COMPUTER BASED MONITORING AND CONTROL OF FEDBATCH FERMENTATION PROCESS AS AN AIM AND A TOOL FOR POSTGRADUATE RESEARCH

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Abstract: Education of postgraduate students raises questions not only for the teaching of problem-solving skills, but mainly for teaching of design skills and providing high-level research. Development of the postgraduate research projects very often requires interdisciplinary knowledge. For example the control-engineering project requires knowledge for the process under control characterizing it from chemical, biotechnological, mechanical point of view. Alternatively, the biotechnological research project requires knowledge how to monitor and control the process under investigation in order to obtain the necessary information for its specific characteristics. This paper addresses these educational challenges by presenting research between students from different engineering disciplines working on a common international collaborative project.

Keywords: Educational aids, Computer-aided instruction, Control engineering, Data acquisition, Software tools, Real Time control.

1. INTRODUCTION

The implications of modern computer technology for tertiary institutions create lots of challenges related to improving the delivery of educational outcomes at reduced cost and at a higher quality. This holds true particularly for the engineering disciplines which experience continuous growth requiring that the skills of the student be constantly upgraded. The use of computer technology has become an extremely important facet in the teaching of engineering concepts and principles. Students across all engineering disciplines need to be prepared for the increasing use of this technology in their future places of employment.

Many of the research laboratories at universities are equipped with different types of lab scale processes, which require monitoring and control in a modern way. Normally these processes have different types of instrumentation purchased over the years, which have to be integrated in some unique way in order to build a required modern control system. The existing off-the-shelf industrial control technologies are very expensive. They have too many functions, which are unnecessary for the university laboratories, and at the same time they cannot supply the researcher with the needed modern control approaches for process identification, simulation and control.

One possible solution to the above problem is the joint research work of postgraduates from different disciplines on one common project. The final result is a product of a joint effort giving answers to different research questions. It also extends the student's knowledge. This approach was implemented between the postgraduate students of the Department of Electrical Engineering, Peninsula Technikon, South Africa and the Biotechnology group, the University of Karlsruhe, Germany. The paper describes the developed system for monitoring and control of fed batch fermentation process. The system is based on LabVIEW - software package and control strategy that has established itself as one of the leaders in the field of automation of different industrial processes and of the existing processes in the University research Labs. The system is designed by the research projects of the control-engineering students and used for the research projects of the biotechnological students in the field of fermentation. From an educational point of view, LabVIEW is used as a design tool for real time complex control systems and it is seen as a tool enabling one form of Computer Aided Instructions (CAI) methodology. The considered computer technology in the paper is used to develop and enhance the skills of students from the fields of electrical and biotechnological engineering, as it requires interdisciplinary knowledge and experience (Tzoneva, 2000). The knowledge gained is useful for the future work of the postgraduates.

The paper starts with a brief overview of the field of Computer Aided Instructions, covering predominantly the issue of using computerized tools for facilitating complex tasks at the tertiary institutions. Based on this the developing of design skills in the students using research projects and the computer and software design packages is discussed. Then the set of capabilities offered by LabVIEW are briefly explored which is followed by the description of the fermentation process and the developed system for monitoring and control. The assessment of the achieved educational outcomes is discussed at the end of the paper.

2. COMPUTER AIDED INSTRUCTION

The ever-increasing sophistication in computer hardware and software continues to make computer technology a vital tool for educators (Kallis, 1997). Computer Aided Instruction employs one of the following methods (Bligh, 1998):

- Drill and practice in performing a particular set of skills in the field;
- Tutorial in which the computer instructs the student in some area of knowledge in somewhat the same way a teacher would in a one-on-one situation;
- Demonstration of the material;
- Simulation modeling;
- Instructional games.

In this project the computer is used as an instructional tool for a drill and practice in performing design skills in the control engineering and biotechnology fields of education and research. The results of the design project will be used for a drill and practice of the future students using the system. The computer with the developed system displays the data in a format that is easy to interpret and the student is able to easily identify any deviations of the controlled system from an expected result.

The developed program assists the student in that the data is acquired automatically, logged periodically to a database, and graphically displayed. The data does not have to be manually recorded. The student is thus left with more time to take additional off-line measurements of samples during the cultivation.

Design skills teaching is one of the main directions of the research work in both Departments. The purpose of the design is to create workable system given a set of constraints. The basic elements of design are (Tzoneva, 2000):

- a system to be designed. It is characterized by desired specifications,
- a required knowledge – it covers physical principles from one side and different methods of design from other side,
- an experience – this covers areas such as the likely direct effect of particular choices. The experience is gained from working in the field or from case study.
- design skills – this is ability to assess the effects of choices made at any point in the design process. Design skill is the ability to select the options at any stage in the past, present or future, which will increase the chance of success of the design process.

The lecturer’s aim is to develop the postgraduate students as good designers. We have to produce students who can think critically and take responsibility for their decisions. The problem for us as teachers is how to teach design knowledge and design skills using the existing educational system from one side and how to increase the student’s practical experience using the research and the interdisciplinary projects from the other side. Our approach is based on:

- Developing an engineering curriculum using notion of an engineering transformation system concept,
- Using the computer tools, as software packages MATLAB and LABVIEW,
- Developing connections between the Research and Education, Tertiary institutions and Industry.

The concept of the Engineering Transformation System (Tzoneva, 2000) contains the idea of useful proportion of design knowledge, design methodology and design tools within the process of technical system’s creation. Designing is a multi-faceted activity which could be presented by the functioning of this transformation system. The knowledge and methodology are built through the curriculum development in which all parts of the design process are included on the basis of using modern computer technologies. The design tools are the computers, the different software packages and the management of the whole design process. The link between education and research, scientific knowledge and its application is leading for all subjects and projects at the both tertiary institutions, included in the developed system.

3. THE SOFTWARE TOOL

LabVIEW (**Lab**oratory **V**irtual **I**nstrumentation **E**ngineering **W**orkbench) is a revolutionary graphical programming development environment based on G programming language for data acquisition and control, data analysis, and data presentation. LabVIEW gives the flexibility of a powerful programming language without the associated difficulty and complexity because its graphical programming methodology is inherently intuitive to scientists and engineers (Bishop 2001). LabVIEW is being used throughout industry and also in tertiary institutions especially in science and engineering applications. LabVIEW programs are called VI's (virtual instruments). The computer in the developed system acts like a virtual instrument and it replaces the traditionally expensive equipment which is one of the objectives of this collaborative project. At the same time the LabVIEW technology allows different type of hardware, as in the considered case, to be incorporated in one system.

4. THE CULTIVATION PROCESS

The process to be monitored and controlled is the cultivation of *Haloferax mediterranei.* This process takes place in a 10-litre tank called a bioreactor. The aim in this cultivation is to produce extracellular polysaccharides (EPS) with maximal yield. This is done in two phases, namely the

- batch phase, during which biomass production takes place and the temperature is controlled at 38 degrees Celsius, and
- the fed-batch phase during which extracellular polysaccharides are produced and the temperature is controlled at 45 degrees Celsius (Mironescu, *et al.*, 2002).

The mode that is interesting from a control point a view is the fed-batch fermentation, because of its flexibility (Mkondweni, 2002). It is the one that is used for the experiments.

The monitored and controlled system process variables are temperature, pH and DO (Dissolved oxygen). A heater, acid or base pumps and agitation are used to control these variables according to the previously determined set points. The biological variables of the process as concentrations of biomass, substrate and product are measured off-line and are sent to the database via the keyboard.

5. OVERALL MONITORING AND CONTROL SYSTEM

The control and monitoring system consists of a Pentium II PC running Windows NT with a National Instruments data acquisition card (1200) with LabVIEW 6.0 as driver software. The hardware set-up is displayed in the Figure 1 (page 6).

The developed system has the following functionalities:

- Calculation of the Calibration functions.
- Data acquisition for the process variables.
- Logging of the data to an MS Access database.
- On/Off control of certain process variables.
- Calculation and implementation of the feeding function during the fed-batch phase.
- PID control with auto-tuning for control of the dissolved oxygen concentration using the agitation as a controlling variable.
- Distribution off data using TCP/IP or Data Socket in the fermentation laboratory.

The software setup of the system is displayed in Figure 2 (page 6). The various modules are developed corresponding to the system functionalities.

6. THE SYSTEM FUNCTIONS

The process variables and their ranges and set points are displayed in the following two tables. Some of the variables are analog inputs (AI) others are analog outputs (AO) and digital outputs (DO) for the control system.

Table 1 : Input / Output Signal Parameters

Variable name	**Unit**	**Chan**	**Type of I/O**	**Range of variable**	**Range of signal**
Temperature	°C	0	AI	0-100	0-10V
pH	-	3	AI	0-14	0-10V
Agitation	r.p.m	6	AI	0-1000	0-10V
Dissolved oxygen	%	7	AI	0-100	0-10V
Agitation	r.p.m	0	AO	0-1000	0-10V
Feed Pump	r.p.m	1	AO	0-1000	0-10V
Temperature Heating	°C	0	DO	0-5	0-5V
Temperature Cooling	°C	1	DO	0-5	0-5V
pH Base	-	4	DO	0-5	0-5V
pH Acid	-	5	DO	0-5	0-5V

Table 2 : Limit values for the process variables

Variable name	**Unit**	**Minimum**	**Maximum**	**Setpoint**
Temperature	°C	35	48	45
pH	-	7.0	7.5	7.2
Agitation	r.p.m	0	600	300
Dissolved oxygen	%	30	40	35

The errors in the analog inputs and outputs to the computer are linear and the students routinely check the calibration and enter the coefficients into the LabVIEW program. The calibration curve for the temperature is displayed on the Figure 3. Through the calibration curves calculation the biotechnological postgraduate is therefore exposed to the electrical engineering principles for work with signals in a real time computerised environment.

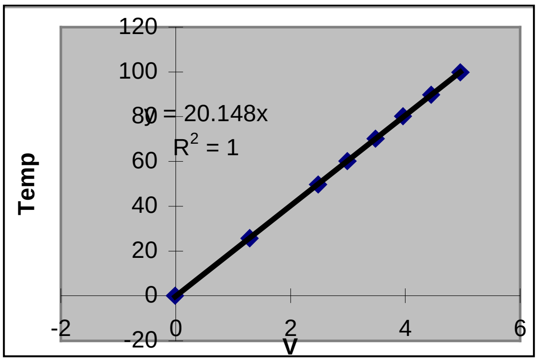

Fig. 3. Temperature calibration curve

The database was developed using the SQL command language in LabVIEW. The physiochemical process values are logged automatically, while the biological data is entered manually. The database front panel is displayed in Figure 4.

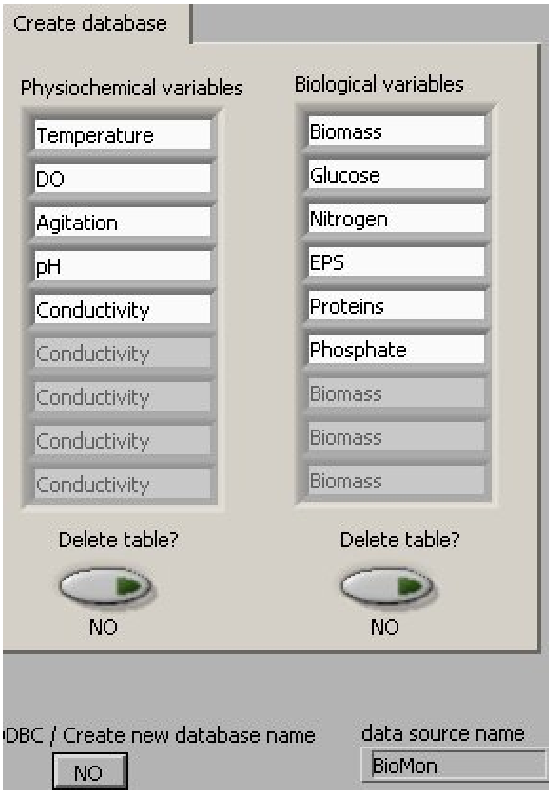

Fig. 4. Creation of the database

The on/off control algorithm for the temperature and pH are exactly the same except that the outputs go to different pumps, heaters and valves. The temperature control front panels are displayed in Figure 5.

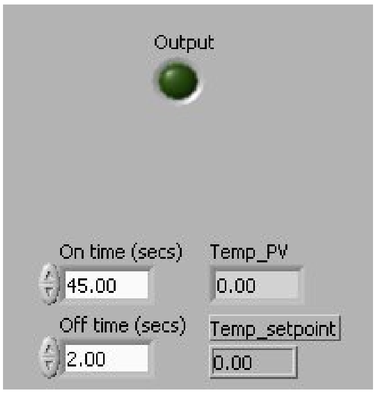

Fig. 5. On / Off Control for the Temperature

The feeding rate is calculated on the basis of the steady-state behaviour of the process. Implementing a formulae and controlling the rate at which the pump turns determines the feeding rate. The front panel for the feeding function is shown in Figure 6.

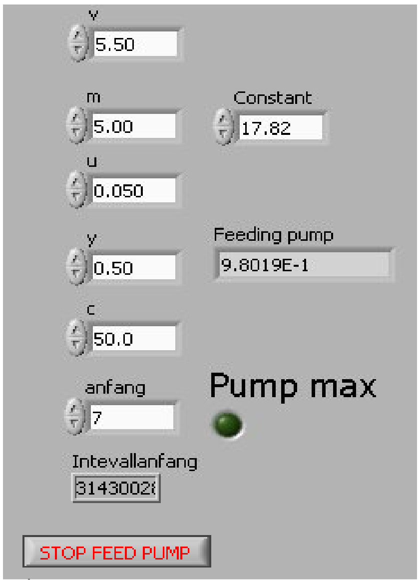

Fig. 6. Feed Function

The auto-tuning function is used to calculate optimal PID parameters in order to improve the controller response and ensure that the process variable is controlled as close to the setpoint as possible.

7. EXPERIMENTATION

The real work of the system for monitoring and control was validated during the three full cultivations of the fermentation process. During this time the parameters of different functions of the system were adjusted according to the process requirements. Some results for PID autotuning are shown in Figure 7, where DO is the dissolved oxygen concentration, SP is the setpoint for DO and Agit is the agitation. The autotuning procedure started with the initial PID parameters Kc =148,2454,Ti = 0,1570,Td = 0,0314. Parameters after 15 cycles of tuning are Kc = 8, 6760,Ti = 2, 2880,Td = 0, 4576

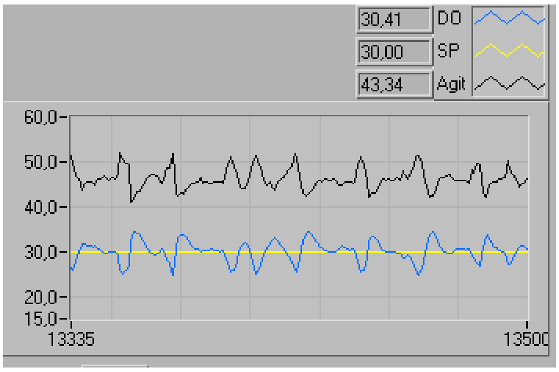

Fig. 7. Results after 15 cycles of auto-tuning

The process behavior with the auto-tuned parameters is better than the previous method of selecting the coefficients in an ad hoc manner. The value of the steady-state error is reduced and the rise time is shorter with the new algorithm.

8. EDUCATIONAL OUTCOMES

The collaborative project has achieved the stated objectives for the control system specifications on one side and the educational objectives on the other. The stated control system objectives,

- User-friendly operator interface.
- Status of process variables to be graphically displayed in real-time.
- Real-time control of pumps and valves directly influencing physiochemical variables.
- Realization of auto-tuning PID control of the dissolved oxygen concentration.
- Status of various control equipment to be displayed.
- Faults, errors and alarms to be easily identified.
- Logging of data to allow for easier interpretation and extraction of data for analysis.
- The operator to have option to change the minimum, maximum and setpoint values as desired.
- Modular structure of software algorithm to be developed in order to allow for expansion and improvements to the program.

have been realized and the system is functional and in use. The obtained results from the auto-tuning algorithm are better in comparison with the conventional PID control results. The future developments consist of real-time simulation and process optimization and inclusion of the developed system in a network of similar systems in the laboratory.

The aims of the project supervisors and educators were

- to estimate the success of the educational programmes in developing the postgraduate students as good designers, and
- to increase the existing and build new knowledge and design skills in the postgraduates by the work in a real interdisciplinary environment through developing of interdisciplinary projects.

The participants in the project were placed in a real situation where they had to find solutions to real problems. Work on the project required the following capabilities from the postgraduates:

- to recall work studied or to acquire new knowledge for the physical principles and to apply the different methods of design,
- to select the proper solution from a couple of possibilities on the basis of estimation of the consequences,
- to assess the importance of the decisions made by the colleagues from the other field,
- to assess the effect of the choices made at any point of the project.

The postgraduates finished the project in time and achieved the previously stated objectives, which can be considered as a positive development in both institution’s curriculum, incorporating design methods, design tools and working collaboration between research and education.

The joint work of the postgraduates from the collaborating institutions on the project was presented and assessed at the research seminars provided separately – at the University of Karlsruhe and at the Peninsula Technikon. The participants were respectively from the field of biotechnology and from the field of electrical engineering. They displayed great interest and asked many questions. The successful project realization and implementation showed that a specialist in one field can understand and develop knowledge in other fields if they make decisions together in trying to achieve one common goal.

9. CONCLUSION

The paper presents an interdisciplinary project for a simple but effective computer system for monitoring and control of a fed-batch fermentation process for the production of extracellular polysaccharides in the research laboratory at the University of Karlsruhe. The project was part of a joint collaborative initiative between Peninsula Technikon, in Cape Town South Africa and the University of Karlsruhe, in Germany. It is developed to cater for

- the requirements to monitor and control the average case of fermentation plants as a project for the electrical engineering postgraduates from the Peninsula Technikon, and
- the requirements for process technology optimisation and modelling as a project for the postgraduates at the University of Karlsruhe.

The project is applicable with minor changes to every bioreactor. It will be used for practical experiments with undergraduate students and as a computer tool giving new possibilities for development of other, more complex projects at both institutions.

One problem which engineering education addresses is to teach students to solve technical problems independently. Educational institutions face various challenges in obtaining the balance between adequate knowledge, the engineering skills in using design tools and the engineering design methodology. The institutions are finding innovative ways to disseminate and use knowledge. One of them is the interdisciplinary research joint project. The results from the described projects are very positive and prepared the postgraduates for the real work environment in industry.

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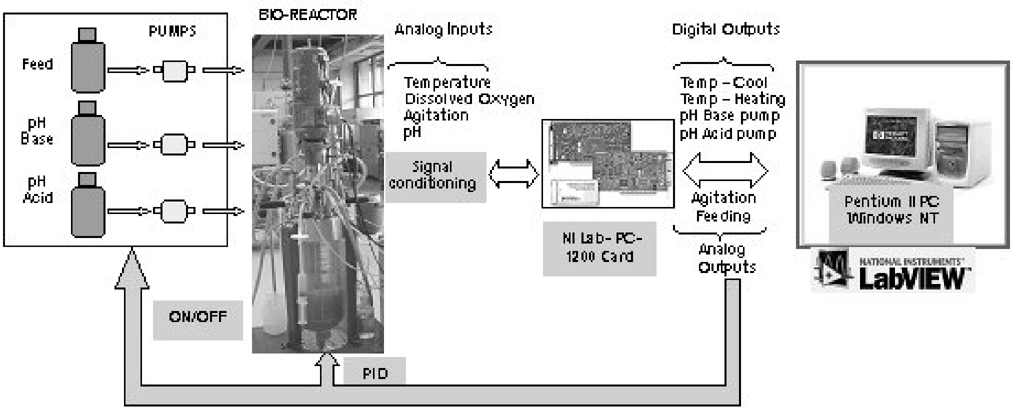

Fig. 1. Hardware Layout

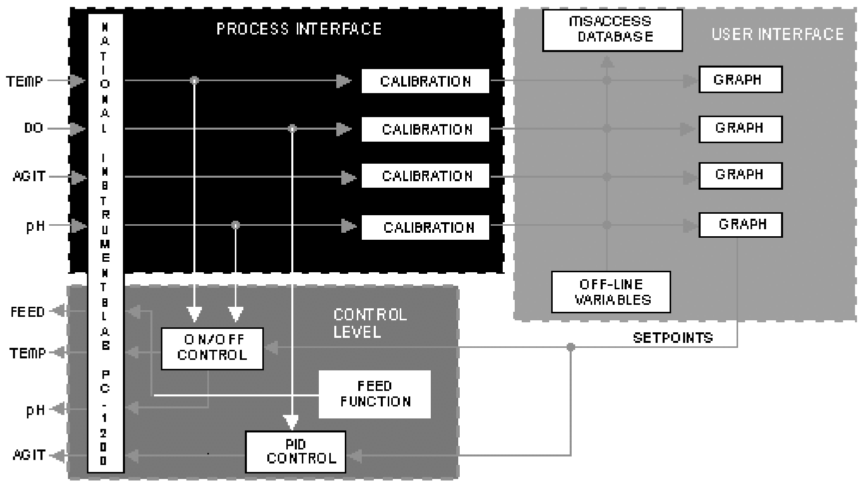

Fig. 2. Software Layout