International Journal of Innovative
Computing, Information and Control
Volume **13**, Number **1**, February **2017**

 ISSN 1349-4198
pp. 75–84

INDUSTRIAL SUPERVISORY SYSTEM USING CLOUD COMPUTING

Jaime Alvarenga dos Santos[1], João Paulo Carvalho Henriques[1]
Renzo Paranaíba Mesquita[1], Alexandre Baratella Lugli[1]
and Max Mauro Dias Santos[2]

[1]Department of Industrial Automation
National Institute of Telecommunications (INATEL)
CEP 37.540-000, Santa Rita do Sapucaí, MG, Brazil
baratella@inatel.br

[2]Department of Electronics
Federal University of Technology – Paraná (UTFPR) – Campus Ponta Grossa
CEP 84016-210, Ponta Grossa, PR, Brazil
maxsantos@utfpr.edu.br

Received June 2016; revised October 2016

Abstract. *This article aims to present the implementation of a supervisory automation system that uses a cloud database for data storage and decision making. A brief background about supervisory systems, cloud computing and the advantages and disadvantages of this application will also be discussed.*
Keywords: Cloud computing, Database, Supervisory systems

1. **Introduction.** Nowadays, the studies addressing the theory of control and industrial automation are implemented with computer systems that make the processing of information. If in the past the treatment was restricted to physical devices and mechanical controls, now it is possible to analyze the information in more detail to assess the system status and program a decision based on the information.

In this context, this paper aims to present a new form of application for data acquisition in industrial systems where the information is stored in a hosted database in the cloud and is presented to the user using a web page connected to this database. The web application is also a platform for cloud resource and the user accesses the data through a browser.

The concept of supervision automation system using OPC is presented in [1-4]. Li et al. [5] present a web-based supervisory system using database; however, the authors did not explore the practical implementation of supervisory system using cloud database and the benefits of the technology.

Cloud computing is a strong trend in the computer industry. This service is based on the demand, that is, the user pays only for used application, and there is no need to invest in infrastructure. The advantage of this technology is to use the service available anywhere, regardless of platform, and with the same ease to access the Internet using personal computers [1]. In this way users can analyze in real-time and easy way all the variables involved in the industrial process.

In cloud technology, databases are not installed in the local servers. The information is stored in a media connected to the Internet; consequently, manipulation of information, that is very important in decision-making, will be done remotely.

The process data, in this work, use sensors connected to analog inputs of PLCs (Programmable Logic Controllers). Thus, the supervisory system receives information from PLCs using the OPC (OLE for Process Control), and stores it in an SQL (Structured

Query Language) based database through a technology called ADO (ActiveX Data Object).

This work is structured as follows. Section 2 presents the definition of supervisory systems, their architecture and applications in industrial environments. In Section 3, the concept of database and management systems will be presented; the definitions, models of service, location and the essential characteristics of cloud computing will be discussed. In Section 4, the application development and results will be presented, and finally, in Section 5, the results will be discussed.

2. **Supervisory System.** Due to the complexity of industrial systems and the number of variables to be controlled and monitored, the use of graphical interfaces that ease system access is of paramount importance. In this context, a supervisory SCADA system (Supervisory Control and Data Acquisition) has become indispensable in control of machines and processes [2].

The supervisory systems consist of one or more computers running specific supervisory software that allow you to monitor, operate and control remotely and in real time, a plant or an industrial process [3].

A typical SCADA system is composed by the central station (computer system) connected to a control system, such as PLCs, in which the field elements, sensors and actuators are connected. Figure 1 shows standard hardware architecture of the SCADA system [4].

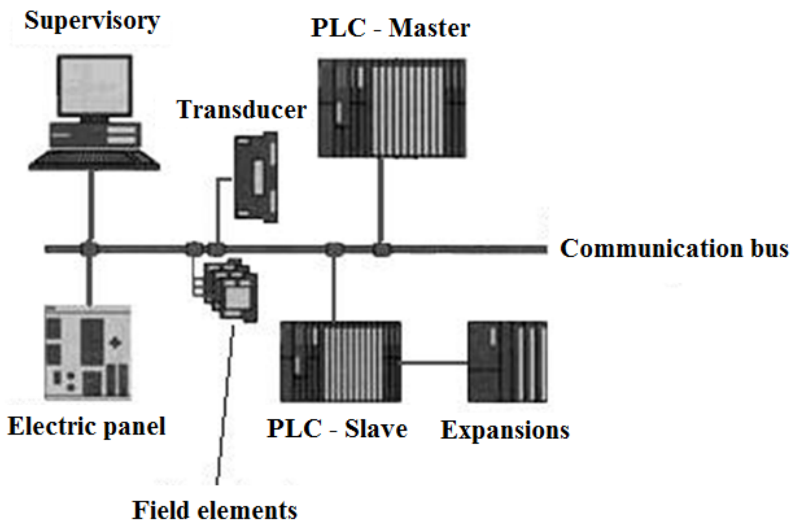


Figure 1. SCADA system [4]

Field devices, in particular sensors, are responsible for measuring and transmitting the process variable to the controller, converting physical parameters such as pressure, temperature and flow rate in standard signals in the PLC [3].

PLCs perform the manipulation of process data, which means, the control system is done through specific functions, such as sequential logic, registration and control times, counters and arithmetic operations and control functions of dynamical systems such as Proportio-nal-Integral-Derivative (PID) control [2,4].

The central computer that has the supervisory software receives the data coming from the PLC, and interprets this data as an alarm or event. An event can indicate whether a circuit is ON or OFF, OPEN or CLOSED. The alarms may contain analog data represented by one variable, for example, the alarm of a level measurement. When the variable value is not between the minimum and maximum ranges established, the computer interprets as an alarm and informs the operator [2].

Data received by central computer are transformed into visual information and presented to the operator by a graphic display unit or HMI (Human Machine Interface) in the form of icons or pictures [2].

The supervisory systems in most cases can operate in two modes [2].

- **Development Mode:** in this mode, the screens are developed, and the tags (variables) are associated with graphical objects that represent the process to be monitored.
- **Runtime Mode:** it is represented by the environment developed in the development mode and allows PLC's real time operation.

In the runtime mode, the operator can execute commands on the process, such as to maneuver, start or finish tasks and in particular to monitor and work with alarms.

The data that is collected via PLC can also be stored in a database, and through it is possible to produce estimates based on information from history, enabling analysis and improvement actions in the future.

The architecture of an SCADA system can be implemented using equipment from different manufacturers. The lack of standardization between the hardwares causes the no interconnectivity between them. Thus, the OPC technology is a communication protocol maintained by the OPC Foundation (OPC-F) established on October 17, 1996 in Chicago, in the United States, that allows equipment from different vendors to exchange information without interruption [5,6].

Figure 2 shows a communication between standard software (supervisory system) and a field device using the OPC protocol. The OPC protocol is implemented in pairs: Client and Server. The OPC server, usually installed in the PLC, is responsible for adapting the process data to be sent to the OPC client. The client is the interface that makes reading and interpretation of data coming from process [7].

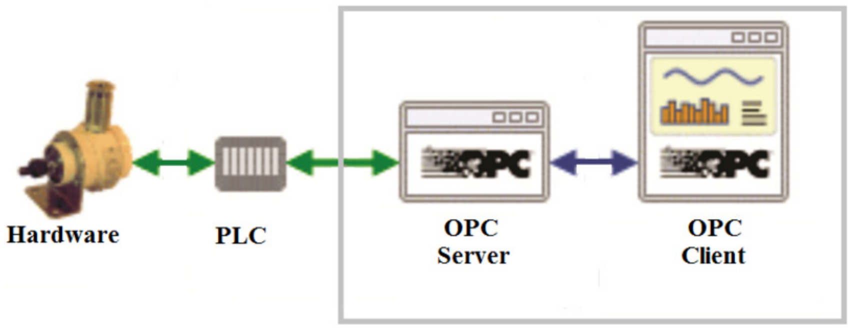


FIGURE 2. Communication between standard software and device [7]

Because it is an open protocol, the use of OPC reduces the costs for hardware manufacturers who need to provide a way for your devices to communicate with any other equipment. Software providers will suit the client features in their products and they become compatible to the devices. It is up to the user to choose any client software that will be able to exchange information [7].

The OPC communication not only restricts the client and server, as shown in Figure 2, but can also connect an OPC client to multiple servers (OPC aggregation), a client to a server over a network (OPC tunneling), and one server to another OPC server (bridge) [7].

3. **Database and Cloud Computing.** In industrial processes of medium or large scales it is common to use data storage and retrieving systems because they are compact, efficient and low-cost. Databases, in this case, generally are used to store information's history, formulas and alarms that are sent by an SCALA system [2].

A database may be maintained manually or it may be computerized. A computerized database may be created and maintained either by a group of application programs written specifically for that task or by a database management system (DBMS) [8]. The implementation of databases improves the production process and results in direct or indirect profitability to companies and services. In industrial systems, a database is used to treat the tags used in some supervisory systems. In order to prepare and plan a database to these systems, some information presented by Moraes and Castrucci (2007) [2] need to be collected:

- Instrumentation diagrams of the plant;
- List of data addresses or PLC register addresses;
- Possible Alarms.

According to them it is also necessary to follow some proceedings before planning the database with some variable types (digital, analogic or string) [2]:

- Choosing the variables scanning speed;
- The variables names must follow logic according to their physical meaning and their coding pattern. Variables that do not have a meaning or that are familiar just to the developer can become a trouble in a future maintenance of the system;
- Variables must be grouped in a significant way, for example, group all similar devices or areas inside a plant.

The cloud computing has gained prominence in the IT (Information Technology) area for revolutionizing the computer industry infrastructure. It is a recent approach, which relates to the use of digital media connected through the Internet, providing services on demand to the users in the same way as public utility services like water and electricity.

The cloud computing services can be divided in three main categories that define an architecture pattern to its solutions [1,10].

Software as a Service (SaaS): the services are provided to the customers via Internet browsers or specified programs. The infrastructure including network, servers, operating systems or storage are not managed by the customer. Being web-based software, it can be accessed anytime and anywhere. Examples of SaaS providers are Google Docs and Salesforce Customer Relationship Management (CRM).

Platform as a Service (PaaS): the PaaS model is responsible to provide an infrastructure to develop, run and publish cloud applications. In this service users can manage their applications without building and maintaining a developing and launching infrastructure. Examples of PaaS providers are Amazon Web Services (AWS) and Microsoft Azure.

Infrastructure as a Service: it is responsible to provide all the necessary infrastructure for SaaS and PaaS. It aims to facilitate the resource distribution such as storage, network and other relevant computational resources necessary to install and execute arbitrary programs, including operating systems and applications.

Figure 3 adapted from Souza, Moreira and Machado (2010) [10] and Grezele (2013) [11] highlights the roles played for different users (including providers and developers). The provider is the key element responsible for providing, managing and monitoring all the cloud computing solutions. The developer and the end user do not get involved in these activities [10]. It is the developer's responsibility to use the platform and infrastructure for rapid application development with a specific purpose. The end user just interacts with the applications hosted in the cloud [10].

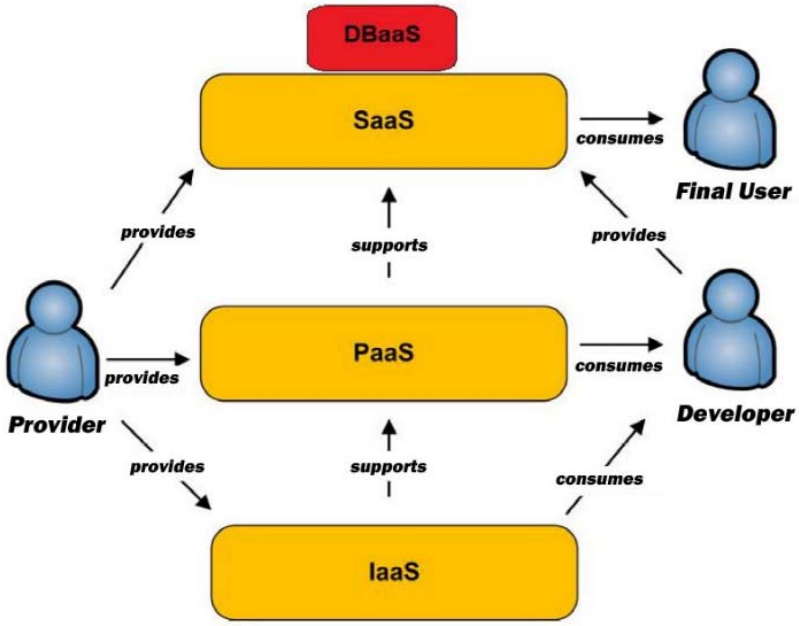


FIGURE 3. Cloud computing service models [10,11]

The database as a service (DBaaS) is an SaaS specialization as illustrated by Figure 3. This is a model that considers the use of the database for cloud storage [11].

Many services are available in the cloud and the DBMS can be one of them. Different from the traditional database management, recently the DBaaS systems have been widely used by large companies [12]. According to Elmariz and Navathe (2011) [12] one of the problems presented in the traditional system is the "lack of support to dynamic partitioning of the data, limiting the scalability and resources utilization".

The DBaaS emerged as a new model to manage data in corporative environments. The tenants hire the service and have access to create, store and query the database located in the provider that should ensure the whole support to get information like availability, performance and quality [11,12]. Figure 4 illustrates a DBaaS structure [1]. A database system like that which has many users must offer a structure that enables to enlarge the database to support multiple programs and query in different geographical regions. It also must be able to do this proceeding while the database is in operation, without the provider interaction in order that the service cannot be affected [1].

In contradiction to the facilities and benefits offered by the DBaaS model, one question is how reliable the environments are to keep the information confidential. Despite the fact that the provider does not expose customer information, it has the techniques responsible to protect the information to him. In this case the user is dependent of the services offered by the provider [11].

An example of a cloud SQL database is one of the integrated services offered by the Azure platform developed by Microsoft and used in this work. It is a relational database as a service, i.e., it is a manager and a database server that uses tools to implement and manage local and cloud databases. The Azure platform also includes web solutions that allow developers to compile, implement and manage web pages using programming languages like .NET, NodeJS, PHP, Python and Java [14].

4. **Application and Results.** In addition to providing a simple way to interact and monitor the plant information, supervision models of automation systems have identified

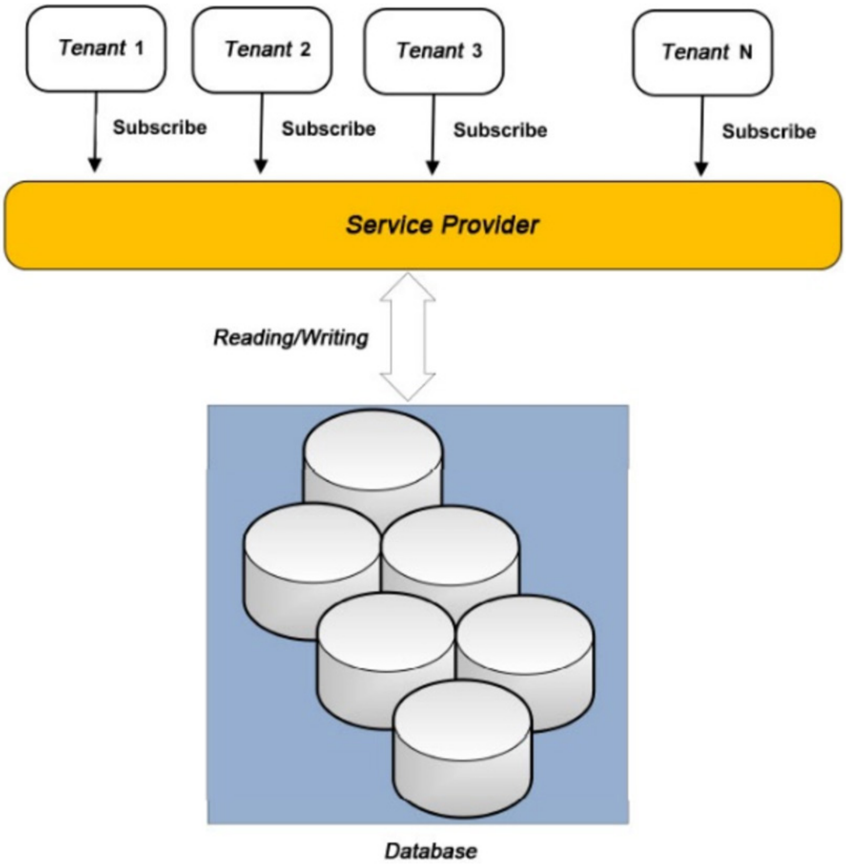


FIGURE 4. Database as a service [1]

the necessity to store the data for analysis and actions of improvement in the future, influencing decision-making in quality control, maintenance, production estimates, and other positions on the factory floor, based on the history of database information.

The developed application provides a process of temperature acquisition to store them in a database in the cloud, as well as a way to select the information stored, involving conventional methods that use automation techniques and alternative methods as information treatment through computer solutions.

Figure 5 shows the block diagram of system elements.

The system has two PT-100 sensors that measure temperature values, and through a transmitter converts the variation of electrical resistance in an automation standard signal, in this case 4 to 20 mA.

For each PLC was available an IP (Internet Protocol) address to identify them on the network. They were connected to a switch by an Ethernet cable and implemented as an OPC server. The server interprets the sensor data, and it provides them in the form of tags on the OPC standard. The tags are imported for the OPC Driver in a supervisory; in this case the E3 Studio software developed by Ellipse software starts to act as an OPC client (installed on a desktop). E3 Studio allowed monitoring the status of analog inputs for graphical interfaces, updating database and displaying the information in real time [16].

Figure 6 shows the practical activity for this paper.

In the E3 Studio (SCADA 1) was set a historical to create a table within the database, whose storing of tags application was set by time, in every five seconds. For the table were created three variables:

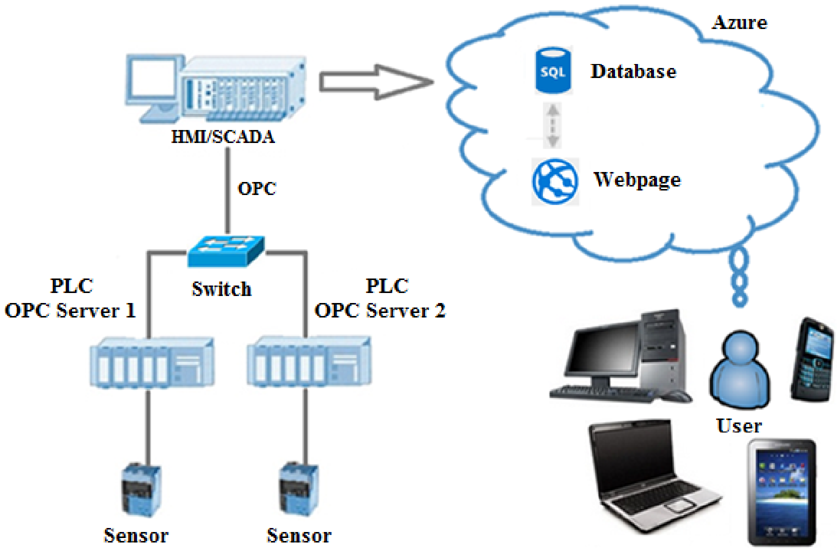


FIGURE 5. Block diagram of system

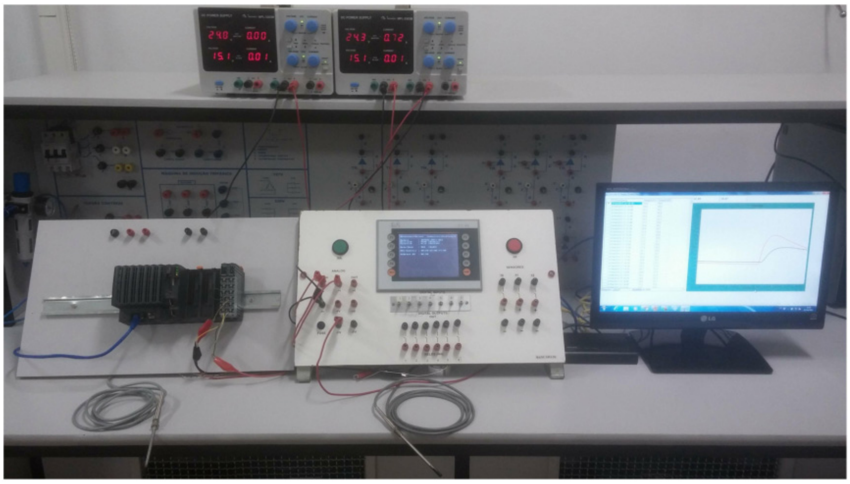


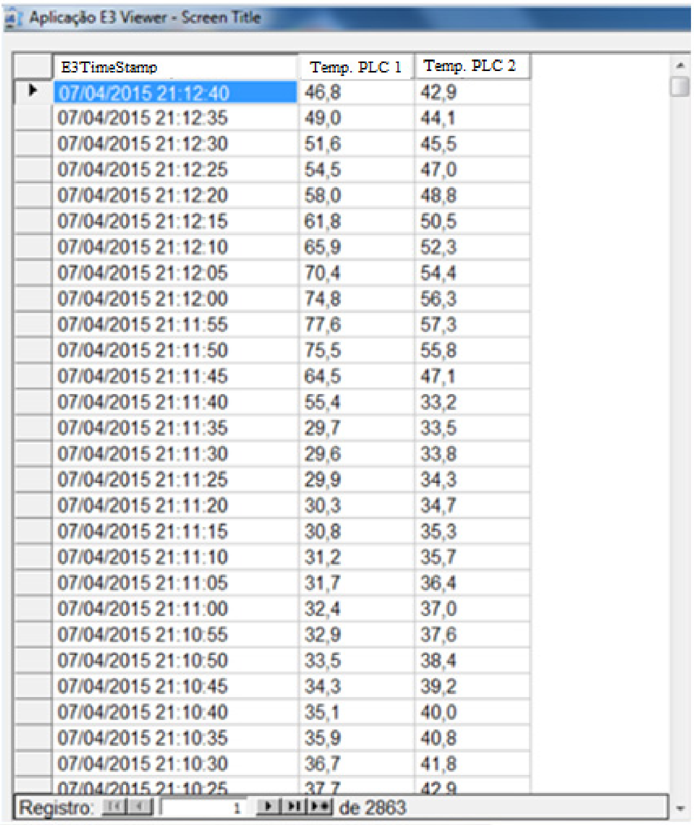
FIGURE 6. Experimental tests in practical activity asssembled

- E3TimeStamp: real time;
- TempCLP1: actual temperature, measured by PLC1 sensor in °C;
- TempCLP2: actual temperature, measured by PLC2 sensor in °C.

In order to connect to the database server in the cloud, the supervisor uses the ADO technology. ADO is used in E3 scripts for all types of operation together to the database. It is a set of objects COM (Component Object Model) created to access information of a DBMS using OLE DB (DataBase). The cloud platform Azure was used to host the system database, and among the options of servers around the world, one server was chosen in the south of Brazil for allocation. Another resource was used in Azure to create and implant a web application, which is a page written in PHP (Personal Home Page) [17] using the WebMatrix tool developed by Microsoft [18].

This was an alternative to connect to the database and display the information in real time, since the access was made by a browser. The server who hosts the page is the same of the database because the proposal was that the delay in the system was the lowest possible.

SCADA 1



E3TimeStamp	Temp. PLC 1	Temp. PLC 2
07/04/2015 21:12:40	46,8	42,9
07/04/2015 21:12:35	49,0	44,1
07/04/2015 21:12:30	51,6	45,5
07/04/2015 21:12:25	54,5	47,0
07/04/2015 21:12:20	58,0	48,8
07/04/2015 21:12:15	61,8	50,5
07/04/2015 21:12:10	65,9	52,3
07/04/2015 21:12:05	70,4	54,4
07/04/2015 21:12:00	74,8	56,3
07/04/2015 21:11:55	77,6	57,3
07/04/2015 21:11:50	75,5	55,8
07/04/2015 21:11:45	64,5	47,1
07/04/2015 21:11:40	55,4	33,2
07/04/2015 21:11:35	29,7	33,5
07/04/2015 21:11:30	29,6	33,8
07/04/2015 21:11:25	29,9	34,3
07/04/2015 21:11:20	30,3	34,7
07/04/2015 21:11:15	30,8	35,3
07/04/2015 21:11:10	31,2	35,7
07/04/2015 21:11:05	31,7	36,4
07/04/2015 21:11:00	32,4	37,0
07/04/2015 21:10:55	32,9	37,6
07/04/2015 21:10:50	33,5	38,4
07/04/2015 21:10:45	34,3	39,2
07/04/2015 21:10:40	35,1	40,0
07/04/2015 21:10:35	35,9	40,8
07/04/2015 21:10:30	36,7	41,8
07/04/2015 21:10:25	37,7	42,9

Registro: 1 de 2863

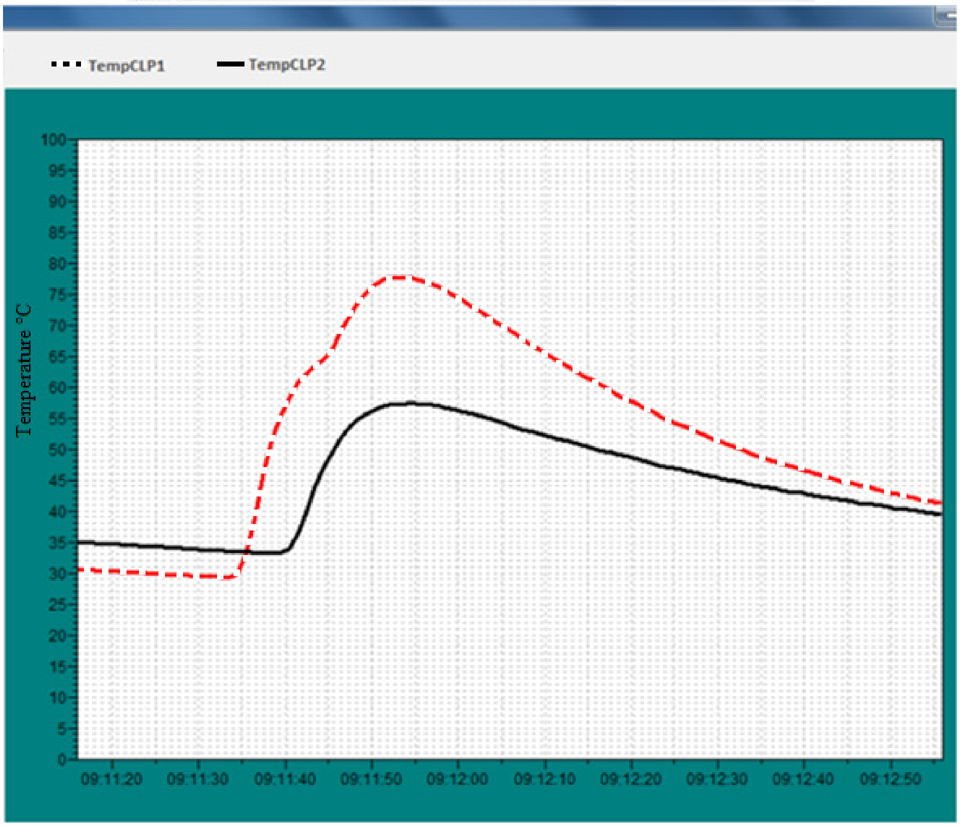
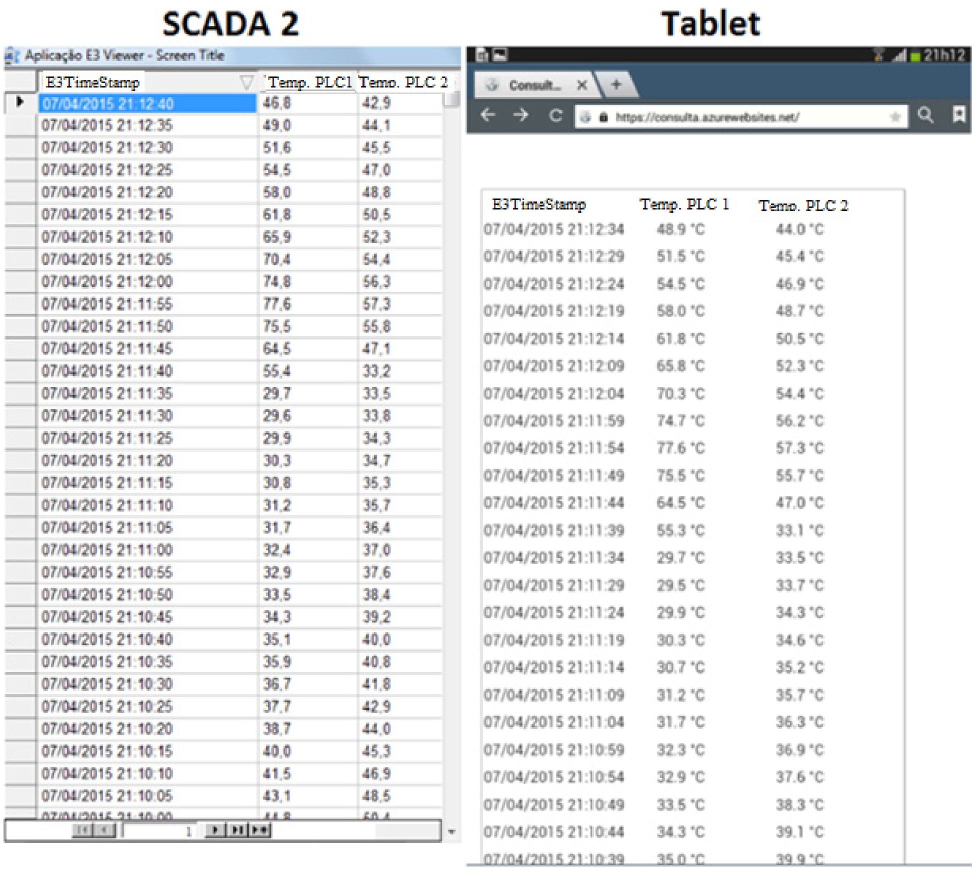


FIGURE 7. Local supervisory system (SCADA 1)



E3TimeStamp	Temp. PLC1	Temo. PLC 2
07/04/2015 21:12:40	46,8	42,9
07/04/2015 21:12:35	49,0	44,1
07/04/2015 21:12:30	51,6	45,5
07/04/2015 21:12:25	54,5	47,0
07/04/2015 21:12:20	58,0	48,8
07/04/2015 21:12:15	61,8	50,5
07/04/2015 21:12:10	65,9	52,3
07/04/2015 21:12:05	70,4	54,4
07/04/2015 21:12:00	74,8	56,3
07/04/2015 21:11:55	77,6	57,3
07/04/2015 21:11:50	75,5	55,8
07/04/2015 21:11:45	64,5	47,1
07/04/2015 21:11:40	55,4	33,2
07/04/2015 21:11:35	29,7	33,5
07/04/2015 21:11:30	29,6	33,8
07/04/2015 21:11:25	29,9	34,3
07/04/2015 21:11:20	30,3	34,7
07/04/2015 21:11:15	30,8	35,3
07/04/2015 21:11:10	31,2	35,7
07/04/2015 21:11:05	31,7	36,4
07/04/2015 21:11:00	32,4	37,0
07/04/2015 21:10:55	32,9	37,6
07/04/2015 21:10:50	33,5	38,4
07/04/2015 21:10:45	34,3	39,2
07/04/2015 21:10:40	35,1	40,0
07/04/2015 21:10:35	35,9	40,8
07/04/2015 21:10:30	36,7	41,8
07/04/2015 21:10:25	37,7	42,9
07/04/2015 21:10:20	38,7	44,0
07/04/2015 21:10:15	40,0	45,3
07/04/2015 21:10:10	41,5	46,9
07/04/2015 21:10:05	43,1	48,5
07/04/2015 21:10:00	44,8	50,4

E3TimeStamp	Temp. PLC 1	Temo. PLC 2
07/04/2015 21:12:34	48.9 °C	44.0 °C
07/04/2015 21:12:29	51.5 °C	45.4 °C
07/04/2015 21:12:24	54.5 °C	46.9 °C
07/04/2015 21:12:19	58.0 °C	48.7 °C
07/04/2015 21:12:14	61.8 °C	50.5 °C
07/04/2015 21:12:09	65.8 °C	52.3 °C
07/04/2015 21:12:04	70.3 °C	54.4 °C
07/04/2015 21:11:59	74.7 °C	56.2 °C
07/04/2015 21:11:54	77.6 °C	57.3 °C
07/04/2015 21:11:49	75.5 °C	55.7 °C
07/04/2015 21:11:44	64.5 °C	47.0 °C
07/04/2015 21:11:39	55.3 °C	33.1 °C
07/04/2015 21:11:34	29.7 °C	33.5 °C
07/04/2015 21:11:29	29.5 °C	33.7 °C
07/04/2015 21:11:24	29.9 °C	34.3 °C
07/04/2015 21:11:19	30.3 °C	34.6 °C
07/04/2015 21:11:14	30.7 °C	35.2 °C
07/04/2015 21:11:09	31.2 °C	35.7 °C
07/04/2015 21:11:04	31.7 °C	36.3 °C
07/04/2015 21:10:59	32.3 °C	36.9 °C
07/04/2015 21:10:54	32.9 °C	37.6 °C
07/04/2015 21:10:49	33.5 °C	38.3 °C
07/04/2015 21:10:44	34.3 °C	39.1 °C
07/04/2015 21:10:39	35.0 °C	39.9 °C

FIGURE 8. Remote supervisory system and tablet web page

In the supervisory system an object called E3Browser was created in a table format for viewing the stored data. Another way to view the data was through E3Chart that displays a graph with tags varying in real time. E3Browser and E3Chart use ADO to recover the data in the database. The writing and reading verification tests on the database were implemented by a second supervisory (SCADA 2) using a laptop (with E3 Studio installed), to operate remotely.

SCADA system presented in Figure 6 is a local supervisory (it can be installed in the control room of a company), and it is connected to PLCs. With SCADA 1 configured as OPC client and connected to the Internet by wired network, the implementation of SCADA 2 for querying has become simpler because it was necessary just to connect to the server of the database, create an E3Browser, enter the query object in E3Browser and execute the command to retrieve the data in the cloud. This supervision system performs the reading of stored data with access to the worldwide web using Wi-Fi.

Using a tablet a browser was opened and the web page created was accessed in the URL (Uniform Resource Locator) "www.consulta.azurewebsites.net". The tablet connection was also made over the wireless network featuring a remote access.

Figures 7 and 8 show graphic displays used for monitoring the historical in database.

The system operated for almost an hour and saved 4,38 MB (Megabytes) of information in the database.

5. **Conclusion.** Systems integration through industrial networks provides great benefits, increasing its use in industries. The solution presented in this paper provides a possibility to implementation using frequency inverters as slaves of the PROFIBUS network, where control is performed through a single supervisory system.

The use of standardized communication protocols such as OPC and PROFIBUS enables new possibilities to control a process. The ability to add different field devices, which were unable to exchange information among them, is one of the benefits of using the PROFIBUS protocol. With the OPC protocol, in addition to performing all the control from one single point, it is possible to distribute it in different locations because of protocol characteristics that allow data access to multiple servers and clients, simultaneously.

Therefore, with the OPC protocol it is possible to create the control via the supervisory system in several distinct points of the application, making the control decentralized and distributed in regard to the user operation in the industrial plant. In addition, due to the use of the OPC, it makes the project as a whole, independent of proprietary solutions.

REFERENCES

[1] M. S. Thomas, P. Kumar and V. K. Chandna, Design, development, and commissioning of a supervisory control and data acquisition (SCADA) laboratory for research and training, *IEEE Trans. Power Systems*, vol.19, no.3, pp.1582-1588, 2004.

[2] J. M. G. Figueiredo and J. M. G. S. da Costa, A concept for an operational management system for industrial purpose, *IEEE International Symposium on Intelligent Signal Processing*, Alcala de Henares, pp.1-6, 2007.

[3] C. Şahin and E. D. Bolat, Development of remote control and monitoring of web-based distributed OPC system, *Computer Standards & Interfaces*, vol.31, no.5, pp.984-993, 2009.

[4] M. Endi, Y. Z. Elhalwagy and A. Hashad, Three-layer PLC/SCADA system architecture in process automation and data monitoring, *The 2nd International Conference on Computer and Automation Engineering*, Singapore, pp.774-779, 2010.

[5] D. Li, Y. Serizawa and M. Kiuchi, Concept design for a web-based supervisory control and data-acquisition (SCADA) system, *Transmission and Distribution Conference and Exhibition 2002: Asia Pacific*, vol.1, pp.32-36, 2002.

[6] F. R. C. Sousa, L. O. Moreira, J. A. F. d. Macêdo and J. C. Machado, *Data Cloud Management: Concepts, Systems and Challenges*, SWIB, Belo Horizonte, 2010.

[7] C. C. de Moraes and P. d. L. Castrucci, *Industrial Automation Engineering*, LTC, Rio de Janeiro, 2001.

[8] P. S. M. Pires, L. A. H. G. d. Oliveira and D. N. Barros, Security aspects in SCADA systems – An overview, *Automation & Control*, no.104, 2005.

[9] L. A. Jurizato and P. S. R. Pereira, Supervisory systems, *Network Technologies*, vol.1/2, pp.105-114, 2002/2003.

[10] D. F. Ribeiro and R. d. A. Leandro, Integration of industrial automation using OPC, *National Seminar on Industrial Systems and Automation*, Belo Horizonte, MG, 2008.

[11] OPC Foundation, *What is OPC?*, opcfoundation.org/about/what-is-opc/, [Accessed in February, 2015].

[12] OPC DataHub, *What is OPC?*, Cogent Real-Time Systems, 1995, www.opcdatahub.com/WhatIsOPC.html, [Accessed in February, 2015].

[13] R. Elmasri and S. B. Navathe, *Database Systems*, Pearson Addison Wesley, São Paulo, 2005.

[14] C. J. Date, *Introduction to Database Systems*, Elsevier, São Paulo, 2003.

[15] F. R. C. Souza, L. O. Moreira and J. C. Machado, Cloud computing: Concepts, technologies, applications and challenges, *ERCEMAPI*, Parnaíba, PI, 2009.

[16] F. Grezele, *Security in Cloud Database Services: Controls for Service Level Agreements*, Master Thesis, Federal University of Santa Catarina, Florianópolis, SC, 2013.

[17] E. L. S. X. Freitas and F. d. Souza, Database cloud: A model for data consistency guarantee, *Brazilian Symposium of Database*, Recife, PE, 2013.

[18] R. Elmasri and S. B. Navathe, *Database Systems*, Pearson Addison Wesley, São Paulo, 2011.

[19] Microsoft, *Azure*, www.microsoft.com/azure, [Accessed in January, 2015].

[20] Microsoft, *SQL Server*, www.microsoft.com/sqlserver/pt/br/default.aspx, [Accessed in February, 2015].

[21] Elipse Software, *About Elipse E3*, www.elipse.com.br/port/e3.aspx, [Accessed in January, 2015].

[22] W. Soares, *PHP 5: Concepts, Programming and Integration with Database*, Érica, São Paulo, 2004.

[23] Microsoft, *Introduction to WebMatrix*, www.msdn.microsoft.com/pt-br/library/gg650436.aspx, [Accessed in March, 2015].