VIRTUAL PLANT LABORATORY SYSTEM OF PROCESS INDUSTRIES FOR EDUCATION

Yiping FENG[1] and Gang RONG

National Key Laboratory of Industrial Control Technology,
Zhejiang University, Hangzhou, P. R . China, 310027

Abstract: A kind of virtual plant laboratory system for process systems engineering education and research is developed, which is deemed an effective and applicable tool. The proposed system consists of pilot tanks, package simulation software of unit operation and a real enterprise information system including DCS, management database and MES (manufacturing execution system). Particularly, positive effects of customizing the virtual education systems to satisfy the needs of specific engineering education and research domain such as modeling, optimization and control of industrial plant, and development and implementation of enterprise information systems are highlighted.

Keywords: process industry, MES, virtual plant, enterprise information systems

1. INTRODUCTION

In modem petrochemical plants, there are hundreds of processes to be controlled, thousands of various orders to be executed, and countless data to be processed or exchanged everyday. The inherent complex makes it a rather challenge to manage all the process flow effectively. On the other hand, facing the growing demands for high quality products manufactured at lower costs with shorter cycle times, process industries have been forced to consider various new product design, manufacturing, and management strategies. Therefore industry has a keen interest in the development of the model-based process technology such as production planning and scheduling or process optimization and control etc. High quality college graduates with hands-on experience in process technology are in urgent need.

Today, physical pilot-plant might be considered expensive and lack of flexibility (Donald, 2000; Horácek et al., 2000). They are generally good only for single loops and PID control, and not suited to multivariable control and plant wide control study. However, with the availability of advanced computing

[1] Author to whom correspondence should be addressed
Phone: 86-571-87952277
Fax: 86-571-87951219
Email: ypfeng@iipc.zju.edu.cn

power and software tools, the technology of computer simulation and visualization contribute remarkably to engineering education. A laboratory simulation system can avoid various field practical difficulties and can provide a wide range of scenarios and plant wide control simulations for training common and emergency procedures (Kheir et al., 1996). An effective laboratory system that permits college students to operate, maintain and study in a simulation industrial environment is considered a key issue in control engineering education these days.

In this paper, a kind of virtual plant laboratory system for process engineering education and research is described. It has been designed to support teaching in many courses related to dynamical system analysis and control system design, and to offer a simulation environment of real petrochemical plant suitable for education and training. It provides an important connection between abstract control theory and the real world.

2. ARCHITECTURE OF VIRTUAL PLANT LAB SYSTEM

In order to let students get a better understanding of the plant wide management decision and unit operations of the process industries, an experiment system, named as Virtual Plant Lab System, has been proposed to "copy" the real running of a process enterprise. As shown in Fig 1, it is composed of several parts that are integrated in a proper way, including a simulation platform, a PCS (process control system), an information integration system and a MES. The simulation based on models of manufacturing and business process of the plant is of virtual. The learner environment of PCS, database and MES is a real one which is almost the same as it looks like in a practical refinery. There are a wide range of products available covering parts of the requested functionality.

2.1 Simulation Platform

The key point of simulation is modeling. Enterprise modeling is defined as the process of capturing the richest possible abstraction of the enterprise from different perspectives (enterprise model set) so that these enterprise models can be used for a wide variety of scenarios in business analysis and managerial decision support (Delen et al., 2003).

With the successful implementation of many ERP (Enterprise Resource Planning) systems, and the wide acceptance of plant control systems, a significant functionality gap has emerged between the two systems that may be filled by the process plant equivalent of a MES. A simulation platform with especial MES functionality has been designed to get manufacturing real-time data and business information of process industries. An enterprise model set has been built up to give the description of business information flow between the resource planning, refinery planning, scheduling, target setting, and operating activities. Meanwhile, the traditional process models and a pilot-plant are designed and integrated to represent the plant dynamic behavior in the simulation platform. In order to get the plant models running, the sticking point is the exceptional calculating capability, and it is made possible by a proprietary computing architecture that permits multiple simulations to run concurrently on single or multiple computers.

- Enterprise model set

Different business units view their business area with a different degree of summarization. In design of enterprise model set, the different levels of aggregation that are used in various applications such as real-time monitoring, oil accounting, scheduling, planning, etc are defined. As shown in Tab 1 (Peter et al., 2000), the model set is not only can support but also can simulate most of the key functions of an enterprise. Discrete-event model has been used to simulate business processes such as crude supply and product shipment. The detail of the model set will be discussed in further research work.

- Process Models

Process models are a set of dynamic models representing the characteristics of the unit operations in Tab 1. A simplified typical oil refining flow composed of 3 atmospheric vacuum distillations and 2 heating furnaces is employed. Models of this flow are accomplished through both commercial available simulation software and direct differential equations obtained from the physical laws. The input values (values for some manipulating variables) of the models are from the control output of the DCS and the output values (values for some controlled variables) are sampled by DCS.

- Pilot-plant

A pilot-plant of 6 tanks is designed as a part of the process models to construct a Hardware-In-Loop simulation and control environment (see section 3).

2.2 PCS platform

PCS platform is the physical under-layer of the system. It is composed of various external hardware system (e.g., DCS, PLC, pilot tanks) in order to simulate the real process control system with quite fidelity. Particularly the pilot tanks and the process models of unit operations are integrated to be controlled by the DCS at the same time.

2.3 Data integration platform

Data integration platform consists of a real-time database and a relational database. Emphasis is placed on the need for the implementation of suitable information models to facilitate an integrated manufacturing environment. An information model is a representation of concepts, relationships, constraints, rules, and operations to specify data semantics for PCS and MES applications. How information models are used to define data requirements and how, in a practical application, information models enable information sharing and exchange are considered to get a better design of database. In this project, the dynamic operation data and discrete business data from the simulation platform have been integrated into real-time database (PI Data Archive) and relational database (Oracle) respectively. This leads to the better application visibility and enable leaner to get deep understanding of the complexity of large-scale application environments.

2.4 MES application system

Based on the data integration platform in this project, a Manufacturing Execution System or MES was built up, which allows real time visibility, control, and access to all manufacturing resources—including equipment, labor, orders, and inventory. The real value of MES systems is the data that is automatically converted into “actionable information”. This leads to easy implementation of MES application packages such as operations performance evaluation, decision measuring, planning, scheduling, sales and shipping. MES professionals can also take advantage of real-time information to change their plants' production and equipment conditions in real-time, resulting in the avoidance of costly downtimes or other losses, improved equipment utilization, and accelerated product delivery.

3. STUDENT USE OF THE LABORATORY

The undergraduate and graduate curriculum of control engineering in the university include computer science , control theory, advanced control theory, process engineering, multivariable control, optimal control, fault detection and diagnosis, system identification, modeling and simulation etc. The courses are offered in parallel with the experiments in the Virtual Plant Laboratory.

The laboratory is open to all the students. The time schedule and experiment design is flexible. Task-based learning method is highly encouraged which usually is more challengeable and requires more time than following step by step instructions of the experiment prepared in classical fashion. Most students who opt for the control sequence enroll for the experiments actively. About 200 undergraduate and graduate students join the experiments in different levels annually.

3.1 Task-based learning

Task-based learning is employed in our system all through the education process. Task-based learning is a learning strategy that incorporates specific instructional preplanned activities, focused on a specific aim, and allows for the flexibility of the situation and students. A task-based learning process usually performed in three steps: task design, task execution and quality evaluation, as Fig 2 shows.

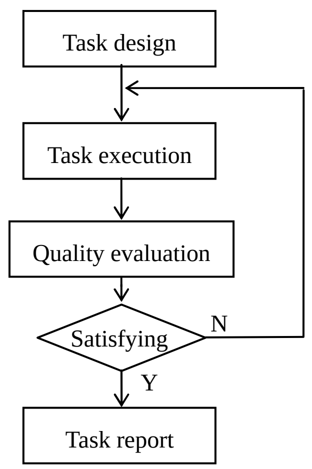

Fig.2. Step of a task-based learning process

Various experimental tasks are designed. Some of them are as follows:

- Evaluation of simulation process models both from commercial available simulation software and direct differential equations obtained from physical laws
- System identification and model-based control
- Data communication between various hardware and software, such as DCS, PLC and databases
- Construction of advanced control systems using DCS and evaluation of control algorithms
- Design of Hardware-In-Loop simulation

Such loosely structured problems inspire students particularly the excellence ones with infinite interest. As the tasks are so different from ordinarily schoolwork, they have no obvious solutions and need creativity to be accomplished.

3.2 Hardware-In-Loop simulation design

The importance that engineering students should be exposed to the real-world early is generally accepted. They need to deal with measurement noise, friction, saturating valves and motors. It is also very useful for them to have some experience in “making a real system work” (Kheir et al., 1996). So a number of pilot equipments have traditionally been used in control laboratories all over the world. But laboratory equipment is expensive to buy and costly to run and maintain, and as the inherent complex of petrochemical plants, it is difficult to build all the model equipment of a real petrochemical plant in a laboratory. So a right combination of hardware and software called Hardware-In-Loop simulation system is applied in the lab to implement a “real-time” approach to process control education.

The commercial software, such as Aspen Dynamics, PI database and MATLAB, with completed or user defined process modules are available and easy to do multi-loop or plant-wide control simulations. However, hardware design needs more attention. Besides those ready-to-buy computers and network systems, a pilot plant is designed.

The pilot-plant is composed of six quadrate tanks which are arranged as shown in Fig 3. Under each tank a differential pressure sensor is installed to measure the liquid level. Six flow meters are installed in pipes. Several switch-valves are used to divide the flow so that liquid is channeled to aim tank. By adjusting the valve knob, students can choose to design different experiments.

The uniqueness of this pilot-plant is that the outlet board of each tank is substitutable, and the intercepted area of each tank can be changed by put a cask into it. Some different outlet boards and casks are prepared beforehand. The mathematic model of each tank can be altered both by change the outlet board or cask. It is extendible and modifiable and can provide a wide range of scenarios for process experiments. For example, students can perform process identification and modeling exercises on real plant and tune real controllers on the DCS, then they can write describing differential equations and solve them numerically using MATLAB. What is the most important is that it can be modeled as partial oil tanks and integrated into our process models and enterprise model set of a refinery. For example, the oil movement model, a part of enterprise model set, is built up to represent source and destination of a material movement, composition tracking and total quantity over time duration. Using the oil movement model of the pilot tanks, a so called Hardware-In-Loop oil movement and oil blending simulation system can be constructed.

Such a Hardware-In-Loop simulation system has many advantages. Some parts of the virtual simulated process can be switched to the pilot plant simply by changing some connections. And the scope of the simulated object can be changed simply by software. This flexibility has important economic and academic consequences.

Students participate in all the design, manufacturing, debugging and modeling of the pilot-plant. Usually the mathematic models obtained trough arithmetic by students are not in accord with those held by commercial identification software, but they will use all the survey data to work over the dislocation until they get satisfying result. The experiment process gives students a more practical way of learning and provides a meaningful task in which students are actively plunged. Detailed report is required to be submitted at the end of each task. The detail of the survey will be presented in further paper.

4. CONCLUSION AND SIGNIFICANCE

The Virtual Plant Lab System appears to be a very useful tool, which has been evaluated positively by the students themselves. Students can actively learn and acquire the knowledge about internal mechanisms of process technology and enterprise information system through interactions with the system. In this paper, only one of the experimental tasks of the lab-tutoring plan is discussed as the limit of paper length. In fact, this system has also been utilized in research work on control theories and MES methodologies by researchers in the university.

ACKNOWLEDGMENTS

This work was supported by 863 Program of China.

REFERENCE

Delen, D. and P. C. Benjamin (2003). Towards a truly integrated enterprise modeling and analysis environment. *Computers in Industry*, **51,** 257-268.

Horácek and Petr (2000). Laboratory experiments for control theory courses: A survey. *Annual Reviews in Control*, **24**, 151-162.

Kheir, N. A., K. J. Aström, D. Auslander, K.C. Cheok, G. F. Franklin and M. Masten (1996). Control Systems Engineering Education. *Automatica*. **32,** 147-166.

Donald, M., Y. Brent and W. Svrcek (2000). A completely real time approach to process control education for process systems engineering students and practitioners. *Computers and Chemical Engineering*. **24**, 1481-1484.

Peter J and Lawrence. Closing the loop between ERP and DCS. http://www.ris-resolution.com/papers/artc/ARTC2000.htm

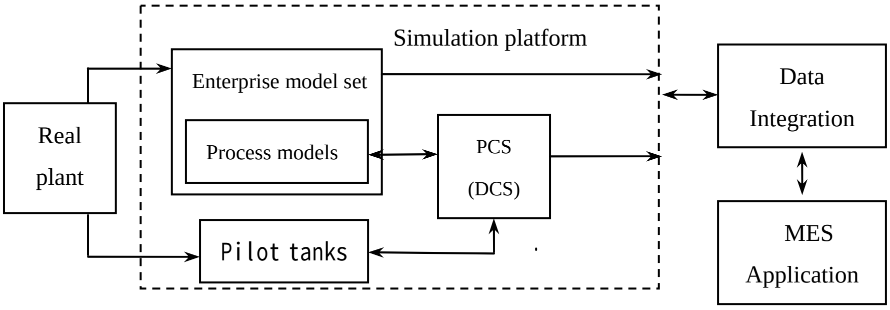

Fig.1. Principle structure of Virtual Plant Laboratory System

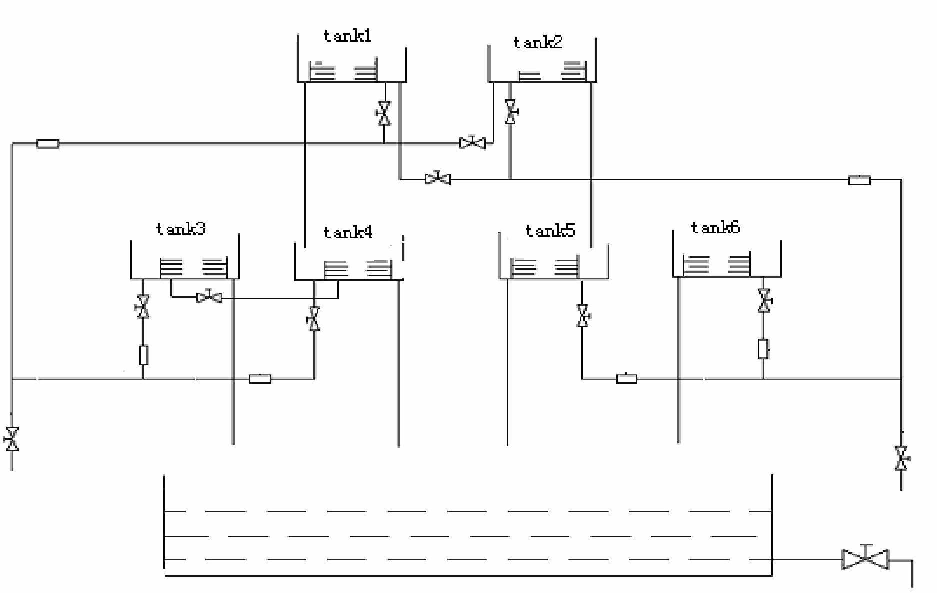

Fig.3. Principle structure of pilot plant

Tab 1 Enterprise model set of a refinery

<table>
<tr><th></th><th>Inbound Logistics</th><th>Crude Management</th><th>Processing</th><th>Blending</th><th>Product Management</th><th>Outbound Logistics</th></tr>
<tr><td>Planning (period averages)</td><td>Supply Forecasting</td><td colspan="4">LP Planning</td><td>Sales Forecasting</td></tr>
<tr><td>Scheduling (transactions)</td><td>Purchase Orders</td><td colspan="3">Scheduling</td><td>Offsite</td><td>Sales Orders</td></tr>
<tr><td>Target Setting (actions)</td><td>Receipt Nominations</td><td colspan="2">Operator Instructions</td><td>Blend Recipe</td><td colspan="2">Storage and Shipment Nominations</td></tr>
<tr><td>Operations (flows)</td><td>Crude Supply</td><td>Crude Management</td><td>Unit Operations</td><td>Blend</td><td>Product Release</td><td>Shipments</td></tr>
</table>