EDUCATION IN CHEMICAL PROCESS CONTROL USING THE SUPERVISORY LABORATORY APPLICATION

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The developed CAPE (Computer Aided Process Engineering) application provides a helpful tool for performing the student laboratory works of the chemical process control program of study, allowing an efficient transfer from theoretic concepts to practical exemplification. Different pilot plants, such as: liquid accumulation in a tank, heat transfer in a jacketed reactor, gas accumulation in a set of reservoirs or flow of liquid in a pipe-network, are fitted with specific instrumentation. By means of the special developed application and built in serial communication facility of the μP-based REX F-400 local controllers (with RS485-RS232 converter) the pilots are connected to the PC. Application makes the practical demonstration of the different steps of the chemical process control curriculum possible: mathematical modelling coupled with process identification; frequency response; stability; dynamic behaviour of transducers and actuating elements; P, PI, PD, PID controller response and tuning.

Introduction

Developments of information technology and computer sciences make teaching and learning concepts change rapidly in the attempt to capture their spectacular progress. In the last years a set of new education systems have emerged, such as: computer aided e-learning, long-distance (space-distributed) learning, teaching systems for life-long learning, interactive teaching systems, electronic courses, all using the computer as the main target-oriented tool. Soon, the new learning methods will replace the traditional education methods.

Modern education processes are also assumed in chemical engineering education. Computers can play different roles in chemical engineering education, such as: simulation, data acquisition and monitoring, computer aided testing, visualization, virtual reality. Using special applications, the correlation between theoretical concepts and practical examples becomes possible, having continuously growing hardware and software support.

The paper presents the results of implementing CAPE tools in the education process of chemical engineers at "Babes-Bolyai" University of Cluj-Napoca, Faculty of Chemistry and Chemical Engineering, in the field of chemical process control. The use of a special developed application provides a helpful tool for performing the laboratory works of chemical process control programme of study, allowing an efficient transfer from theoretic concepts to their practical exemplification.

Experimental

Laboratory set-up

The laboratory equipment consists of different pilot plants where processes such as: liquid accumulation in a tank, heat transfer in a jacketed reactor, gas accumulation in a set of reservoirs or flow of liquid through a pipe-network may be investigated by experiments.

A schematic illustration of the pilot plants with related instrumentation is presented in *figure 1*.
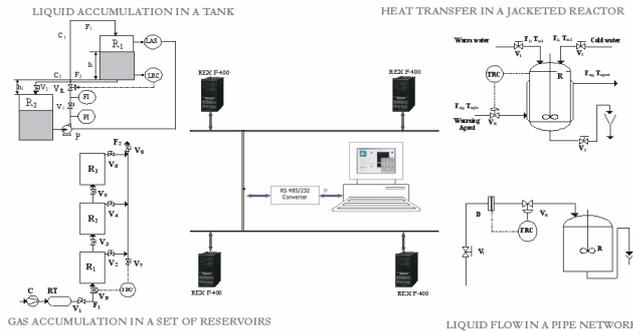

Figure 1. Schematic representation of the pilot set-up.

Each of the pilots is fitted with specific measuring, actuating and control instrumentation [1]. The µP-based REX F-400 local controllers, connected by serial RS485-RS232 converter to a PC, represent the regulatory control level. The PC represents the upper supervisory control and the monitoring level of the two-level distributed control hierarchy.

PC – local controller communication

The computer-aided process engineering (CAPE) application performs several tasks. The first task allows the bi-directional communication between the local controllers and the PC, using a specific protocol [2, 5, 6]. This application achieves the serial link between a PC and the pilot plants fitted with µP-based REX F-400 controllers, with the help of an RS485-RS232 converter.

In order to attain the communication, a specific transmission control procedure has been implemented. When data are needed to be read from the controller, the computer has to send a polling sequence in a ten-character format shown in *figure 2*. The meaning of the characters is: EOT – character used for initialising the data link; 1 – two characters used for selecting the device address; 2 – two characters used for selecting the controller memory area; 3 – two characters used for specifying the identifier group; 4 – two characters used for identifying requested data and ENQ – character indicating the end of the polling sequence.
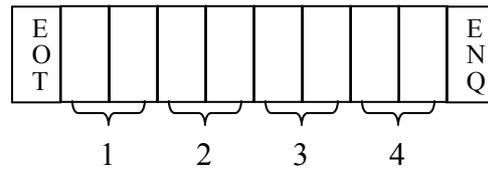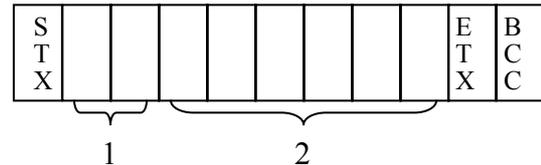

Figure 2. Format of the polling sequence.

The answer of the controller to the polling

procedure has the format presented in *figure 3:*

Figure 3. Format of the answer sequence to the polling procedure.

where the eleven characters structure has the following significance: STX – character used to indicate the beginning of a text; 1 – two characters used for identifying the transmitted data; 2 – six characters used for representing the transmitted data, including the sign and the decimal point; ETX – character used to indicate the text ending and BCC – character used for error detection, calculated by using horizontal parity.

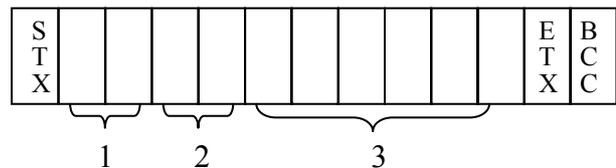When transmitting data to the controller, the computer has to send the sequence in a format shown in *figure 4:*

0Figure 4. Format of the data sequence sent to the controller.

where the eleven characters structure has the following significance: STX – character used to indicate the beginning of a text; 1 – two characters used for identifying the controller memory area; 2 – two characters used for identifying the transmitted data; 3 – six characters used for representing the transmitted data, including the sign and the decimal point; ETX – character used to indicate the end of the sequence and BCC – character used for error detection.

When receiving data, either the controller or the computer sends an ACK (acknowledge) character or NAK (not acknowledge) character to inform the sender about the integrity of the

received data. In case the NAK character is received the sender resumes the transmission. The communication application is developed using LabView software environment in order to provide compatibility with other modules of the application.

Monitoring and supervisory control

The basic task of the CAPE application allows the monitoring operation of the pilot plants, offering a general overview on the pilot processes and being also provided with override alarm functions. This task is accomplished by using the polling procedure. The computer sends the polling sequence and receives in return all requested process information together with controller status from the REX F-400 controllers belonging to each pilot plant.

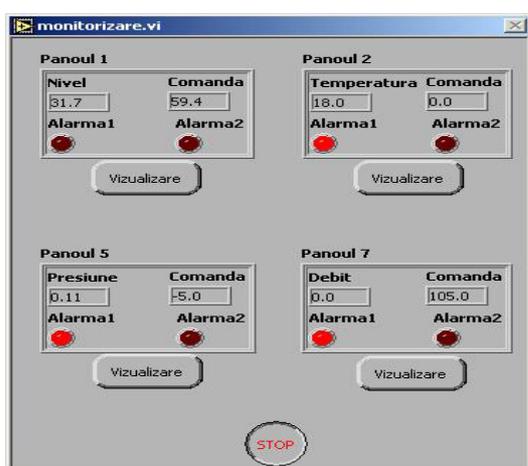The main window of the application performing the monitoring task is presented in *figure 5*.

Figure 5. Monitoring application window.

Main pilot parameters of the pilot plants are: level, temperature, pressure and flow rate are displayed together with the associated control variable and the state of the two point alarm.

By the operation of the visualisation button another task, the main task of the CAPE application, allows acquisition and display of the detailed information on each particular pilot plants dynamic behaviours and their controller status. The main task also offers the means for sending control actions to the corresponding pilot plant.

The functions of the main task are achieved by using both the polling and data transmission procedures. The first step is checking the status of

Local mode/Computer mode identifier. If the controller is set in *Local mode*, polling procedures are used for achieving the communication. For this case, only a detailed monitoring operation is allowed because the user intervention on the pilot plant is permitted merely from the on-site controller panel. The control actions that may be performed by the user from the CAPE application window become active only in *Computer mode*. This way choosing the preference of the command source sets the priority for the local controller panel against the computer application, as it is commonly required in practice in the usual applications.

The application window accomplishing the main task is presented in *Figure 6* with exemplification for the pilot plant of liquid accumulation in a tank and the control of the tank level by manipulating the outlet flow rate.
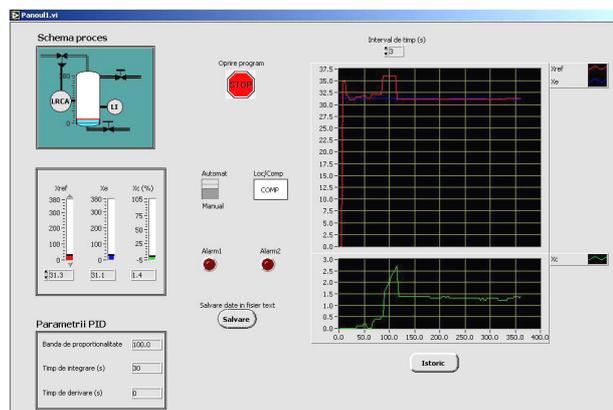

Figure 6. Main application window.

This task achieves several functions. The first one is the waveform graph visualization of the most important variables: the controlled variable and the setpoint, on a two-point chart and the manipulated variable, on a separate chart. The two-point LED alarm (*Alarm1* and *Alarm2*) is also presented on the main application window in order to keep track of any violation of the particular security thresholds. The *Local/Computer* indicator displays the status of the *Local/Computer mode*. The application has special functions for the control combined with the display of the important application variables. It is the case of the Start/Stop (*Oprire Program*) control of the application, the *Manual/Automat* switch and the sampling time (*Interval de timp*) control. The setpoint variable (*Xref* in engineering units) and the control variable (*Xc* in %), the latter only for Manual mode, may be changed by using special slide controls/indicators fitted also with combined numeric command and

display. The process variable (*Xe* in engineering units) is only displayed using a dual slide-numeric indicator. The PID tuning parameters may be changed by using the distinctive controls for proportional band (*Banda de proportionalitate*), integral (*Timp de integrare*) and derivative (*Timp de derivare*) time constants.

Visualization of historical process information may be used for on line or off line data interpretation and processing. When the History (*Istoric)* control is activated all acquired data is displayed, up to the current time, allowing zooming for detailed graphic representation, analysis or plotting. A special function of the application performs on line saving and storing of the acquired data in specific text files. This action is carried out when the Save (*Salvare)* control is activated from the application window. Post-processing of data saved in the file may be done with usual text editors.

A sample of the historical window and visualization of the saved data opened from the text file with Notepad editor are presented in *figure 7.*
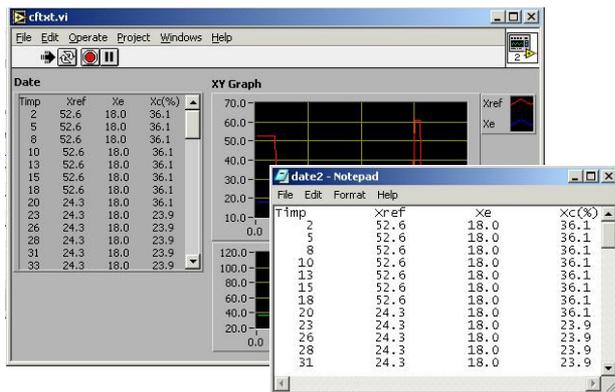

Figure 7. Historical application windows and saved data opened in Notepad editor.

Operations such as sending data to the controller, receiving data from the controller, controlling errors that may occur during data transmission, saving data in a file and analysing the historical evolution are all accomplished in separate application modules. This application structure allows an immediate extension and adaptation of the application to other pilot plants.

When operating the pilot plants from the application it is possible to change interactively the setpoint value for each PID controller generating a two-level hierarchical control system.

Incentives for process control education

For the mathematical modelling purpose the CAPE application serves as a useful provider of accurate process experimental data and a versatile process input (manipulated) variable function generator [3]. The investigation step shaped process input variable is easily generated with the application, synchronization with acquisition of the process response being directly accomplished. The experimental data, e.g. the step response of the process output variable to the different input variables, are used for building the experimental based model. This experimental model is compared with the first principle model obtained on the basis of mass, energy and momentum conservation principles. Fitness or mismatching between the two models reveals the way student has succeeded to gain knowledge on theoretical versus practical approach of system modelling, considering the linear or nonlinear behaviour.

When studying the frequency response of the process the sine wave generation used for investigation is performed by the CAPE application and the response is displayed, saved for subsequent study or analysed on-line. Concepts as bandwidth, crossover frequency, gain or phase margin get a practical insight. As a result, the stability may be further addressed both in an open and closed loop.

The CAPE application also assists the study of different measuring and actuating instruments of the pilot plants based on the accuracy of data acquisition, especially for the case of the rapid change of the measured or manipulated variables, and when revealing aspects of nonlinear behaviour.

Understanding the time evolution of open loop step response of P, PI, PD and PID controller is important from the educational point of view in the perspective of closed loop feedback control. The supervisory CAPE application may perform the step change and record the open loop step response of the classical control laws incorporated in the REX F-400 controller together with the specific functions usually present at the industrial controllers.

Controller tuning may be carried out either on experimental basis or with analytical methods; comparative analysis between the obtained control performance results may show the incentives and drawbacks of these alternative approaches. The application serves as a convenient tool for manipulating the tuning parameters and for

revealing their effectiveness in different cases of pilot process control.

The supervisory CAPE application allows centralization of the information from all pilot plants offering the supervisory control ability when changing setpoint values for each of the controlled pilots [4]. Extending the application for performing a multivariable control strategy, with Model Predictive Control at the higher level of the control structure and PID controllers at the regulatory control level, is straightforward.

Conclusions

The flexibility of the application makes the practical demonstration of the different steps of the chemical process control curriculum possible, such as: mathematical modelling coupled with process identification (first principle and experimental based modelling), frequency response, stability, dynamic behaviour of transducers and actuating elements; P, PI, PD, PID controllers response and tuning, process monitoring and demonstration of the supervisory or multivariable control strategy (e.g. Model Predictive Control).

Implementation of this CAPE application in the education process of chemical engineering offers an efficient transfer from the theoretical concepts to their practical exemplification.

CAPE application is assembled in a module-based structure offering both an easily extending facility and direct adaptation to other pilot plants for performing the laboratory works in other fields of engineering education.

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