Development Environment of Expert System to Operate in Real Time with Industrial Automation Supervisory System

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Abstract **-** Normally the operator's interaction with Supervisory Systems developed for an industrial automated process is a manual process, which depends on the operator's skills and the constant operation's attention.
This work presents the development, application and tests of the expert system denominated SISES "Sistema de Integração de Sistemas Especialistas e Supervisórios", that means System of Integration Expert Systems and Supervisory Systems. The SISES was developed to operate in real time with Supervisory Systems and to have the ability to analyze the available data in the Supervisory System and to make inference. The SISES´s perform was tested by a simulation methodology process and also in a real nylon industrial production.

Key-words **-** Artificial Intelligence; Expert Systems; Supervisory Systems; Industrial Automation

1. INTRODUCTION

1.1 – Industrial Automation Levels

One of the theoretical forms [1] to classify the automation degree in productive processes is the industrial automation pyramid, which consists of 5 levels: Level 1 – Machine, Level 2 – Station, Level 3 – Cell, Level 4 – Central, Level 5 – Plant.
In this classification, the Supervisory Systems (S.S.) operate at cell level receiving information from controlling devices such as programmable logic controllers (PLC) and frequency inverters. The S.S performs several vital functions in an automated process and also operates as man-machine interface (M.M.I.) with human operators, so that they can analyze, make diagnostics, make decisions and interfere in the process. Therefore, the dedication, knowledge, response time and assertiveness of human operators are fundamental, in order to achieve quality levels. Being so, it is possible to realize that the interaction between operators and Supervisory Systems, which occurs at cell level [2], is a manual process and therefore subject to all types of occurrences resulting from non-automated processes.
This article presents the development, application and testing of an expert system named System of Integration of Expert Systems and Supervisory

Systems "SISES" elaborated to operate in real time with S.S to automate the functions performed by human operators. The SISES enables two forms of operation:
- To operate as a total or partial substitute to human operators
- To operate as a real-time advisor to process operators.

2. SISES

The SISES [3] is a computer tool or development environment of Expert Systems that communicate with Supervisory Systems. The SISES consists of two macro-blocks: Interface Module to Supervisory Systems (M.I.S.S) and Expert Systems Building Module (M.C.S.E)

2.1 -Expert Systems Building Module (M.C.S.E)

The M.C.S.E has an environment where E.S.s are built. Figure 1 illustrates the M.C.S.E organization, which consists of three modules:

- Knowledge Base: this is the set of rules obtained by the engineer about the knowledge and stored in the SISES file.
- Bases Editor: this is the tool that allows editing and modifying the Knowledge Base.

- Inference Machine: this is the SE portion that performs the inferences and conclusions about the knowledge base. In the SISES, the Inference machine operates employing the backward chaining algorithm [4] [5].
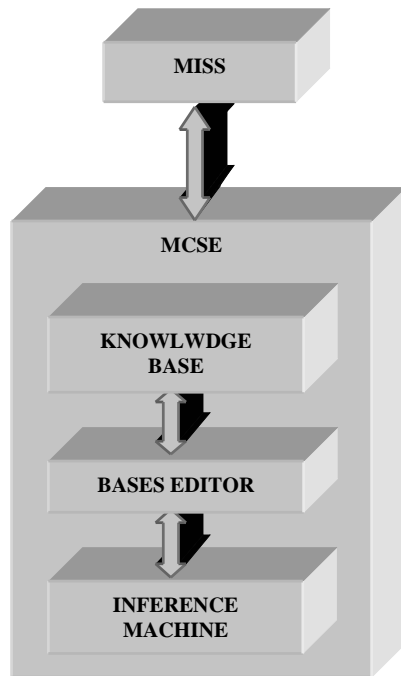

Fig. 1 – Basic Architecture of SEs generated in the MCSE.

2.1 - Interface Module to Supervisory Systems (M.I.S.S)

The M.I.S.S is the communication module of the Expert System (E.S.) with the S.S. As most of the current S.S.s, it operates with the Windows® operational system, and since also the S.S. selected has been the RSView® of Rockwell Software, the SISES was elaborated aiming at compatibility to these significant products of the worldwide market.

However, the SISES scientific and methodological fundaments can be applied and developed for any other operational environments and S.S.s. The S.S.s development environment selected to operate with the SISES in this research work enables different forms of communication with the Windows. However, the most efficient communication is performed by the specific Dynamic Link Libraries (DLLs: RsvApplication.dll and RsvProject.dll.

This fact occurs because any other communication for with the RSView indirectly uses these same DLLs, and therefore more steps are added to the SISES communication with RSView.Figure 2 illustrates the MISS functionality.
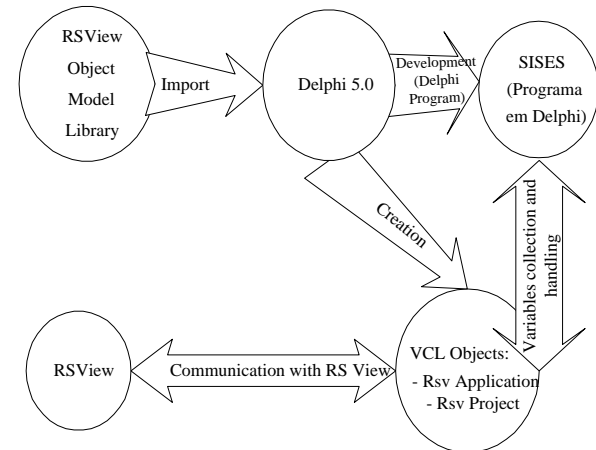

Fig.2 - SISES Communication with the RSView

3. APPLICATION, TESTS AND VALIDATION

3.1- Industrial tests used with the SISES validation tests

The SISES validation strategy was to select an actual industrial process of significant complexity to serve as basic platform for testing. The selected was the nylon polymerization and drying of an industrial plant installed at the Camaçari petrochemical complex in Bahia, which produces small particles similar to rice grains, known as "Chips". The Chips are raw material for several industrial processes as, for example, manufacture of tire lining. The automation system developed to control and supervise the process must be, as per specification determined by production engineering, able to control different physical variables.

The most important of them in the drying stage is the viscosity coefficient of the Chips produced. The viscosity ratio specified for each production batch determines the definition on which "process algorithm" recipe is necessary to achieve the expected results. The temperature control is one of the major parameters that make up the process recipe. It must be stressed that the presence of oxygen in the Chips during or after the drying phase, oxidize them, making them of little commercial value. To prevent this oxidation, the

drying phase develops with vacuum internal to the dryer. Once the drying cycle is ended, Nitrogen is injected, which provides an inert atmosphere to the chips that will be stored in warehouses that keep the desired atmosphere.
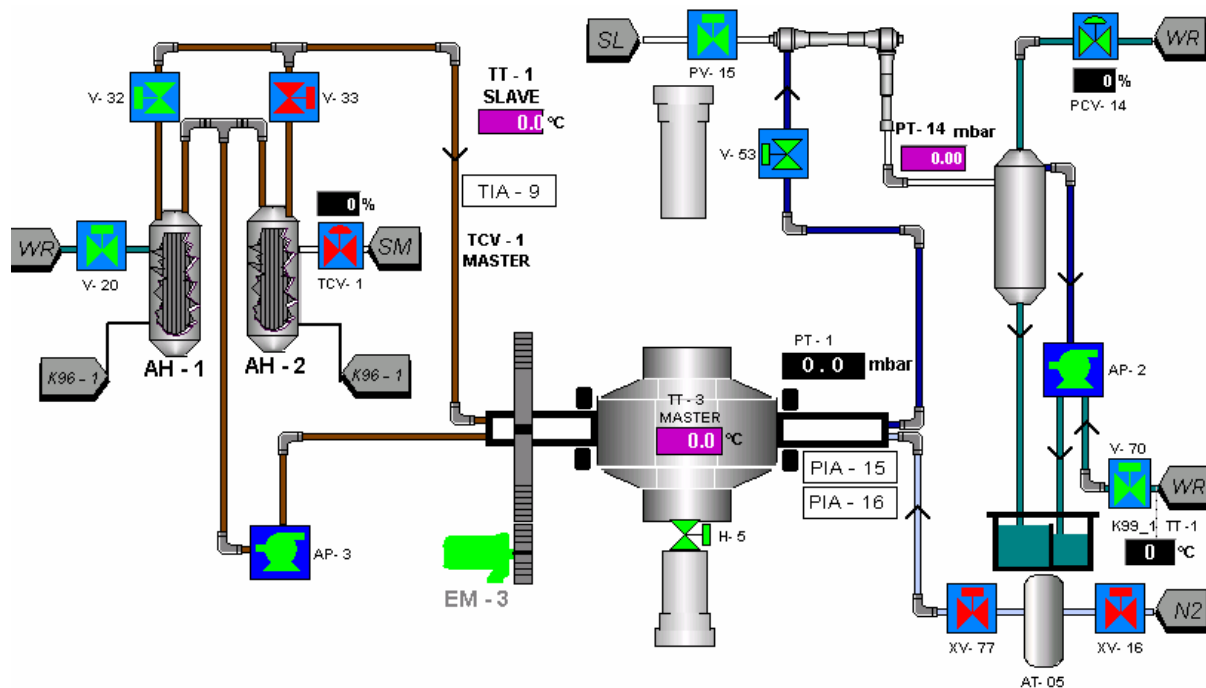

Fig. 3 – Major components of the nylon drying process

The automation system implemented has six Programmable Logic Controllers (PLCs) and approximately 7000 digital and analog input and output points. Data communication and transmission is performed through four industrial communication networks, being two of them used for field data transmission to the Supervisory Systems.

The drying subsystem has one PLC programmed with 2000 lines in ladder language. Part of this programming employs actuation routines indexed with the process logic elaborated pursuant a structuring of the Sequential Flow Chart type [6]. Figure 3 shows part of the drying subsystem.

3.2 – Testing Strategies and methodology

The SISES validation strategy consists of two parts: simulation and field e tests.
Figure 4 represents this methodology.

3.3-Simulation Tests

For conducting simulation tests on an automated industrial environment consisting of Programmable Logical Controllers, sensors, inverters and actuators interacting to the S.S. the

software RSLogix Emulate 5 [7] was selected, which allows simulation of complex processes. This software enables to emulate processing ladder lines or blocks of a Sequential Flow Chart (SFC) as if it was one or several PLCs. This emulator, likewise the PLCs, uses for data exchange medium the RSLinx [7] communication software, which software manages the entire data exchange between the PLCs and the S.S.
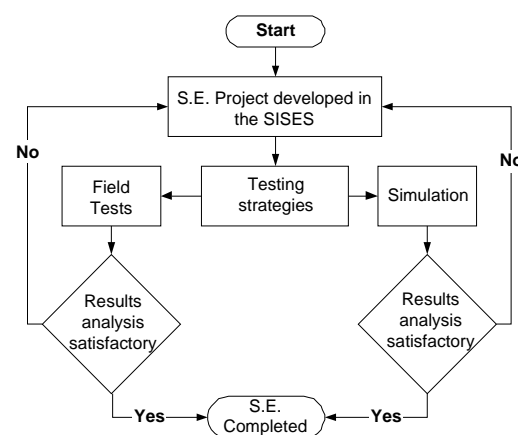

Fig. 4 - Strategies for E.S. elaboration with SISES

However, the RSLogix Emulate 5 emulator alone is not sufficient for emulating a process, because it is not capable by itself to simulate field answers. Being so, the emulator needs a field events generator.

In the tests conducted, the process simulator was divided into two major parts:

- Four programs written in ladder language, which are capable of simulating the return signals from valves and motors.

- Supervisory screens where the major analog values and some digital of most relevance to the process are handled.

Figure 5 exemplifies part of the process simulator. Note that the characteristics of the ladder language implemented to the PLCs emulator program allow variables indexing. This programming methodology significantly saves program lines in complex controls.
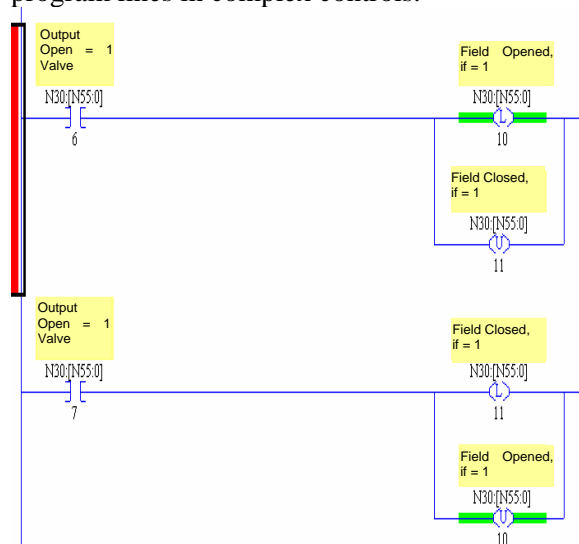

Fig. 5 - Field signals simulator implemented

The process simulator for the tests has shown to be capable of properly simulating the operations or occurrences of normal progress and the operations or occurrences of abnormal situations as well.

3.4-Development and tests for the E.S. elaborated

A specific E.S. was elaborated for the process in question based on the field operators' knowledge and on the knowledge by the industrial plant process engineers. This knowledge was absorbed based on the methodologies indicated in the references [5]. The knowledge elicitation phase was elaborated in the following stages:

- Elaboration of generic questions to the system expert about the system, such as, for example: "What would you like to alert the operator to prevent a major problem in case of failure of specific equipment?"

- Elaboration of heuristics by the expert, such as, for example: "In case of a spinning pump shutdown, take the following action: - Check for the Reactor level and reduce its set point to around 10%; Reduce the Lewas pumps speed; Reduce the H-3 and H-9 base-loads; Check for the water flow to the rectification columns."

- Interpretation and analysis by the knowledge engineer of the heuristics presented, searching, to the greatest possible extent, for inconsistencies that may be confronted to the expert.

- Translation of the knowledge learned into the SISES rules.

- SISES test with the rules functioning in real conditions.

- Returning to first phase up to obtain satisfactory results

3.5- Field Tests

The field tests were intended to complement the tests conducted in the simulation. They were conducted with the agreement by the engineering team of the industrial plant selected. By reasons of safety, in these tests, the SISES did not directly actuate in the process, but it reported to the operators the results of its inferences via a message screen. The SISES was implemented just to one of the three computers existing for the industrial plant S.S., by security reasons also.

3.6- Testing criteria for the SISES validation

Five SISES validation criteria were stipulated:

- *System overall performance criterion*: the system as a whole must perform satisfactorily.

- *S.S. performance criterion*: the S.S. must not suffer significant performance decrement.

- *Execution time criterion*: the time for the E.S. come to a conclusion may not be of an order of magnitude higher than the standardized times that the human operators have to achieve the same conclusions.

- *Compatibility criterion*: the SISES cannot require so many resourced from the

operational system (Windows) that impair its performance.

- *Assertiveness criterion:* the E.S. must come to correct results.

3.6.1 – Overall performance criterion

Both for the simulation tests and the field tests the SISES overall performance was excellent, as there was no downgrading or performance reduction to the automated process control.

3.6.2- Supervisory System performance criterion

Both for the simulation tests and the field tests no reduction to the S.S. performance was detected.

3.6.3- Execution time criterion

For the field tests, the E.S. elaborated had a number of rules approximately equal to 75. The practical experience for the case has shown that, at this E.S. complexity level, the information inferred met the performance expectations, that is, these rules condensate information sufficiently significant about the industrial system to justify the E.S elaboration.

For this number of rules, their response times were of the same order of magnitude than the supervisory system updating (approximately 2 seconds). This time was measured with the S.S.-SISES running in a 750MHz Pentium III PC, with 128MB Ram. The time tends to be even shorter with the use of faster machines.

For the simulation tests, the E.S. assembled has a number of rules approximately equal to 40, elaborated by the knowledge engineer.

For this number of rules, their response times were of the same order of magnitude than the supervisory system updating (approximately 2 seconds). This time was measured with the S.S.-SISES running in a 750MHz Pentium III PC, with 128MB Ram. The time tends to be even shorter with the use of faster machines.

The communication has shown fast and reliable, evidencing the correctness of the strategy of use of the RSView DLLs for communication. For a number of variables of approximately 75, this communication was of the same order of magnitude than the S.S. updating time.

3.6.4- Compatibility criterion

The SISES tests were conducted in three different platforms: Windows 98, Windows NT 4.0 SP6 and Windows Me. In all of them, the o SISES has shown compatible to the operational system; the NT platform was used with field tests only, while the others were used with simulations. With all platforms, the SISES has operated as expected.

3.6.5 Assertiveness criterion

3.6.5.1- Assertiveness criterion in simulation tests

In the simulation tests, 400 abnormal occurrence situations were provoked, which diagnostic was known to the knowledge engineer. Being so, the SISES assertiveness was gauged for each case. Table 1 illustrates the results obtained

	% hits on the expected diagnostic	Response Time
N° of alert situations = **250**	100%	<1,8s
N° of critical situations = **150**	100%	<1,5s

Table 1- Results from simulation tests

3.6.5.2- Assertiveness criterion in the field

In the field tests, the S.S. to which the SISES was connected had its performance easily compared against the two other identical S.S.s, which did not have the SISES. The test was conducted for approximately 170 hours with no interruptions.

The SISES operated as an advisor to the operators. All occurrences diagnosed by the SISES and by the operators were recorded.

Approximately 440 occurrences were found during the tests, and the percentage of hit was 100%. Being so, it is possible to conclude that for this work stage the SISES objectives were also achieved for the assertiveness requirement.

4. CONCLUSIONS

The SISES was developed within the scope of the EPUSP Rockwell Automation covenant, in the Automation Engineering Department of the Polytechnic School of the University of São Paulo.

During the field tests phase, the correct results, the clear and objective messages that have been provided by the SISES, have encouraged the industrial system operators to accept them and to follow their "tips". The SISES has presented the conclusions about the actions that the operators should take, within times of approximately 2 seconds, making it much faster than the normal times for taxing the same conclusions, which can often be in the order of minutes. The SISES performance has been satisfactory under all testing criteria.

As possibilities of future enhancements, it is worthwhile mentioning:

- Inclusion of the time factor into the heuristics as to better weighting a possible action by the SISES;
- Enhancement to the M.M.I. making the operation even easier to its users;
- Research on new I.A.[8] techniques to improve the SISES range and assertiveness;
- Research on new I.A. techniques to develop methodologies and tools for SISES and E.S. construction, including [9] machine learning.

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