

# A Proposal to the Supervision of Processes in an Industrial Environment with Heterogeneous Systems

Rodrigo B  
SOUZA

Adelardo A D  
MEDEIROS

João M A  
NASCIMENTO

Heitor P  
GOMES

André L  
MAITELLI

UFRN - Universidade Federal do Rio Grande do Norte  
UFRN-CT-DCA / Campus Universitário / 59072-970 Natal – RN – Brazil

*rbSouza@dca.ufrn.br*

*adelardo@dca.ufrn.br*

*joao@dca.ufrn.br*

*heitor@dca.ufrn.br*

*maitelli@dca.ufrn.br*

**Abstract** – The need to manage the production in different industrial sectors creates a strong demand for process information. Information is generated and presented by a supervisory system, by collecting and treating raw data from the processes. Data can arrive from different physical processes and through different communication protocols and/or access media. This paper proposes an acquisition methodology to allow the supervisory system to access data independently of these characteristics of the process and of the communication channel.

## I. INTRODUCTION

Supervisory systems for industrial processes are also known as SCADA (*Supervisory Control and Data Acquisition*) systems [1]. A SCADA system must be able to process information and make it available to the operator of the process or any other user of the supervision software [2]. It can also work in the supervisory control level to directly act on the process [3], sometimes including a certain degree of machine intelligence.

A supervisory system in an automated industrial environment is essentially composed of four elements [4]:

- 1) Physical Process: it is the object of the supervision and the main element of the overall system.
- 2) Control Hardware: it is used in the physical interface and to control the process.
- 3) Supervision Software: it acquires, treats and distributes process data.
- 4) Communication Network: it is the responsible for the traffic of information.

An industry can have several different physical processes in its production environment. The monitoring of these processes is done in a specific way for each kind of process. However, information needed by the management about all the processes should be presented in a unified way. We call this kind of environment an *environment of heterogeneous processes*.

The process control hardware is basically composed of sensors, actuators and controllers. A controller has the important role of maintaining the process working and stable. Besides, it must also provide a physical interface to access process data.

Many times, in industrial environments, several kinds of controllers are used. Each controller can have a specific way to access and store process data. This implies a variety of

communication methods. This kind of industrial environment will be called an *environment of heterogeneous devices*.

In this paper we call *heterogeneous systems* those systems inserted into industrial environments of heterogeneous processes and/or heterogeneous devices. We call an *automation subsystem* each distinct pair formed by one physical process and its corresponding control hardware.

The supervision software (called supervisor, for short) must access the field devices to obtain process data. Data must be treated to become useful information. Another important role of the supervisor is to provide data to higher-level management software. The usual situation in many heterogeneous systems is to use a distinct supervisor for each different automation subsystem.

The communication network is in charge of the information traffic and is used by the supervisory system while acquiring process data. Usually, it is composed of two subnetworks: the *field network* and the *supervision local network*.

Field networks permit data exchange between controllers and sensors/actuators by means of point-to-point connections carrying input/output signals [5]. To achieve a deterministic communication, the majority of field networks are based on a master-slave architecture. In this kind of network, slave controllers never initiate a communication. These controllers only respond to requests made by the master controller. Some of the more usual implementations of the master-slave architecture in industrial environments are the *modbus* [6] and *profibus* [7] networks.

The supervision local network almost always uses LANs (Local Area Network) based on Ethernet TCP/IP [8,9]. This LAN provides the communication medium needed to share process information. The supervisors usually use supervision local networks based on the client-server architecture to share this information [10,11].

In several heterogeneous industrial systems, data acquisition and information presentation is a very specific procedure for each automation subsystem. In this context, many of the current supervisors can be used with one and only one subsystem. Consequently, data integration for information management is a more difficult task.

This work proposes a methodology to acquire data from heterogeneous systems in a homogeneous way. This approach allows to collect process data and to deliver information to management systems, independently of the nature of the supervised processes and of their control and connection devices.

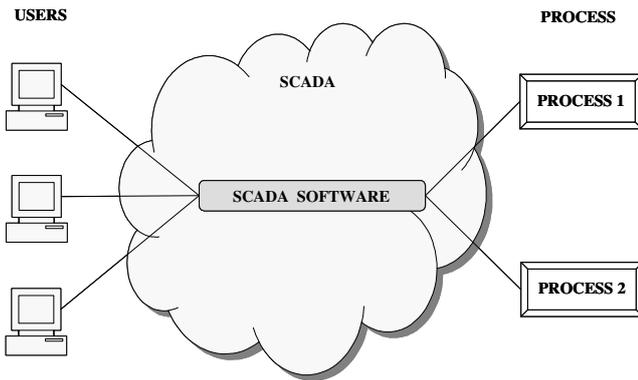


Fig. 1. Supervision by grouping the automation subsystems.

## II. PROPOSED SOLUTION

Each subsystem of a heterogeneous SCADA is composed of one or more clients, a single server and one or more masters accessing the processes. This paper proposes virtually grouping the several supervision subsystems into a single system, according to the schema in Fig. 1. The supervision system must be able to use the existing supervision and field networks and must allow several simultaneous clients.

For that, this system must have a standardized communication interface between the new server and the clients of all subsystems. In the same way, we have to standardize communication between the server and the masters of all subsystems. The communication standards between the clients and the server and between the server and the masters will be called CCP (Client Communication Protocol) e MCP (Master Communication Protocol), respectively (see Fig. 2).

### A. Clients

Clients translate requests from the users into CCP functions. These functions, when possible, are independent from the physical process. The CCP function is sent to the server with the request id and the virtual address of the physical process. When the server sends back the corresponding reply, the client exhibits it to the user.

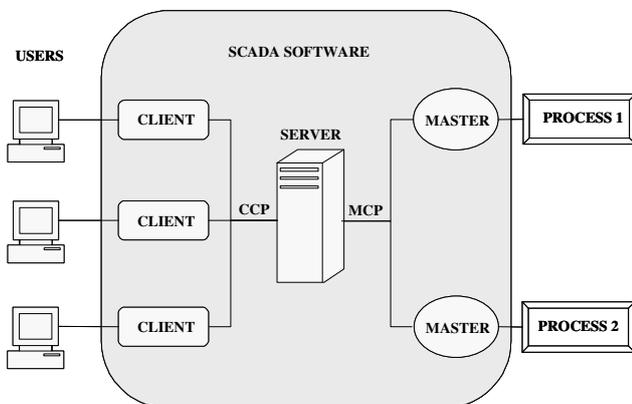


Fig. 2. Proposed supervision architecture

### B. Server

The server receives CCP requests from the clients. The virtual address of the process is used to determine the corresponding master and the physical address of the actual process. After verifying the validity and syntax of the CCP function, it is translated into one or more MCP functions. The MCP functions are then sequentially sent to the appropriate master. When the MCP requests are received, they are eventually combined, translated and sent to the clients.

### C. Masters

The masters are in charge of communication with the physical processes through the control hardware. In this case, the controllers are the slave stations in the field network. Masters receive the MCP functions from the server and translate them into native functions of the controllers. The answers of the controllers are sent to the server.

## III. IMPLEMENTATION

This section presents one possible computational implementation of the proposed architecture. The implementation is divided into three applications: client, master and server.

### A. Client Application

The client application sends requests to the server and treats the replies it sends back. For this, three concurrent processes have been used. The first process, Client Process 1 (CP1), waits for a solicitation from the user, generates a request, sends it to the server and inserts the request into a buffer of requests without answer, Client Buffer 1 (CB1). The second process, Client Process 2 (CP2), waits for replies from the server, withdraws the corresponding request from CB1 and exhibits the result to the user. The third process, Client Process 3 (CP3), generates timeouts by periodically inspecting the CB1 buffer to assess the elapsed time since each request was sent. Fig. 3 illustrates that architecture.

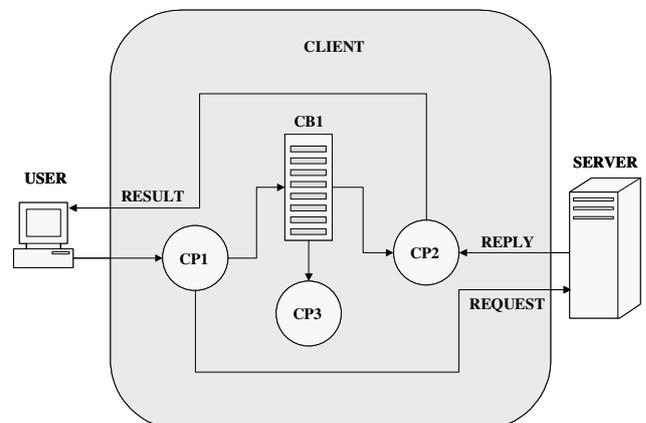


Fig. 3. The client application.

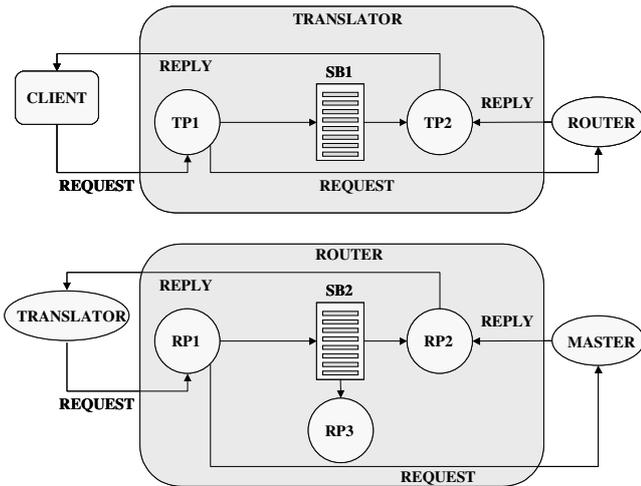


Fig. 4. The server application.

### B. Server Application

The server is divided into two sub-applications: the translator and the router, as in Fig. 4. The former translates CCP functions to MCP functions. The latter routes the MCP functions to the appropriate master.

The translator has two concurrent processes: Translator Process 1 (TP1) and Translator Process 2 (TP2). TP1 receives a request from a client, maps the CCP function into a set of MCP functions, insert them into a buffer of mapped functions, Server Buffer 1 (SB1), and sends them to the router. TP2 waits for replies from the router and, when one of them arrives, verifies if all the MCP requests corresponding to one CCP request have already been executed. If yes, it sends the CCP reply to the client and eliminates all the set from the SB1 buffer. If no, the status of the MCP request in the SB1 buffer is changed to already executed.

The router is formed by three processes: Router Process 1 (RP1), Router Process 2 (RP2) and Router Process 3 (RP3). RP1 receives the requests MCP from the translator, routes them to the appropriate masters and inserts them into the buffer of requests waiting for replies, Server Buffer 2 (SB2). RP2 waits for answers from the masters and, when they arrive, removes the corresponding requests from SBS and sends the reply to the translator. The RP3 process cyclically examines the SB2 buffer looking for timeouts: when one is found the request is withdrawn from the buffer and the translator is notified.

### C. Master Application

The master is the simplest element of the SCADA software. Its main function is responding to server's requests by communicating with the physical process. To execute this function it uses three concurrent processes. The first process, Master Process 1 (MP1), receives MCP requisition from the server and converts them to the language understood by the

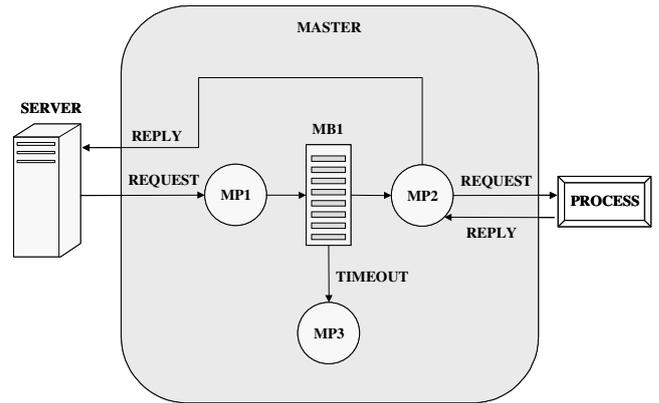


Fig. 5. The master application.

actual controller connected to the process (modbus, profibus, etc.). This requisition is then inserted into an execution queue, Master Buffer 1 (MB1). A second process, Master Process 2 (MP2), cyclically executes the first request in the MB1 queue, sends the answer to the server and removes the requisition from the queue. The third process, Master Process 3 (MP3) periodically inspects the MB1 queue to detect timeouts. The overall operation of the master is showed in Fig. 5.

## IV. APPLICATION AND RESULTS

This section shows an application of the implemented architecture: a SCADA software to be used in the automation of oil wells. This application is a result of a partnership between the UFRN and the Brazilian petroleum company Petrobras.

The system to be supervised is a very heterogeneous one, mainly because the region where the supervisor will be used is large and has more than 3,000 wells. The existing field network that connects the controllers of the wells to the master computer is based on low-band (9600bps) radio links. The wells use different methods of oil elevation and different controllers: each pair (elevation method x controller) can adopt a different communication protocol and used to be monitored by specific supervision softwares.

The main methods of artificial elevation currently used in oil industry [12] are:

- Gas-lift (GL) – compressed gas is injected into the well to elevate the oil to the surface.
- Electrical Submersible Pumping (ESP) – a cable transmits energy to an electric motor, coupled with a submerged centrifugal pump that generates pressure to elevate the oil.
- Sucker Rod Pumping (SRP) – The rotation movement of a motor is converted into an up and down movement of a rod. A pump at the end of the rod uses the up and down movement to produce a cyclic pumping of the oil to the surface.
- Progressive Cavity Pumping (PCP) – a progressive cavity pump is immersed in the oil well. The

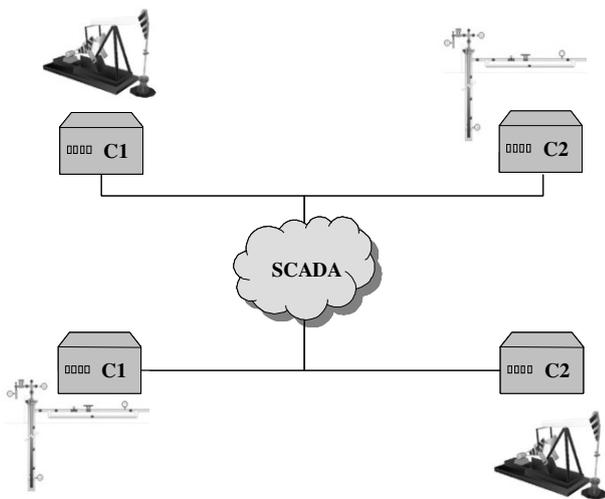


Fig. 6. Heterogeneous system for oil artificial elevation with four possible automation subsystems.

geometry of the pump creates a set of hermetical cavities. When the pump's rotor turns, the cavities progressively move along the pump's axis and push the oil towards the surface.

Each one of these artificial elevation methods has its own variables to be monitored, characterizing a heterogeneous processes environment. Besides, because of the particularities of each process and its monitored signals, several automation companies have developed specific controllers, characterizing an environment of heterogeneous devices. Fig. 6 illustrates a heterogeneous system with four possible automation subsystems: two methods of artificial elevation (GL and SRP) and two distinct control equipments (C1 and C2).

Because of their particularities, the automation subsystems we can observe in Fig. 6 are normally automated by different enterprises. Fig. 7 shows a situation where users need infor-

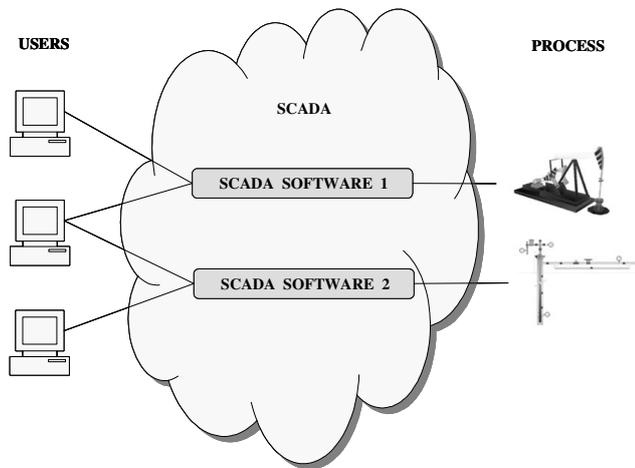


Fig. 7. Supervision of oil wells inserted into distinct automation subsystems.

mation from different wells in two distinct automation subsystems: the users shall interact with different SCADA softwares. Using the architecture proposed in this paper, a single client interface can obtain information from all wells, creating the situation represented in Fig. 1.

Our first supervision system using the proposed architecture is being used to monitor nine wells using the Gas-Lift elevation method and ZAP-500 controllers made by the *HI Tecnologia* Brazilian enterprise. Currently, new automation subsystems are being added to the system to allow monitoring thousands of Sucker Rod Pumping wells with different controllers. The first prototype of the new version is monitoring two of these wells. Fig. 8 presents the main screen of the implemented client application.

The field network uses the previously existing structure composed of master computers and radio links with transmission rate of 9,600 bps and a mix of proprietary and mod-bus protocols. The private communication network (intranet) of Petrobras is used as the supervision local network.

An illustrative (and simplified) step-by-step example of what happens inside the system is the following:

- 1) The client periodically generates `GET-INFO` requests. `GET-INFO` is a CCP function to obtain several general parameters of a well; these parameters are presented in the main screen of the client application (Fig. 8). At a given instant, a `GET-INFO 9624` request is generated, where 9624 is the virtual address of one of the wells being presented in the main screen.
- 2) The `GET-INFO 9624` request is stored into the CBI buffer and sent to the server, using the local network.
- 3) The server analyses the request and the database to conclude that the 9624 well is a Gas-Lift well with a certain controller. Using this information, the `GET-INFO` request is decomposed into several MCP requests (`GET-GASPRESSURE`, `GET-FLOW`, etc.) by the server's translator. These requests are stored into the

Campo	Pozos	Estação	Método de Elevação	Controlador	Scan	Rádio	Auto	Status	PID	Observações	Reservado
LPX	3	LPX-A	Gás Lift Contínuo	ZAP-500	Sim	NÃO	NAT	NAT	NAT	Sem Controle	
RFQ	4	RFQ-A	Gás Lift Contínuo	ZAP-500	Sim	NAT	NAT	NAT	NAT	Ptfo e Tfp sem sinal	
RFQ	10	RFQ-A	Gás Lift Contínuo	ZAP-500	Sim	NAT	NAT	NAT	NAT		
RFQ	20	RFQ-A	Gás Lift Contínuo	ZAP-500	Sim	NAT	NAT	NAT	NAT		
RFQ	28	RFQ-A	Gás Lift Contínuo	ZAP-500	Não	NAT	NAT	NAT	NAT	Ptfo e Tfp com valores anormais	
URP	2	URP-A	Gás Lift Contínuo	ZAP-500	Sim	NAT	NAT	NAT	NAT		
VRG	2	VRG-A	Gás Lift Contínuo	ZAP-500	Sim	NAT	NAT	NAT	NAT	Ptfo e Tfp sem sinal	
VRG	3	VRG-A	Gás Lift Contínuo	ZAP-500	Sim	NAT	NAT	NAT	NAT	Tfp sem sinal	
VRG	4	VRG-A	Gás Lift Contínuo	ZAP-500	Sim	NAT	NAT	NAT	NAT	Tfp oculto	

Fig. 8. Main screen of the implemented client application.

- SB1 buffer and communicated to the router.
- 4) The server's router uses database information to conclude that the well's physical address is 39 and that the well number 39 is connected to the master number 3. Using this information, the MCP requests GET-GASPRESSURE 39, GET-FLOW 39 and so on are stored into the SB2 buffer and sent to the master.
  - 5) The master receives the MCP requests and stores them into the MB1 buffer.
  - 6) The master broadcasts by radio a modbus GET-GASPRESSURE 39 request, addressed to the controller of the well number 39. This request was chosen because it was the first one in the MB1 buffer.
  - 7) The well controller responds to the modbus request with a GET-GASPRESSURE 44.5 reply using the link radio of the field network. The number 44.5 is the current gas pressure value in the well number 39.
  - 8) The master receives the modbus reply from the controller and sends a MCP GET-GASPRESSURE 44.5 reply to the server. The corresponding request is removed from the MB1 buffer and the next request in the buffer (GET-FLOW) is sent to the well's controller (step 6).
  - 9) In parallel, the server's router receives the MCP reply. The corresponding request is removed from the SB2 buffer and the arrival is communicated to the translator.
  - 10) The GET-GASPRESSURE request is marked as already executed in the SB1 buffer by the server's translator. Then it verifies if all the MCP requests mapped from the CCP GET-INFO request were attended. This is not the case, because the GET-FLOW request and others have not yet been executed, so the server waits.
  - 11) The steps from 6 to 10 are repeated with the other MCP requests (GET-FLOW, etc.).
  - 12) When all the MCP requests are executed, these requests are removed from the SB1 buffer and the server's translator sends a CCP GET-INFO reply to the client. This reply contains the current gas pressure value (44.5), the current flow of oil and so on.
  - 13) The client removes the corresponding CCP request from CB1 and shows the results to the final user. A new GET-INFO request can be generated concerning the next well in the list.

The low band of the radio links between the well's controller and the master computer can introduce severe delays in the system when multiple clients are monitoring wells connected to the same master.

To minimize this problem, a buffering procedure was introduced in the master application. All requested information is stored before being sent to the server. If another client requests the same piece of information and the buffered one is recent, the already available value is immediately sent to the server and a new use of the link radio is avoided. We also introduced a pooling procedure: when the link radio is not being used, the master autonomously requests information from the controllers, to update the buffered values.

## V. CONCLUSIONS

The implementation of the prototype showed that is possible to evolve from several mono-user master-slave subsystems to one multi-user client-server supervisor software.

One advantage of this architecture is its applicability to heterogeneous systems. Any user with access to the supervision network can remotely access information about a process, no matter which automation subsystem the process is based on. Only the server (not the clients) needs to know details about communication with the slave stations. Changes in the control hardware of processes are transparent to users.

As communication between clients and the server is based on a standard protocol, different human-machine interfaces (dedicated applications, web-based interfaces, etc.) can be implemented and simultaneously used.

## REFERENCES

- [1] J. Melendez, J. Colomer and J. L. Rosa, "Expert supervision based on cases," *8<sup>o</sup> IEEE International Conference on Emerging Technologies and Factory Automation*, 2001.
- [2] L. B. Becker, W. Pardi Jr and C. E. Pereira, "Proposal of an integrated object-oriented environment for the design of supervisory software for real-time industrial automation systems," *Fourth International Workshop on Object-Oriented Real-Time Dependable Systems*, 1999.
- [3] E. Ozdemir and M. Karacor, "Run time position estimation with basic sensors in real time SCADA applications," *7<sup>o</sup> International Workshop on Advanced Motion Control*, 2002.
- [4] A. Daneels and W. Salter, "What is SCADA?," *7<sup>o</sup> International Conference on Accelerator and Large Experimental Physics Control Systems*, 1999.
- [5] S. Viturri and D. Miorandi, "Hybrid Ethernet/IEEE 802.11 networks for real-time industrial communications," *10<sup>o</sup> IEE International Conference on Emerging Technologies and Factory Automation*, 2005.
- [6] Modicon Industrial Automation Systems, *Modbus Protocol Reference* <http://www.eecs.umich.edu/~modbus>, 2004
- [7] PROFIBUS, *Description Técnica Profibus*, <http://www.profibus.org.br>, 2002
- [8] A. S. Tanenbaum, *Redes de Computadores*, Editora Campus, 1997
- [9] J. Jasperneite and J. Feld, "PROFINET: An integration platform for heterogeneous industrial communication systems," *10<sup>o</sup> IEE International Conference on Emerging Technologies and Factory Automation*, 2005.
- [10] G. Bucci and C. Landi, "A distributed measurement architecture for industrial applications," *IEEE Transactions on Instrumentation and Measurement*, 2003
- [11] L. Zhi and Z. Hao, "The study and realization of SCADA system in manufacturing enterprises,"
- [12] J. E. Thomas, *Fundamentos de Engenharia de Petróleo*, Editora Interciência, 2001.