EXPERIENCES IN AUTOMATION EDUCATION APPLYING 'LEARNING BY DOING' IN MULTIFUNCTIONAL TEAMS

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Abstract: The paper deals with the design and implementation of a pallet-based conveyor system using open control and communication systems at Tampere University of Technology. The realization has been mainly based on the work of senior undergraduate students at a special teaching course focusing on systematic design of machine and factory automation systems as well as on project and teamwork and project management. Experiences of this kind of "learning by doing" course and development work are discussed as well as the implemented and developed system at the light assembly laboratory. Special attention is paid to the developed open PC-based control and communication system designed in a concurrent frame for machine control, I/O communications, software connectivity, user interface and maintenance program. Copyright ©2000 IFAC

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1 INTRODUCTION

The design and development of machine and factory automation systems involves the work of more than one person, and usually the cooperation between different teams within the same company. Owning the time critical deadline than OEMS (Original Equipment Manufactures) are facing currently, efficiency in the cooperation work is a key issue.

Conventional automation systems are typically customized systems so that both the hardware and software vary from case to case and from supplier to supplier. This means poor flexibility, re-usability and maintainability. All this is in strong conflict with current manufacturing needs.

Since the late eighties the introduction of the openness philosophy based on standard hardware and software components has helped the design of modern open control systems. Nevertheless, the design and implementation of modern automation systems ends up in a concurrent engineering (CE) working frame where a collaborative teamwork within experts on different technologies and within the same OEM enables selection of the best-in-class components for each of the necessary technologies.

Tampere University of Technology (TUT) has long traditions in automation education. Since 1987 TUT has offered a special degree program of Automation Engineering. The students can focus their studies on different fields of automation, incl. process automation, machine automation and factory automation. Both theoretical and practical studies are available.

The area of machine and factory automation is very wide and new technologies are coming and new expertise is needed all the time. Since 1992 a course named as *System engineering in machine and factory automation* has attempted to fill the needs of the industry and to train and prepare the students for the real automation engineering work in industry. The students are put in contact with the newest technology both in theory and practice applying the philosophy 'Learning by doing'.

2 ORGANIZATION OF THE COURSE

The target of the course *'System Engineering in Machine and Factory Automation'* is to teach the *technology of multi-technological automatic machines, devices and systems, systematic design methods, effective group and teamwork methods,* principles of *productive project work methods* and *project management* (Figure 1).

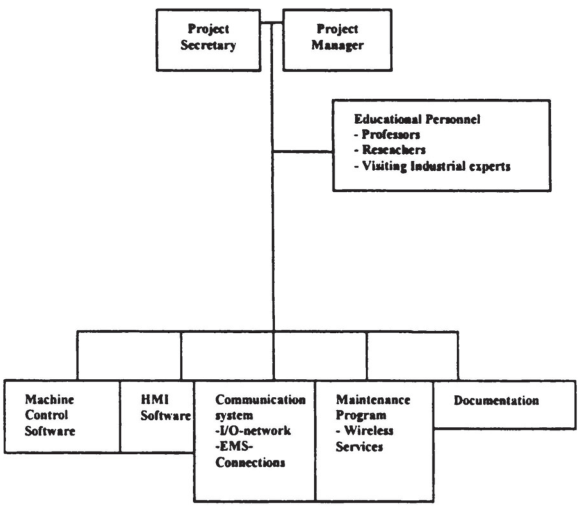

Fig. 1. Course Organization Charts

The project is organized like a normal industrial automation project. The *formation of the multifunctional teams* is one of the more difficult tasks for the educational personnel. *A questionnaire* has been developed which together with the individual interests and the academic background of the students (degree program, years involved in the University, courses, special expertise, ...) pave the way for the selection process. Students with different backgrounds give additional value and visions in the team. The target of this questionnaire and related discussions is to make it sure that the *know-how- and motivation-profile* in each team meets the needs of their subproject.

Each of the multifunctional teams must be capable to develop the assigned task and work in a *concurrent engineering* frame within the team and with the other teams. The project manager and the secretary are in charge of maintaining a friendly and working *communication* channel *between the teams.* Also *today's new communication technologies* have given project secretaries a new scope. There must be a common way of communicating, in a way that is accepted by everyone. Cooperation and communication between teams is essential during the whole project to make it possible to build up a fully integrated system.

The size of each team is planned to be big enough to make it a real team with typical teamwork problems that must be solved.

At the beginning of the semester the first thing to do after organizing is to make the project plan. That plan specifies and confirms in detail the demands and working methods supposed to be followed during the project course. A preparing course in project management is supposed to be studied before this project course and all these learnings are then applied phase by phase in practice during of the project work.

The close contacts between TUT and the industry are utilized also in this course. Several visiting experts from the industry give interesting and practically oriented lectures on different needed technologies. These lectures have been very useful and important both for motivation of the students and for clarifying and emphasizing of the taught subjects.

3 DESCRIPTION OF THE APPLICATION TASK

The main idea was to renovate *a pallet-based conveyor system.* These types of conveyor systems are widely used in the final assembly lines of electronics and electromechanical industry.

3.1 Brief functional description

The system consists of five different conveyor modules. Main module has a main upper line for transporting pallets between work phases and main lower line is reserved for returning of the pallets to beginning of the mainline. The shift between levels is accomplished through the use of two lift modules situated at the extreme ends of the main line. Two additional modules are taking care of material flow from the main line to work stations (Figure 2). The pallet-based conveyor system allows circulation of different products with different production processes in the system.

Two work phases are included in the designed system. One consists of sub-assembly tasks in the Low Cost Assembly Cell (LCAC). LCAC is a cartesian robot built up earlier at the laboratory during the same course in the spring-98. A single-level auxiliary conveyor reaches the LCAC and transports pallets between the main line and the

LCAC. There are two parallel conveyors side by side. These two conveyors are connected to each other by another conveyor which is not changing the orientation of pallets. This kind of conveyors are widely implemented in the automatic assembly cells and are known as *loop conveyors*.

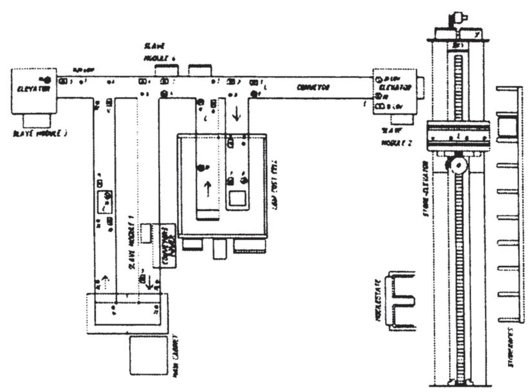

Fig. 2. Layout of the pallet-based conveyor system

The turn station composed of two turn units drives the other work phase. A similar auxiliary conveyor to the one described for the LCAC reaches this station. Depending from the basic layout there is a possibility to choose whether the orientation of pallets is not changed or is rotated 180 degrees. In a coming course a second automatic assembly cell for electronics production will be designed and implemented, placed at the end of this auxiliary conveyor.

3.2 Previous proprietary control system

The control system of the pallet-based conveyor system was a traditional proprietary PLC-based control system with parallel wired I/O. This control system had some distributed properties with compact mini PLC's but nevertheless overall controls was achieved by a central control unit. During the course the control system was replaced by an Open PC-based control with distributed I/O serial bus.

3.3 Guidelines of the new implementation

The imbalance between student resources and knowledge was noticeable. Technological knowledge of the teams was quite good for designing a traditional control system but in this case little more was needed because of the novelty of the applied technology. Thanks to additional training, sufficient team size (7 persons) and balanced distribution of work within team members no big problems, however, existed with human resources.

Different guidelines were needed for guiding the teams in their work during the course. One important topic was the money. Similarly to industrial practice the economical point of view was taken into serious consideration during design of the new system. This also gave the students a proper perspective to choose correct hardware and software components correctly. A basic guideline was: "Buy what you need, not more". Because of the nature of the task (software orientated) and because of the knowledge among group no outside resources were needed during implementation of the new control system.

Guidelines for choosing the correct software and hardware components were given during extensive exercises. One of the more important guidelines during exercises was the openness. Learning of the advantages that the openness can provide in a control system design was the main objective during this course. Fielbuses were also studied thoroughly during these exercises.

4 DESIGN AND IMPLEMENTATION OF THE NEW AUTOMATION SYSTEM

The design of the control solution was the result of two main different actions, the functional requirements analysis and the selection of the suitable components.

The adoption of PC-based control systems tries to decrease the integration time and provide more alternative solutions to the system integrator or OEM. The task of the integrator during the previous stages of the design is to analyze the real requirements of the system, especially in terms of system performance.

Selection of the main components like the hardware platform, the *operating system*, the *control software application, the connectivity tools between software applications and the I/O network*; is an easy task if the analysis of the system is known

The selection process is followed by the implementation of the different applications. Each of these working packages must be done in a synergy process for the teams in charge, only the design and implementation of this kind of systems in a unified form can guarantee the full success at the end of the project.

It is important to emphasize, that in the case of a control system based in PC technology, the control target program will be run on the same platform where the system is designed, this will provide a better understanding of the real possibilities for the designer. Due to the existence of a unique platform the interactions between the development and debugging process are easier

4.1 Functional analysis

A down-top approach has been applied for analyzing the problem. Solution is not a straight forward, instead there are several nested and parallel iterations to be made, sometimes jumping between analysis and selection.

The machine itself must be analyzed before the control system can be designed. It is needed to figure out how the machine works from both the mechanics and the process side. It is needed to analyze what are the eyes and ears for the control system. What kind of sensors and where located will collect the essential information for the controller. Within later iterations this information is specified in more detail with exact types of sensors (capacitive, optical, inductive, PNP, NPN, digital, analog, intelligent, serial, ...). The same must be done with the actuators as well, but actuator types and locations are usually more or less tight by the process or by the mechanical designers of the machines. A control engineer needs just to fulfill the control task that the selected actuator needs.

In the discussed project the sensors and actuators and their locations were already partly defined beforehand, because we were making modernization of the control system, instead of building a totally new machine.

When the amount and locations of needed sensors and actuators are known, the other parts of control system of the machine can be thought over. Very natural solution was to use fieldbus for collecting the I/O-data to the controller, because parallel wiring of the I/Os into the PC is less natural than in case of traditional PLCs, being at least an inconvenient way to do that. Based on previous information it is possible to analyze, how the states of I/Os can be delivered to the controller – what is the media and how the I/Os are connected to it. The machine must be analyzed again from following viewpoint: Are there groups of I/Os in some smaller area for locating a fieldbus slave terminal for these I/Os or are all I/Os uniformly distributed all over the machine. This will affect the selection of fieldbus. Different approaches can be taken, like optimizing costs, wiring, connection points, etc. In our case there already exist some control cabinets with valve terminals. These control cabinets were selected as placement of I/O terminals. Optimization was done based on wiring lengths and costs.

Selection of the controller has been going on simultaneously. The amount of I/Os and I/O terminals led to one controller system, which can take care of all control tasks. The controller was defined to be PC based and the operating system (O.S.) was wanted to be familiar to students and researchers that lead to selection of Microsoft Windows NT as the O.S. The controller was analyzed based on earlier made research. The programming language was wanted to be graphical flowcharting for research reasons. For minimizing the hardware cost the Human Machine Interface (HMI) was located in the same PC as the control software. This also simplifies data communication between the controller and HMI.

	Hardware platform	Operating System	Control Software Application	Human Machine Interface	I/O Network	Connectivity tools between applications
Hardware platform		5	2	2	4	1
Operating System	5		4	4	2	4
Control Software Application	2	4		4	5	5
Human Machine Interface	2	4	4		2	5
I/O Network	4	2	5	2		4
Connectivity tools between applications	1	4	5	5	4	

5	Tight
4	
3	
2	
1	No interaction

Fig. 3. Selection Matrix. It shows the relationship between the different components of the system

The fieldbus had to fulfill a structure of terminal based slave stations but the fieldbus topology itself did not matter. The speeds of different commercial fieldbuses are high enough for this type of conveyor application. The fieldbus scanner card and drivers available for the controller had to be studied, as well as the needed and available I/O components for the considered fieldbus. Selection of the fieldbus can be made based on these features.

In parallel to the other phases the project team had to analyze the connectivity and interfaces that fulfill the specified level of system connectivity.

4.2 Selection Process

The selecting of technologies and hardware is based on four different aspects (Lastra, 2000):

- Technical specification
- Corporate policy
- Specification by end-user
- Country specific aspects

The teams after a period of work together with researchers in the Laboratory and strong contact with software and hardware control suppliers presented the following proposal:

- The control will run in a main *industrial PC* (Nematron Corp.), where the Human Machine Interface (*HMI*) will be also executed.

- The selected Operating System was *Windows NT* (Microsoft) powered by Hyperkernel, a commercial Real Time Subsystem for NT.

- OpenControl (Nematron Corp.) was selected as the *control application software*, and *visual flowcharts* as the programming languages were the control program will be developed.

- The *Human Machine Interface (HMI)* will be developed using InTouch (Wonderware Inc.) and the connectivity will be based on *DDE*.

- The I/O communication will be accomplished using *Profibus-DP* working at *1.5 MB/sec*. The configuration would be a *mono-master/multi-slave network*.

- *Also there was interest in the group to include* remote maintenance *properties into the system. One of the more interesting properties was to implement remote communication between machine and the operator using* GMS-SMS-technology.

4.3 Implementation phase

The implementation phase is a key issue to make the system work perfectly. A proper selection of components is already half of that, but without well-made implementation we can't obtain all benefits offered by the sophisticated components to be used.

Connectivity issues are very important concerning automation systems, especially in PC-based open solutions when you can make multi-vendor solutions. At the very beginning of implementation it's necessary to plan not only the communication gateway but also the information what will be transmitted. There are standard connectivity tools like DDE and OPC, which are widely used in PC-based applications. Many control software vendors have also drivers to different hardware in their programs to ease the communication and make the implementation more fast and easy. Integration of drivers reduces number of applications needed to run in the system, helps design and eliminates multiple databases (Lastra, 1999).

Faster design cycles call for better tools for developing the control applications. Good visualization is one thing to create a code which is easy to understand and fast to develop.

The students of the course were divided into three different teams. The first team was responsible for the HMI and DDE connection to logic and Excel. The task of the second team was to design the logic part based on functional requirements of the conveyors. They also had to implement it with the OpenControl- control software. The third group was responsible for mechanical and electrical installations including cabling.

All of these teams were working parallel planning their applications and requirements by themselves, but collaboration between the teams had to be very close and intensive to make sure that all components and subsystems can be connected together.

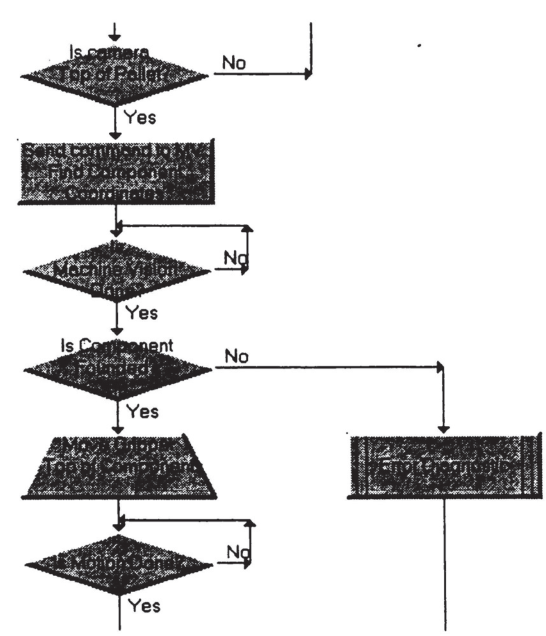

Fig. 4. Programming environment using Flowcharts

At the beginning of the project meetings between all teams were most important to define reliable connections between different applications and to define the I/O network. When communication issues were decided all teams were able to start work for their tasks separately. As mentioned before, the work was done parallel so that hardware of conveyor system weren't finished before software development. Because of defined communication, software could be tested by simulation before the real implementation so that the total throughput time could be minimized (Tuokko, *et al.*, 1999).

5 ACHIEVEMENTS AND CONCLUSIONS

Essential key things which have influence on the results of this kind of student project include *motivation of the students* and *successful cooperation between the research and teaching staff.* Students offer a *potential additional resource* which can be utilized in the research work. And on the other hand the *research staff can be tutors* for the students and thus help the teaching staff in the project. This is important because so many different expertises are needed in this kind of automation project.

The students *work in teams* where the *team members have different backgrounds* with a *common goal.* The individual portion of *each member's work must be adapted to the needs of the other team members* and the *dialogue and communication* has to be fluent and sufficient.

A challenging project work with the asked systematic approach in project management and documentation is a demanding job for students when they have simultaneously also many other things and studies to work with. That's why there have sometimes been problems to *motivate and encourage the students to commit themselves* to all the key goals of the course. Most of the theoretical lessons are at the beginning of the course, and so many students can't see the importance of those lessons and methods until at the end of the course when thinking backwards the time spent and the work done.

The discussed project has offered students a possibility to use *real state-of-the-art automation components and devices in practice.* This together with the applied *learning-by-doing* method has helped in motivation so that most *students have even surpassed themselves and exceeded the expectations.*

Experiences of the course and received feedback from the students and industry show clearly that *Learning by doing* is a very good and effective way to *learn and adopt knowledge and skills in automation and control systems.*

The course improves ability in *problem solving in automation technology.* The problem is introduced from the very beginning to the students and entirety of their actions is in order to solve it. This increases each member's *responsibility* of the project improving the obtained results.

Students are in *contact with the newest technology* both in theory and practice. The channels how the technologies are presented differ from traditional ones. Here the *strong contact* that the Tampere University of Technology has *with the industry* enables *visiting lectures* from industry, which sometimes give a different point of view that the faculty.

As a material result, the laboratory *increases and improves the facilities* yearly, *improving the complexity of the project and learning space* for the coming editions of the course.

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