A Remote Engineering Solution for Automating a Roller Hearth Kiln

Juarez Bento da Silva[1], Benedito Renê Fischer[2],Gustavo Ribeiro Alves[3], João Bosco da Mota Alves[4]
[1] Southern University of Santa Catarina, Araranguá, SC, Brazil
[2] São Paulo State University – UNESP, SP, Brazil
[3] Polytechnic Institute of Porto, School of Engineering, LABORIS, Porto, Portugal
[4] Federal University of Santa Catarina, Florianópolis, SC, Brazil

***Abstract*—Remote engineering (also known as online engineering) may be defined as a combination of control engineering and telematics. In this area, specific activities require computacional skills in order to develop projects where electrical devives are monitored and / or controlled, in an intercative way, through a distributed network (e.g. Intranet or Internet). In our specific case, we will be dealing with an industrial plant.**

Within the last few years, there has been an increase in the number of activities related to remote engineering, which may be connected to the phenomenon of the large extension experienced by the Internet (e.g. bandwith, number of users, development tools, etc.). This increase opens new and future possibilities to the implementation of advance teleworking (or e-working) positions. In this paper we present the architecture for a remote application, accessible through the Internet, able to monitor and control a roller hearth kiln, used in a ceramics industry for firing materials. The proposed architecture is based on a micro web server, whose main function is to monitor and control the firing process, by reading the data from a series of temperature sensors and by controlling a series of electronic valves and servo motors. This solution is also intended to be a low-cost alternative to other potential solutions. The temperature readings are obtained through K-type thermopairs and the gas flow is controlled through electrovalves. As the firing process should not be stopped before its complete end, the system is equipped with a safety device for that specific purpose. For better understanding the system to be automated and its operation we decided to develop a scale model (100:1) and experiment on it the devised solution, based on a Micro Web Server.

***Index Terms*—Tempretaure control system, ceramics industry, roller hearth kiln**

I. INTRODUCTION

Two kiln types are used for firing materials in the ceramics industry: the tunnel kiln and the roller hearth kiln. A major difference between these two kiln types is that the former allows a faster firing cycle with considerable productivity gains and energy savings [1], [2]. The use of roller hearth kilns was initially confined to floor and wall tiles, but since some years ago it has been extended to all types of table ware (decoration, biscuit firing, gloss firing, in-glaze), sanitary ware, and even clay materials for civil construction. This type of kilns usually works 24 over 24 hours, while also supporting break periods on the weekends (or longer periods), with quick setup times, which presents and additional vantage over tunnel kilns. Depending on the type of insulation and conveyor rollers used, it accepts temperatures of up to 1250 ºC, for pottery firing, or up to 1400 ºC, for porcelain firing.

The roller hearth kiln to be automated, in particular, measures 145 metres long by 2.4 metres width (see figure 1), and uses natural gas, which has an higher calorific power than other fuel types and therefore allows a more uniform firing and hence an higher productivity. The target kiln contains 35 ramps, where 32 are for firing and 3 for cooling. Each stage is 4 metres long and contains two thermocouples and two valves or servo motors.

Figure 1. Photo of the roller hearth kiln installed at AngelGres.

Figure 2 presents a simplified view of the roller hearth kiln operation. A new row of tiles enters the conveyor stage through the left side and, if there is a blank space available for firing, it enters inside the firing chamber. If there is no space then it goes into a waiting stage until there is one. The materials move inside the chamber by means of a conveyor belt that rolls by the action of special ceramic rollers, adapted to work inside the firing chamber. The hydraulic press that eliminates any empty spaces within one row of tiles (X-axis) is represented in blue colour while two sensors (bottom of figure 2) detect any spaces between two adjacent rows (that move along the X-axis). The bottom part of figure 2 illustrates the output of the roller hearth kiln where the finished up products are taken from. The following stages can also be identified in figure 2: (1) the entrance point to the kiln; sensors that control the ceramic materials awaiting to enter the kiln (2) and those entering the kiln (3); (4) sensors that control the spacing between two adjacent rows of ceramic materials, inside the kiln, in terms of an Y-axis; (5) this sensor will indicate if there is NOT an empty space in the kiln entrance – in this situation the ceramic materials will be placed in type of buffer (i.e. a waiting stage); (6) this sensor acts in the opposite way of sensor 5, i.e. if the kiln entrance is empty then a new row of ceramic materials will be allowed in that stage; finally, sensor 7 controls the spacing in terms of an X-axis (see also sensor 4).

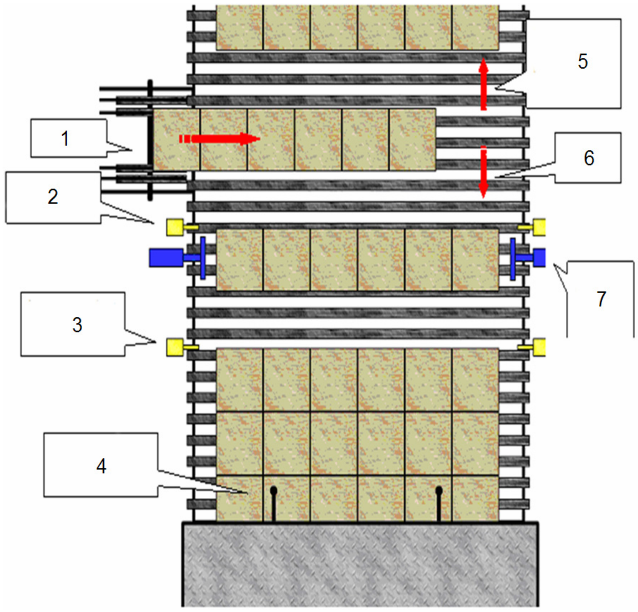

Figure 2. A simplified schematic diagram of the kiln.

The firing process, which occurs inside the roller hearth kiln, is one of the most important in the ceramics overall production process. The main reason for that importance is that the quality of the final product depends most from that process alone, i.e. the mechanical resistance, the dimensional stability, the resistance to fire and heat, etc., depends from the firing process. Some companies choose to include a drying stage, before starting the firing process in itself. This procedure aims to reduce the water quantity (humidity), inside the ceramic materials, until it reaches a level sufficientely low so that the firing process is done under the most adequated conditions. The fastest firing process for ceramic materials is now done in roller hearth kilns. In this type of kilns, the ceramic materials are carried inside by a conveyor belt, while a series of burners (burning natural gas or Liquefied Petroleum Gas – LPG) situated along the interior kiln walls produce the heat. Table I describes the main operations performed inside the roller hearth kiln, in the ceramic materials, during the firing process.

Until the present moment, the kiln operation process done at the company that contacted the authors is monitored and controlled in a 100% manual fashion, i.e. it requires the intervention of a given number of human operators. In this way, the quality of the firing process depends mostly upon the skills and past experience of the human operator that is controlling it.

TABLE I.
MAIN OPERATIONS PERFORMED INSIDE THE KILN, IN THE MATERIALS UNDER THE FIRING PROCESS.

Temperature	Operation
Until 150ºC	Eliminate free water inside the material
150 – 250ºC	Eliminate water particles attached to the material. Decompose some iron hydrates.
350 – 650ºC	Eliminates water particles inside the material.
400 – 600ºC	Burn organic substances.
573º	Transform alpha-quartz into beta-quartz.
700 – 800ºC	Beginning of the fusing of the alkalis and oxides of iron
800 – 900ºC	Decomposition of carbonates. Oxidation of carbon.
1000ºC	Beginning of the mass fusing with CaO and FeO with silicate formation.
Up to 1200º	Formation of the phase glass-ceramic with size reduction and porosity.

Source: Navarro et al, 2001 [3]

His/her function is to permanently watch the temperature readings and, depending on the ceramic materials that are inside the kiln, control the electrovalves that burn the natural gas or LPG. When a problem occurs (e.g. the ceramic materials do not enter the kiln with exactely the same characteristics, as some depend upon the raw material used to manufacture them, which sometimes change over the time) the operator has to intervene so has to diagnose it and act accordingly. This sort of intervention thus requires qualified and experienced operators.

The automation system under development is manly focused in the temperature monitoring and control process, inside the kiln. It aims the process efficiency and cost savings. This requirement will be addressed by the use of low-cost devices able to implement the required monitor & control operations. Among the critical problems associated with the firing process, two are especially considered in our work: one is concerned to automating the all process and the other concerns to the fact that sometimes one (or more) roller(s) that sustain and drive the conveyor belt break, causing the ceramic materials to fall into the kiln interior floor until the moment the human operator detects the problem and stops the firing process. Until this human action does not occur, the ceramic materials keep falling into the kiln floor and hence are lost, adversely affecting the company's productivity. One of our goals is therefore to install specific sensors able to automatically detect this sort of situation and immediately stop the all process, even if the damaged rollers have to be manually swapped.

We proposed to the ceramics company that contacted us to develop remote engineering solution for monitoring and controlling the firing process. This solution relies on the connecting facilities provided by Ethernet technologies, associated to Intranet/Internet. We will also use a new Micro Web Sever (MWS), essentially an upgrade of an older version developed at our lab [4, 5], which will connect to the temperature sensors via a 38-channel A/D converter that will use the SPI (Serial Peripheral Interface) to communicate with the MWS. The setpoint of each temperature sensor is to be defined by a web page hosted by the MWS, which will also show the temperature readings. The person in charge of the production process (i.e. the system administrator) will be allowed to change the system parameters, and to stop or reinitiate the firing process.

II. THE PROBLEM

The present system comphreends 35 adjustable temperature sensors (thermopairs), that control 10 servo motors and 22 electrovalves. Three other temperature sensors monitor the temperature at the final kiln stage, where the ceramic materials undergo a cooling process. When the process ends, i.e. when the ceramic materials exit the kiln it is necessary to perform a quality control check-up in order to assure that: (1) those materials are within their pre-specified dimensions; (2) there are no empty spaces inside them (i.e. they are not hollow) or irregularities in their surfaces; (3) among other quality control aspects. Parts of the quality control process are done manually, by an human operator, while others are done by a machine. The number of employees involved in the quality control stage could be redirected to other functions if this process could me made fully automated. With this mind, the company included in the automation requirements the quality control process, involving some sort of specific, dedicated, sensors.

Another specific problem is that sometimes there are blank rows (i.e. rows without any ceramic materials) inside the kiln, which adversely affect the firing process, namely because they create different heat distribution conditions inside the kiln. To avoid this sort of situations, the production supervisor has to continuously inspect the interior of the kiln, by opening small inspection windows located all along the kiln. When he/she spots an empty row, he/she has to open some ventilation windows to reduce the kiln temperature, at that specific location, in order to avoid over firing the neighboring rows filled with ceramic materials.

III. SYSTEM DEVELOPMENT

Figure 3 presents a conceptual view of the all system, where the roller hearth kiln operation is to be monitored and controlled by one (or more) MWS, which are to be accessed through an Ethernet-based network (either an Intranet or the Internet). A different machine is responsible for recording the process history. The interface to the control system is to be provided by a simple web page, following a client/server approach. The all idea is that the operators may change (or set) the system fucntional parameters through that simple web page. The block depicting the control circuitry (fig. 3 – top – right corner) is responsible for reading the 38 temperature sensors, via a 10-bit, 38-channels A/D converter. As previously stated, the A/D converter communicates with the MWS via the SPI port. The MWS, in its turn, communicates with the client applications via an Intranet or the Internet. The client may be a simple web browser (supporting Java) displaying the temperature readings and enabling the user to set up the trigger conditions for activating the electrovalves. The actuators (that drive the electrovalves) will be controlled through a dedicated module (labelled as "power board" in the control circuitry block) that communicates with the MWS via an I2C bus.

The client application is basically an HTML page with some Java applets embbeded on it. These Java applets are responsible for getting the data readings from the MWS and for passing the new parameters (set up by the user) to the MWS, which will use them to control the servomotors and the electrovalves. The interaction between the cleint and the server is established through a CGI running on the MWS.

Figure 3 also illustrates the possibility for acessing the all process status either through an Intranet installed at the ceramics company (clients directly accessing the MWS through the Ethernet) or through the Internet, in which case the connection is made via the World Wide Web (WWW).

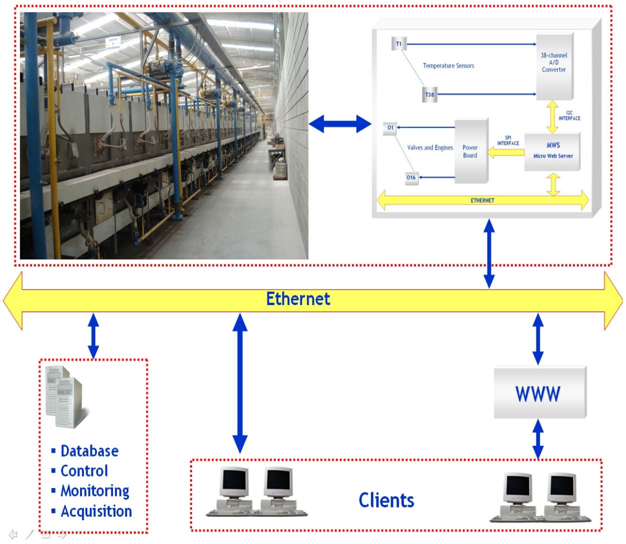

Figure 3. A conceptual view of the all system.

Figure 4 presents a close view of the temperature readings (obtained from the thermopairs), which are concentrated in one panel. Based on these readings and on an internal (confidential) document that defines the set up points according to the type of ceramics material that will undergo the firing process, an human operator sets up those same points. The bottom-right corner of the figure illustrates the actuators in more detail.

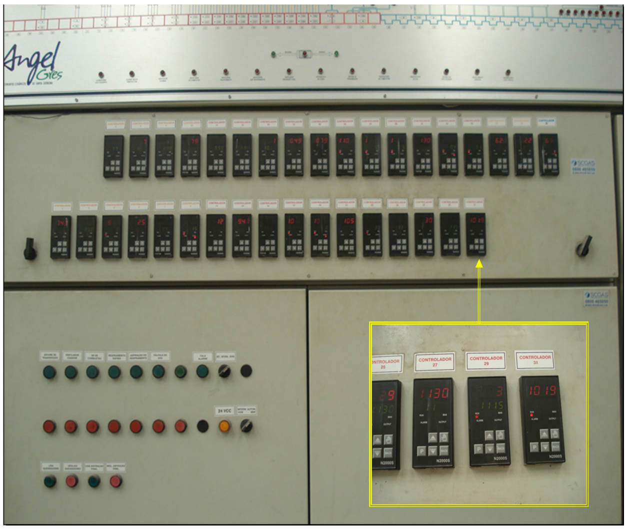

Figure 4. Temperature sensors.

During the development of the automation process, all the information contained in those internal (confidential) documents will be transferred into a database, accessible (and updatable) from the client software. The automation of this process will also reduce human errors that sometime occur, although the main goal is to speed it up, considering the time that it now takes (as a manual process). The access to the database is therefore subject to security considerations due to the type of information contained on it, i.e. it reflects the company "know-how" on the firing process. Notice that this information is updated according to the input of experienced operators.

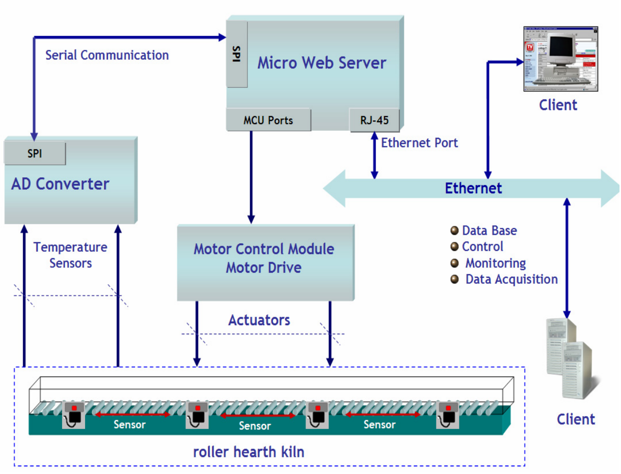

Figure 5. General view of the process.

Using MWS to automate the kiln operation process entails a number of advantages and future possibilities, some of them having already been described in this paper. However, and if the client interface is to be accessed through the Internet (in an open connection), specific attention should be devoted to security aspects, i.e. on how to protectd the data, as ceramic companies compete among themselves in obtaining the best parameters for controlling the firing process. This also applies to control commands and firmware updates on the MWS. Regarding these security aspects, the MWS implements an authentication procedure while transferring data, based on the RC4 cryptography algorithm. This is a rather simple algorithm, yet providing a sufficient security level, that involves either the addition of 8-bit elements or swapping variables stored in a state table with 256 bytes. It may also imply some multiplications. Given its simplicity it is easily implemented in embedded systems.

A. *The hardware architecture*

Figure 6 illustrates the control circuitry block (fig. 3 – top right corner) in more detail, with the MWS playing a central role. Due to this reason, we describe the MWS in detail in the following subsection.

B. *The Micro Web Server (MWS)*

Figure 7 presents a block diagram of the MWS, built around a low-cost, low-power Atmel AT90S8515 microcontroller, which supports the TCP/IP protocol. The microcontroller in itself runs at 8 MHz and contains three internal memories: (1) static RAM, (2) programmable Flash memory, and (3) EEPROM. The right part of the block diagram illustrates the interconnections with the outside world. A serial I2C EEPROM, with 64 kbytes, is used for storing the code and the file system of the MWS. The physical interface with the Ethernet is done through a RealTek RTL8019AS device, which supports the Ethernet 802.3, full duplex communication mode. The default interface is done via a 10BaseT (RJ45) port, although it also supports an AUI port (optical link). Finally, the MAX 232 is a driver/transceiver for serial, RS-232C, communication.

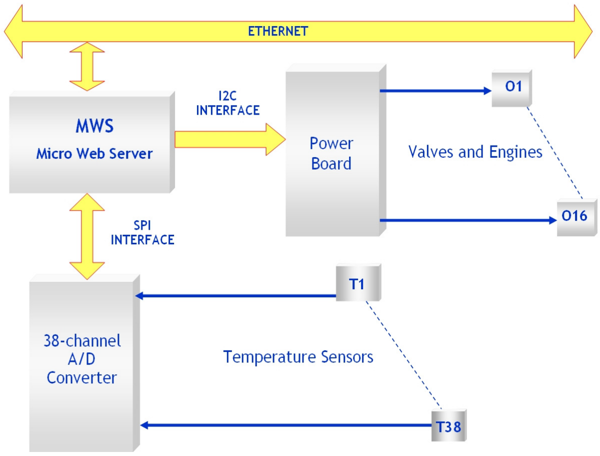

Figure 6. A block diagram of the control circuitry.

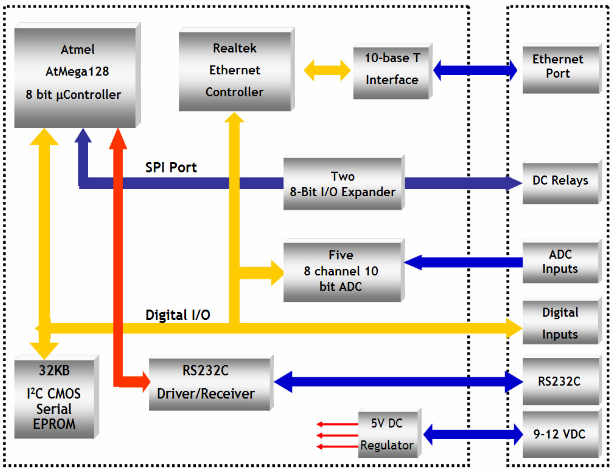

Figure 7. MWS block diagram

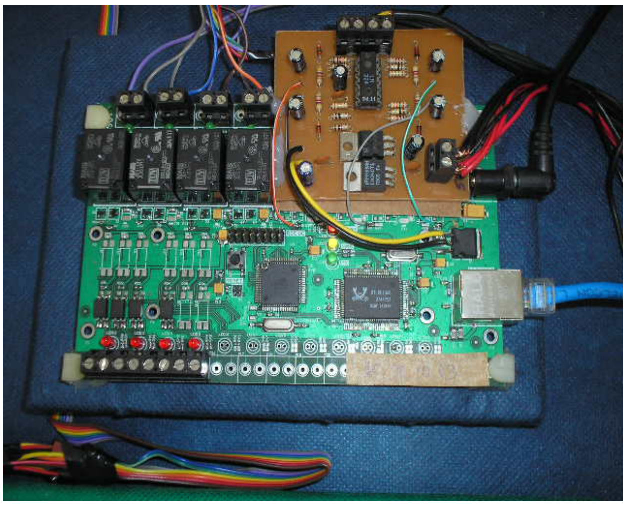

Figure 8. A close photo of the MWS

The software developed for our MWS includes some firmware (e.g. I/O functions) and the application code. The firmware is mainly based on a simple kernel, whose structure is illustrated by figure 9. The RealTek device implements the two bottom layers, leaving the remaining ones for the microcontroller. The layer on the top is related to the web http application server, while the remaining ones (network and transport) contain the TCP/IP stack and the network adapter drivers.

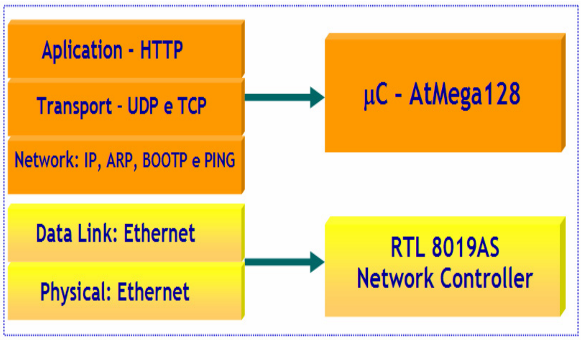

Figure 9. Firmware layers used in the MSW.

The Address Resolution Protocol (ARP) is also handled within the MWS, which means associating an Ethernet address to an IP address. An unique Ethernet address is allocated to each MWS. The IP address may be obtained in a static or dynamic form. In a static form it is determined in advance and then stored inside the microcontroller flash memory. In a dynamic form it uses the BOOTP protocol, to repeatedly ask for a valid IP address. The MWS also responds to ICMP (Internet Control Message Protocol) Echo Requests (normally associated with the "ping" command), which allows an easy way to measure the total RTT (Round Trip Time).

The MWS also supports UDP-type (User Datagram Protocol) packets, normally used by applications such as SNMP (Simple Network Management Protocol) and DNS (Domain Name System). At the TCP/IP level, our MWS responds to HTTP GET requests (normally issued by the web browsers), which are addressed to the TCP80 port. As any normal web server, our MWS responds to such requests by sending HTML (HyperText Markup Language) documents, text, or images. In all cases, the system kernel handles all the Internet protocols listed above. One restriction identified so far is the total length of one Ethernet packet (1400 bytes) for answering an HTTP GET request, in order to save memory resources. There are however several HTML coding techniques that allow working within this restriction, without affecting the quality of the service, namely HTML frames and multiple JPEG or GIF images. The MWS functionality is also easily upgradable, which allows for the integration of JavaScripts (either into the HTML code or as separate modules) and Java applets, or CGI (Common Gateway Interfaces) routines.

C. Implementing a prototype

In order to verify and validate the proposed solution for automating the firing process, we developed a scale model of the roller hearth kiln. The model is 1.45 metres long, i.e. we followed a 100:1 scale for building it. All the characteristics of the kiln used at AngleGres were preserved, while the model also enables us to test new functionalities like the crash detection mechanism. The implemented model does not support 38 temperature sensors but only 4 due to space restrictions. Notice that the temperature sensors used in our model will be the same as the ones used in the real kiln, so their size can not be reduced and hence it would not be possible to install such a large number of sensors in such a short space. Regarding the servo motors and considering the stated reasons, we will just install 4 of them in our model (against 16 used in the real kiln) to control the gas burners. Figure 10 illustrates the current aspect of our scale model, with a detail view of the mechanical part.

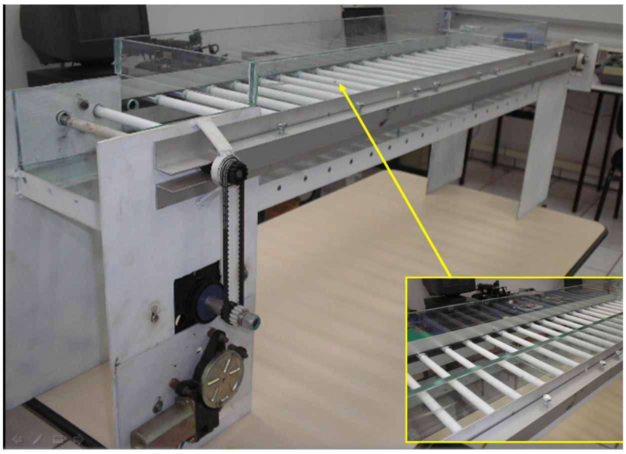

Figure 10. Roller hearth kiln prototype (scale 100:1).

IV. CONCLUSION

The proposed automation system demonstrates not only the feasibility of a monitor&control architecture based on MWS, but also the possibility to use this low-cost devices for such a purpose. These devices are thus characterized by their flexibility and easy adaptation to needs in automation systems. Another example of their application for monitoring&controlling parameters in an automation system has been described in [6], in this case for a scale model of a silo. Another important advantage of the roller hearth kiln model is its ability to be accessed and controlled via a simple web browser, which favours its use in educational, research, and industrial remote applications.

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AUTHORS

Juarez Bento da Silva is a Professor at the Department of Computer Science of the Southern University of Santa Catarina - UNISUL. He is also the responsible for the Remote Experimentation Lab – RexLab Southern University of Santa Catarina. Araranguá, Santa Catarina, Brasil. (mail: juarez@unisul.br).

Benedito Renê Fischer is a Professor at the Department of Mathematics, Statistics and Computer Science of the São Paulo State University – UNESP. São Paulo, Brazil. (mail: brfischer@rc.unesp.br).

Gustavo R. Alves is a Professor at the Department of Electrical Engineering of the Polytechnic Institute of Porto - School of Engineering (IPP/ISEP). He is also the responsible for the LABORIS/ISEP research lab, Rua Dr. Bernardino de Almeida 431, 4200-072, Porto, Portugal (mail:gca@isep.ipp.pt).

João Bosco da Mota Alves is a Professor at the Department of Mathematics, Statistics and Computer Science of the Santa Catarina Federal University – UFSC. He is also the responsible for the Remote Experimentation Lab – RexLab of Federal University of Santa Catarina. Florianópolis, SC, Brazil. (mail: jbosco@inf.ufsc.br)

The authors acknowledge the sponsorship of the European Commission, EuropeAid, Cooperation Office, Programme América Latina – Formación Académica (ALFA), through Project ALFA-II-465-A.

Manuscript received 1st July 2008. Published as submitted by the authors.