Information flow framework.

In this structure, the lower level is composed by the machine tool CNC, or device, where is possible to execute the collection of parameters by calling specific functions for each machine, e.g. using GE-Fanuc FOCAS 2 protocol interface, DDE for Siemens, etc.

The Adapter placed one level up, works translating the specific language of each CNC control to the predetermined MTConnect standard. By using the HTTP protocol, the Adapter is capable of sending the obtained information to the Agent, which also works as a buffer, accumulating data sent by the Adapter. The Agent uses HTTP protocol to send a feedback XML file to the Adapter, confirming the correct information received or notifying possible errors occurred during the process.

The data stored on the Agent can be accessed by an application through the HTTP protocol using HTTP request. This request is interpreted by the Agent and answered with a XML file containing the data required.

The XML file composition is divided into structures called XML schema, making possible the development of an application that reads the file and interpret the information on it. As a result, applications can be develop independently of the focused machine. HTTP protocol makes the development of applications much simpler and accessible. For instance, it is possible to develop an application for remote access of data using any operational system.

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2.1 MTConnect FOCAS Adapter

The MTConnect Adapter based in GE-Fanuc FOCAS 2 protocol interface (GE Fanuc, 2002) acts as a “translator” between a GE-Fanuc 30i CNC controller and the MTConnect Core Agent. It acquires data referent to measurements from the controller using an Ethernet connection and then stores it at the Agent using the HTTP protocol.

The Adapter was developed using the C# programming language. The code creates a C# wrapper for some of the communication functions in the FOCAS2 library, originally written in C, making them simpler and easier to use. It also handles communication with the Agent, using HTTP requests to transmit the acquired information.

2.1.1 User interface

The MTConnect Measurements Adapter uses a simple user interface for configuration, as seen in figure 7.

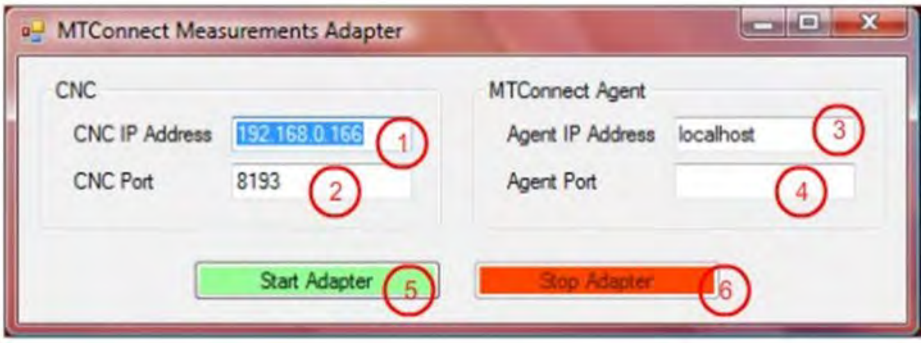

Figure 7. User interface of MTConnect FOCAS Adapter.

1) CNC IP Address field – Enter a valid IP for a GE-Fanuc 30i controller.
2) CNC Port field – Enter a valid port for communication with the CNC controller.
3) Agent IP Address field – Enter a valid IP for the computer running the MTConnect Agent. If the Agent is running in the same computer of the Adapter, localhost may be used.
4) Agent Port field – Enter a valid port for communication with the MTConnect Agent. If the Agent is running in the same computer of the Adapter, this field may be left blank.
5) Start Adapter button – Starts the adapter.
6) Stop Adapter button – Stops the adapter.

2.1.2 Error messages

Some of the possible error messages of the Adapter are described below.

Failure connecting to the CNC server (-16) – The Adapter wasn’t able to reach a CNC controller at the specified address. Possible causes include:

- Incorrect CNC IP Address and CNC Port settings;
- CNC isn’t properly connected to the network;
- The computer runing the Adapter and the CNC are in different networks.

Failure connecting to agent – The Adapter wasn’t able to reach an MTConnect Agent at the specified address. Possible causes include:

- Incorrect Agent IP Address and Agent Port settings;
- The computer running the Agent isn’t properly connected to the network;
- The computer running the Adapter and the computer running the Agent are in different networks;
- The Agent hasn’t been started. To start the Agent, click the “Start Agent” button in the “MTConnect Core Agent” window

Failure acquiring data from CNC server (-16) – The Adapter was abruptly disconnected from the CNC. Probably caused by the CNC shutting down or network issues.

2.2 SDK Agent

The devices.xml file was modified so the Agent would be able to store the specific information required by the application. Details are presented in figure 8.

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```
?xml version="1.0" encoding="UTF-8" ?>
MTConnectDevices xmlns:mt="urn:mtconnect.com:MTConnectDevices:0.9" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="urn:mtconnect.com:MTConnectDevices:0.9 http://www.mtconnect.org/schemas/MTConnectDevices.xsd">
  <Header version="1.0" sender="Company MTConnect Instance" creationTime="2008-09-08T10:00:47-07:00" instanceId="101"
bufferSize="100000" />
- <Devices>
- <Device sampleRate="10.0" name="Mori_Seike_Fanuc30i" iso841Class="1" uuid="mori-seike-fanuc30i" id="id1001">
  <Description manufacturer="Company Name" serialNumber="Serial Number" />
- <DataItems>
<DataItem category="EVENT" id="id1" name="alarm" type="ALARM" />
  </DataItems>
- <Components>
- <Axes name="Axes" id="id105">
- <Components>
- <Spindle name="S" id="id101">
- <DataItems>
<DataItem category="SAMPLE" id="id3" name="Srpm" type="SPINDLE_SPEED" units="REVOLUTION/MINUTE" subType="ACTUAL" />
  </DataItems>
  </Spindle>
- <Linear name="X" id="id102">
- <DataItems>
<DataItem category="SAMPLE" id="id4" name="Xabs" type="POSITION" units="MILLIMETER" subType="ACTUAL" />
  </DataItems>
  </Linear>
- <Linear name="Y" id="id103">
- <DataItems>
<DataItem category="SAMPLE" id="id6" name="Yabs" type="POSITION" units="MILLIMETER" subType="ACTUAL" />
  </DataItems>
  </Linear>
- <Linear name="Z" id="id104">
- <DataItems>
<DataItem category="SAMPLE" id="id8" name="Zabs" type="POSITION" units="MILLIMETER" subType="ACTUAL" />
  </DataItems>
  </Linear>
- <Linear name="D1" id="id108">
- <DataItems>
<DataItem category="SAMPLE" id="id18" name="Dim1" type="POSITION" units="MILLIMETER" subType="ACTUAL" />
  </DataItems>
  </Linear>
- <Linear name="D2" id="id109">
- <DataItems>
<DataItem category="SAMPLE" id="id17" name="Dim2" type="POSITION" units="MILLIMETER" subType="ACTUAL" />
  </DataItems>
  </Linear>
- <Linear name="D3" id="id110">
- <DataItems>
<DataItem category="SAMPLE" id="id16" name="Dim3" type="POSITION" units="MILLIMETER" subType="ACTUAL" />
  </DataItems>
  </Linear>
- <Linear name="D4" id="id111">
- <DataItems>
<DataItem category="SAMPLE" id="id15" name="Dim4" type="POSITION" units="MILLIMETER" subType="ACTUAL" />
  </DataItems>
  </Linear>
  </Components>
  </Axes>
- <Controller name="Controller" id="id106">
- <DataItems>
  <DataItem category="EVENT" id="id19" name="newdata" type="OTHER" />
  <DataItem category="EVENT" id="id10" name="block" type="BLOCK" />
  <DataItem category="EVENT" id="id11" name="execution" type="EXECUTION" />
  <DataItem category="EVENT" id="id12" name="mode" type="CONTROLLER_MODE" />
<DataItem category="EVENT" id="id13" name="program" type="PROGRAM" />
  </DataItems>
  </Controller>
- <Power name="power" id="id107">
- <DataItems>
<DataItem category="EVENT" id="id14" name="power" type="POWER_STATUS" />
  </DataItems>
  </Power>
  </Components>
  </Device>
  </Devices>
```


Figure 8. Devices.xml modified file.

2.3 Application

An application was developed using The MTConnect architecture in order to download from machine the measurement results obtained during inspection routine of step gauge mounted on the machine's table. The inspection routine program was developed in the ESPRIT™ CAM software. The step gauge used 2 ceramic blocks and 2 steel blocks, which has been previously calibrated. They were clamped on the table in two different angles, 45° and 135° and measured using a Renishaw touch trigger probe model OMP60™. More details about the test carried out can be found in Coelho et al. (2009).

Figure 9 shows the set up used in test the OPF monitoring framework using MTConnect standard.

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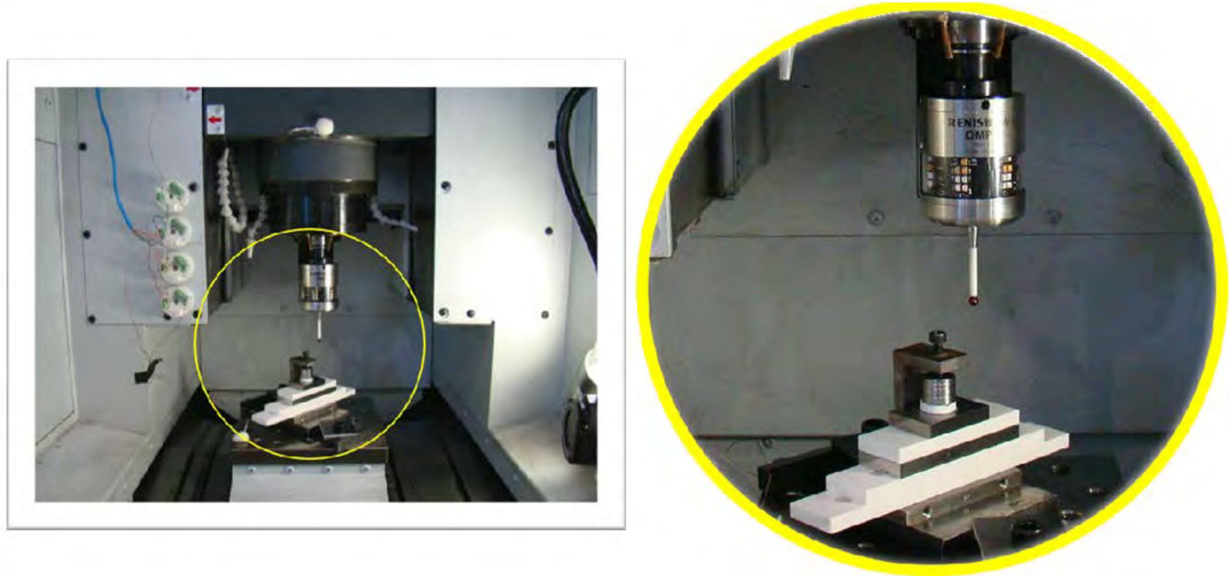

Figure 9. Set up used to calibrate the machine NVD1500 DCG for dimensional inspection (Coelho et al., 2009).

Four different CNC custom macro (CM) variables (#510, #511, #512, #513) stored the output measurement results. The Adapter waits for the end of the routine by monitoring the automatic operation status and then reads the values at those CM variables, sending them immediately to the Agent tagged as Dim1, Dim2, Dim3 and Dim4. The Adapter also sends a “new data” event, so any application retrieving the data from the Agent knows when new information is available. The whole step gauge was measured 10 times for replication purposes and statistical analyses.

JAVA platform was chosen to develop the application due to its portability and remote access possibility through internet. Another interesting aspect of this programming language is the easy implementation of friendly user interfaces. The developed application continuously monitors a parameter of the Agent that indicates if there is a new set of data to acquire (“new data”). When this parameter changes its status, pointing out that there is new information available for reading, the application starts the acquisition.

The exchange of information between the application and the Agent is made in two steps: request from the application (using HTTP protocol) and response of Agent (XML file). The request of information from the application to the Agent is similar to the request made by a user to access an internet website through a browser. In addition, the application uses an algorithm to interpret the information received in the XML file and separate the desired data.

There are several algorithms that convert data from XML files (process called “parse”) into useful information. The one used in this application is the DOM algorithm (Document Object Model). It converts the basic structure of a XML file into a hierarchical tree of nodes just like a data base, making it possible to run through the nodes searching the required information. A typical structure prepared by the DOM algorithm is illustrated below (Figure 10).

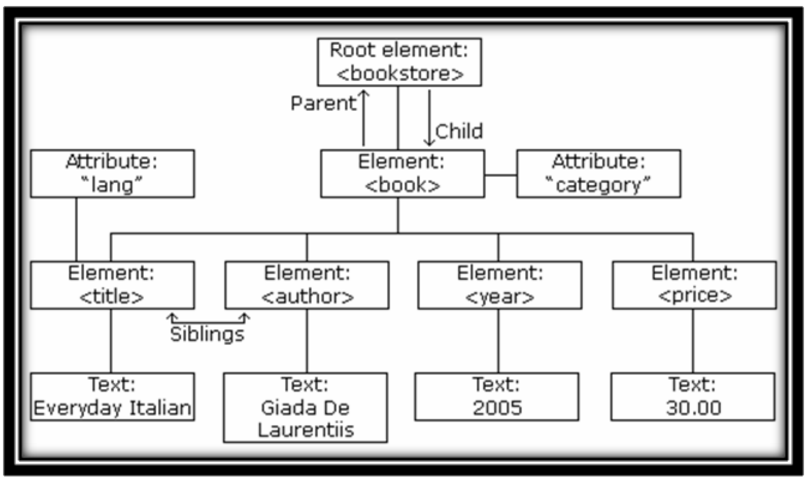

Figure 10. Example of hierarchical tree of nodes prepared by the DOM algorithm.

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To show the acquired data, a graph is used and the monitored dimensions are plotted against measurement number. The application interface with the measurements of dimension 2 and 3 is presented in figure 11.

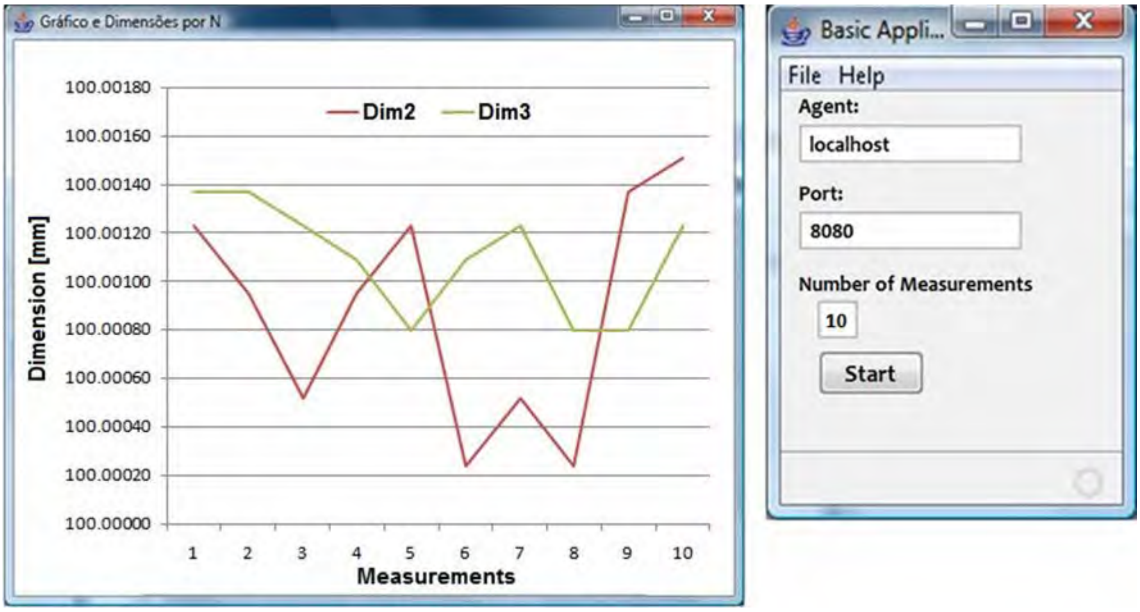
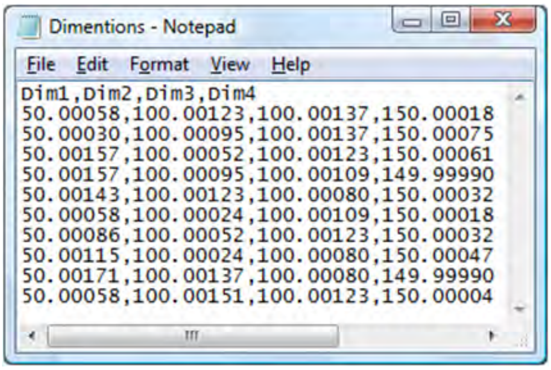


Figure 11 – Application interface.

At the end, a TXT file that contains CSV data, is generated and can be imported into the statistical software for complementary analysis (Figure 12).



Dim1,Dim2,Dim3,Dim4
50.00058,100.00123,100.00137,150.00018
50.00030,100.00095,100.00137,150.00075
50.00157,100.00052,100.00123,150.00061
50.00157,100.00095,100.00109,149.99990
50.00143,100.00123,100.00080,150.00032
50.00058,100.00024,100.00109,150.00018
50.00086,100.00052,100.00123,150.00032
50.00115,100.00024,100.00080,150.00047
50.00171,100.00137,100.00080,149.99990
50.00058,100.00151,100.00123,150.00004

Figure 12 – TXT output file.

In order to avoid the non-determinism of the internet, a timestamp is attached to each data collected, so that the time measured is always used and the actual acquisition rate can be assessed. The acquisition rate is more important for micromonitoring applications than for inspection. In the calibration example here presented the acquisition rate was around 30 points per second.

3. CONCLUSIONS

Although the results are still partial, some conclusions can be drawn at this point:

- The architecture proposed and implemented can be very useful, reliable and robust for supervisory systems, in general;
- Data acquisition for inspection purposes, combined with CAM software, proved to be one suitable application for MTConnect implementation;
- The proposed architecture can be used for several supervisory applications already developed for the traditional architecture.

MTConnect offers alternative Read/Write services similar OPC-DA 2.x/3.x, OPC-XML and OPC-UA, but when the objective becomes remote monitoring over IP, the MTConnect solution offers considerably flexibility.

On the other hand, the CyberOPC Solution replaces the weight of Web Services processing based on SOAP-HTTP with the light-weight Web Services based on JSON-RPC over HTTP, minimizing the computational load.

The MTConnect Application client is basically an HTTP client that is able to process XML text messages, embedding commands to read and write on the Server. HTTP and XML technologies can also be used from Web browsers that support asynchronous requests, such as Internet Explorer, Opera, Firefox and most browsers with JavaScript support, including PDAs and Smartphones. The enormous impact of the HTTP technologies in the Web consumer market indirectly offers a wide range of solutions for visualization SCADA applications based on the MTConnect Communication System.

The authors demonstrated how this approach based on open technologies can perform better that other well-known solutions for data process exchange over IP networks, considering flexibility and portability.

4. ACKNOWLEDGEMENTS

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6. RESPONSIBILITY NOTICE