EQUIPPING A PROCESS CONTROL LABORATORY TO REFLECT CONTEMPORARY CONTROL TECHNOLOGY

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Abstract: All aspects of process monitoring and control have been affected by increasingly powerful and ubiquitous technology. Implementation takes place using standard desktop PC's interfacing with the plant via several systems which are often high performance versions of standard Ethernet technology. These changes should be reflected in the academic environments where control specialists are trained. The Process Control Laboratory environment should offer students the opportunity to experiment with new technologies while remaining flexible and manageable. This article explains the steps taken at the University of Pretoria to ensure that the process control laboratory in the Department of Chemical Engineering is ready for contemporary and future control technology.

Keywords: Data communication, Process Control Laboratories, Monitoring and Control

1. INTRODUCTION

In a fast-changing environment, it is necessary to enable change without compromising the continuity and ease-of-use of a laboratory where data-transfer between equipment and the control system is of primary importance. A process control laboratory should expose students to an environment which is sufficiently close to that found in an industrial environment, but which also leaves opportunities to experience the typical difficulties associated with data communication and in addition, provides an environment in which to experiment. Depending on the need, it should be possible to put emphasis where it is required – either on the process to be controlled, the control technique used, or on the way communication and data transfer takes place.

The development of a facility like a process control laboratory normally evolves over time. This can be due to several reasons, but will include factors like availability of funds, current research projects and current technology. In the case of current technology, data communication techniques should ideally be implemented in a manner that will upset exisiting installations in the least possible way.

On-board A/D hardware was until recently the only available means of communication to measuring and control elements on laboratory test rigs. This caused students to focus more on writing interfacing software than on control. This is a common problem, as Shacham et al. (1996) explains: 'Experience has however shown that a lot of time in the laboratory is spent on coding and debugging, although it is of minor importance to the subject matter'.

Currently, advanced process control is implemented using standard desktop PC's (de Vaal et al. (2000)) interfacing with the plant via several systems which are often high-performance versions of standard Ethernet technology. The communication protocols used to communicate are becoming more standardised and transparent, with the development of OPC in the Windows environment as an example of an open standard available to most users. Virtual seamless access between different systems has become a reality, making possible links between different commercial applications as well as development environments.

These changes should be reflected in the academic environments where control specialists are trained, especially during practical training. Laboratories that have been set up to demonstrate control principles should be equipped to offer students the opportunity to experiment with new technologies while remaining flexible and manageable. (de Vaal & van Niekerk, 1993; Jovan & Petrovcic, 1996) There are many different aspects to consider when transitioning from a more traditional simple setup to one that mirrors industry. Some of these aspects are

- ease of use of experimental setups,
- flexibility of application and setup arrangement,
- reliability of equipment and
- extendability of the final arrangement.

Steps taken to ensure that a process control laboratory for education and research is ready for contemporary and future control technology, should include:

- a move from decentralised A/D conversion to a centralised network-aware converter bank supporting a variety of open communication protocols,
- installation of centralised databasing and information management systems to enable high-level access of process data, like SQL database servers.
- installation of leading edge industrial software systems for SCADA, Human Machine Interface building and base layer controller implementations and
- implementation of a naming system for wiring and equipment based on recognised standards.
- reporting based on live data has become an important factor in keeping control engineers and plant managers informed about the status of their plants. The same can be done in academic environments

2. OVERVIEW OF THE U.P. PROCESS CONTROL LABORATORY

The majority of students doing postgraduate studies in process control in the Process Modelling & Control Group of the Department of Chemical Engineering at the University of Pretoria are chemical engineering graduates, who often do not have a high level of competency with electronics and data communication, but who need to obtain adequate capabilities to experience the real-world difficulties associated with implementation of a plantwide control problem.

The focus in the laboratory is on measurement and control of the test rigs, rather than the nuts and bolts of interfacing the controller and the system. This is in stark contrast to most small-scale control laboratories, where direct connection between the rigs and controlling computers are still used. Direct connection systems were tried in the lab, but the students inevitably spent more time on the setup and programming of the cards than on the control of the rigs.

Figure 1 shows an overview of the facilities in the process control laboratory. There are five rigs available for experiments (de Vaal, 2002). The rigs are all connected to a central bank of A/D converters, which are in turn connected to clients and a SCADA server via TCP/IP networking on Ethernet. The client workstations are then free to run any control/viewing software that the student can obtain or create, as shown in Figure 2. Each rig exhibits unique behaviour to enable students to explore a variety of control problems, ranging from simple SISO systems to highly interactive, nonlinear multivariable systems.

Following present trends in plant-wide PC-based software, communication between the software packages of different vendors can be linked via the OPC protocol. With relatively little effort, a novel model-based control algorithm can, for example, be developed in the Matlab/Simulink environment and can be implemented via a commercial SCADA-system using the Opto22 Ethernet-based system to communicate with measuring and control elements.

This open approach also enables use of commercial simulation packages to model a virtual plant while at the same time running a controller application that had been written in an application environment like Matlab. Matlab/Simulink forms the ideal development environment for development and testing of control strategies it was the ability to develop the necessary software to enable communication between this environment and commercial SCADA systems that provides the required communication environment in the laboratory.

Generating real plant data on one of the test rigs in the laboratory, data can be transferred to any of the commercial application environments to develop a multivariable controller, which can then be implemented on the test rig that generated the initial data.

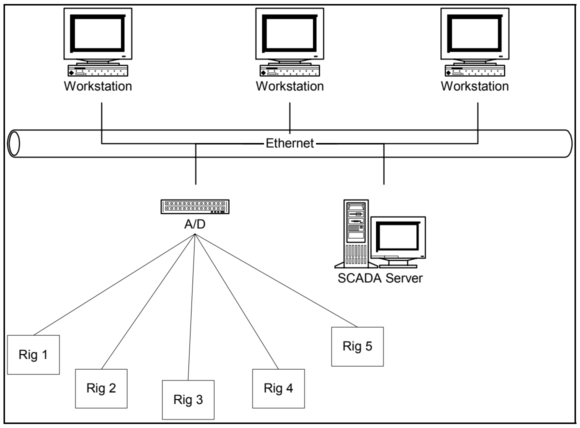

Figure 1: Overview of the facilities in the process control laboratory

In order to apply control theory, easy communication between the student working on a client computer and the rig he/she is attempting to control is a necessity. In addition, the method used to communicate with the equipment must be similar to those to be used later in an industrial environment. To achieve this, the server is connected to the clients via the internal network and runs the process information through an OPC server. Using this abstraction layer causes the client to be unaware of the mechanics of data transfer further than the server.

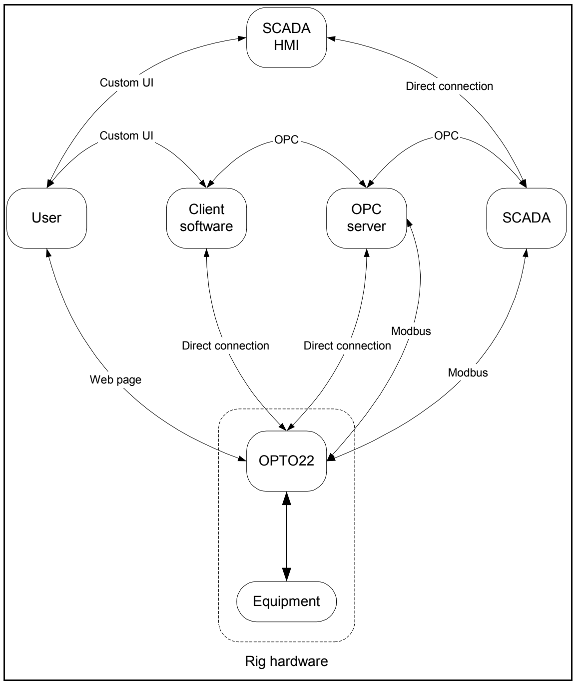

Figure 2: Schematic layout of communication possibilities

2.1 Client-server architecture

A centralised data server and A/D conversion system enables students to experience industry-level SCADA and historian solutions. With SCADA systems installed on the server, students can experiment with the design of Human Machine Interfaces (HMI) and server-based low level control. Furthermore, the use of this type of software can be explored in ways that are impractical on a running plant, familiarising the student with server-side software in a unique way.

An exciting advantage of running a central server is the possibility of virtual rigs that exist only on the server and virtual connections between rigs, increasing the capacity of the laboratory from the five rigs available to an infinite combination of rigs to meet the need for more complex systems.

2.2 Tagging

A tagging system is used in the laboratory that is based on the ISA standards for tags (ANSI/ISA S5.1). This allows the server to appear just as a SCADA system would on a real plant. The use of standard techniques enables the student to apply the knowledge gained in the laboratory to practice immediately.

2.3 Scale-up

It should also be noted that the structure can easily be expanded, as additional test rigs are developed, or additional measuring and control elements are added, since the A/D conversion hardware is located on the Ethernet bus only, and not connected directly to the server. Therefore, if additional server-side software needs to be run, an extra server can be set up to to run the software without downtime on the other server.

2.4 Client-side interface

Software support for the MATLAB/Simulink programming environment has been implemented for rapid development of control solutions. Figures 3 and 4 show the easy connection of the live rig via the OPC connection block in Simulink.

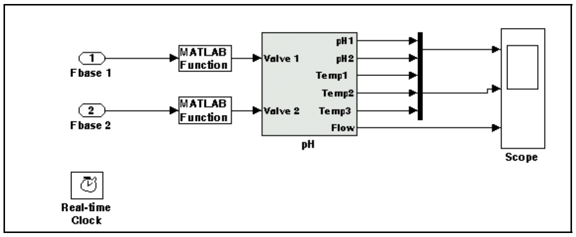

Figure 3: Implementation of a controller using Simulink

Using a computer model of the plant, a block can be built that simulates plant responses. Attaching the prototype control system to the working plant is simply a matter of dragging and dropping the block representing the plant in place of the simulated block.

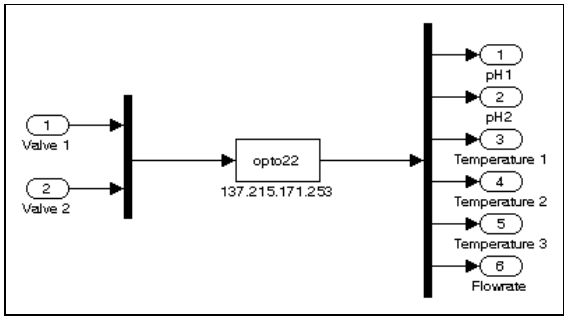

Figure 4: S-function connection to plant instrumentation via Simulink

3. SOFTWARE AND COMMUNICATION PROTOCOLS

A schematic diagram showing the software tools used (and their interaction) for the control of the experimental setups is shown in Figure 5. There are two routes to communicate with the experimental setups from Simulink, which is the software used to implement the control algorithms in the process control laboratory.

The first route can be with the use of the *driver toolkit* from OPTO22 that utilises *ActiveX*, to communicate directly with the A/D and D/A conversion devices (SNAP B3000 brain, etc.).

The second route is with the use of a server and specific *SCADA* (Supervisory Control and Data Acquisition) software that uses *MODBUS/TCP*, a protocol defined for instrument interfacing over an Ethernet connection, to communicate with the A/D and D/A conversion devices.

A custom C^{++} *component* was developed in-house that utilises *ActiveX* to communicate with the server using *OPC*. Figure 5 also shows that the *Driver Toolkit* and the C^{++} *component library* must be installed on the user or client computer. Interfacing of *Simulink* with the experimental setups occurs via a Simulink s-function that was developed in-house (Pretorius, 2001).

The *Real time clock* block is used to force the *Simulink* simulation to run at real time and must therefore be included on the model of the control algorithm used for control. The block icon can be seen in the bottom left corner of Figure 3.

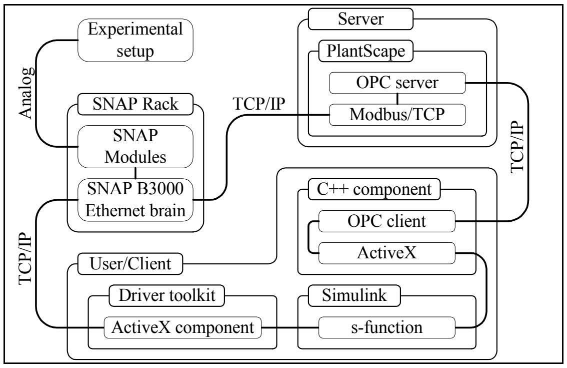

Figure 5: Schematic diagram showing the software tools used (du Plessis, 2002)

4. ANALOG AND DIGITAL SIGNAL TRANSMISSION

An overview of the analog and digital signal transmission configuration as implemented in the control laboratory can be seen in Figure 6.

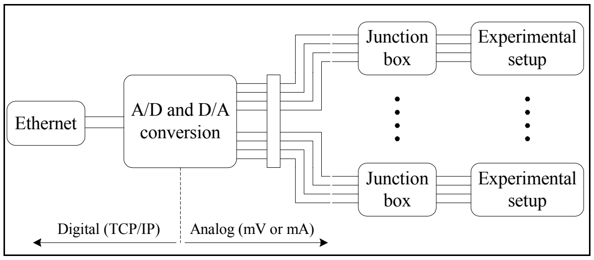

Figure 6: Analog and digital implementation (du Plessis, 2002)

The analog to digital and digital to analog converters are used to transform the analog signals to a digital networking protocol (TCP/IP) and *vice versa*. All the transmission lines of the experimental setups are routed to a centralised case or box (referred to as the *Opto box*) where the A/D and D/A conversion instrumentation is situated. The box is used to protect the expensive instrumentation as well as the open connections from dust and spills. Every rack needs one *B3000 brain* and is used to convert the digital signal to the *TCP/IP* format, the protocol used to transfer data across the *Ethernet*.

5. EXPERIMENTAL RIGS

The scope of investigative research that can be done in a laboratory of this kind ranges from contact with real-world measuring equipment and final control elements through industrial quality software interfaces to advanced control strategies implemented on the available equipment. Control topics that can be studied in the laboratory are equally varied. Some of them are listed below:

- Basic control principles (SISO loops)
- Simple MIMO control (one-way interaction)
- Complex MIMO control, including nonlinear MPC
- Abnormal situation management
- Alarm management
- Automated start-up and shut-down

As mentioned earlier, each of the five rigs has a unique character with associated control challenges (de Vaal et al., 2000). The rigs available for experiments are presented briefly in the following sections.

5.1 Flash drum control rig

Large interaction between the different controlled variables necessitates the use of multivariable control techniques for stable operation. This rig can therefore be used for the development of novel multivariable control techniques or multivariable performance monitoring criteria. Analysis of current multivariable techniques can also be conducted as the rig represents a close approximation of equipment found in industry.

The start-up operation of the flash drum is fairly complex, making it ideal for the implementation of automated start-up and shut down procedures. Abnormal situation management techniques like fault detection and analysis as well as alarm management can be implemented due to the complex nature of the rig as well as the large number of measurements available.

5.2 pH control rig

pH control is a notoriously difficult control problem not only due to its highly non-linear nature and large temperature dependence but also due to the extreme conditions experienced by measuring equipment.

5.3 Variable deadtime temperature control rig

Three paths with different lengths (and different dead times) can be selected by opening and closing manual valves. Four temperatures are measured at different points on the control loop and can be controlled by manipulating heat input from an adjustable heating element.

5.4 Level and flow control rig

Interactive level and flow control necessitates the use of multivariable control techniques. Dead time can be incorporated by using a dead time pan. The robust nature of the rig makes it ideal for the implementation and development of advanced analysis and control techniques like on-line tuning and fault detection. Contemporary control techniques such as fuzzy logic or neural network control can also be attempted, as the system dynamics are straightforward and easily checked.

5.5 Distillation control rig

Strategies that can be implemented include:

- Base layer control system development
- Decoupling design and implementation
- Constrained model predictive control
- Temperature or composition profile control
- Non-linear control
- Automated start-up and shut down

There are certain control problems unique to this experimental rig. The boiler-accumulator at the bottom of the distillation column is spherical. This makes the level control as well as the boil-up rate highly non-linear. Another control problem identified is that the product is mixed and recycled to the feed drum. This results in output variance being recycled back into the column.

6. CONCLUSIONS

Training specialists makes sense. Doing it in a manner that conforms to the requirements of industry at large is not always easy. What remains an absolutely important element in the establishment of a successful programme is total dedication and human material with ability and the will to accept the exciting challenges offered by industry. Once these elements have been established, it is a simple matter to provide the facilities for keen young minds to delve into the wonders of science and technology.

The new centralized A/D scheme, along with a client-server architecture is ideal for a students to apply the knowledge gained in control system studies. The scalability of the system to accommodate new hardware, virtual plants of connections, ease of use for students and the similarity to ‘real’ control situations are all benefits that make the system well worth the expense of installation.

7. ACKNOWLEDGEMENT

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