Future-oriented education with a modern flexible production unit

C. Ungermanns, W. Werth
Carinthia University of Applied Sciences (CUAS)
Europastraße 4, 9524 Villach, Austria
Phone: +43 4242 90500
c.ungermanns@fh-kaernten.at
w.werth@fh-kaernten.at

Abstract - This paper describes the realization of a modern flexible production unit – as output of the international SIAT project "Koop Flexible Automation", which combines various disciplines of process automation, e.g. robotics, process control for CNC-based manufacturing, image processing and analysis [1]. It will be also shown how this production unit is used in education for trainees with different levels of previous knowledge. For this purpose a modular program was developed and a startup with pupils, students and employees of SMEs (Small and medium enterprises) has been performed. The concept of the educational training and first experiences will be discussed.

I. INTRODUCTION

Today's production processes need both flexibility and a high level of automation [2]. Beside these two manufacturing aspects an important customer requirement is the quality of the final product. Therefore within the international SIAT project "Koop Flexible Automation" various flexible cells have been designed. These production units are used in teaching modern automation topics for different target groups. Figure 1 shows the flexible unit of the Carinthia University of Applied Sciences in Villach. It covers all proposed aspects: robotics, flexibility, automation and quality management. The device consists of a transportable part, which can be also used separately in a lecture room and easily decoupled from the production CNC-machine and the CNC-tool. The objective of this unit is on the one hand the implementation of a flexible, fully automated production line with special emphasis on robotics and quality aspects, on the other hand the possibility of sharing this knowledge with pupils, students and SMC (small- and medium- sized companies). It is important to mention that the system was constructed which especially fulfills the didactic demands on teaching and learning.

Due to these objectives the central part of our systems is an industrial robot. This can be seen in the most left part of Fig. 1 and in Fig. 4. Beside that an optical inspection system was designed to produce relevant data for the quality control process.

As an overview the entire process is shortly described in the next section. Then the specific training modules at CUAS are mentioned and two training units are described more detailled.

Figure 1: FlexCell

II. PROCESS AUTOMATION

The coaction of all units is described in the following section.

The process, shown in Fig. 2, starts with the manual loading of the unprocessed part into the system. In *S1*, the first optical inspection system determines the position, the size, and the orientation of the part and communicates this information to the robot. The robot handles the part into the milling machine (*S2*) where they get labeled. After the processing is done, the robot handles the part to *S4* (drying station).

Next, the robot handles the part into *S1* where a second optical inspection system reads the labeling. After this step is complete, the robot handles the part again to *S2* where is it milled. After an ultrasonic cleaning (S3) and a drying step (S4) the finished work piece is optical characterized with a high resoluted optical measurement system (*S5).* The measured data from all optical inspection systems is stored in a central database for online statistical analysis. Finally, the robot handles the part to *S6* where, depending upon the measurement result from *S5* and the online analysis, the part is classified as OK, out of control limit or scrap (out of specification). The process automation also allows for a classroom mode, where the CNC milling machine is absent. Instead, a placement area is present where the teacher can exchange an unprocessed part by a processed part.

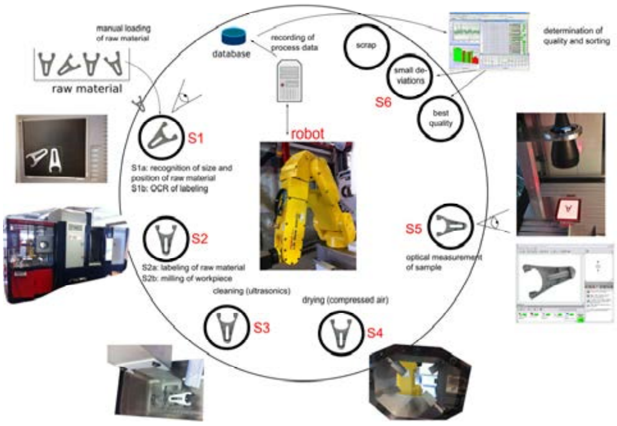

Figure 2: FlexCell Process Automation Overview

III. Flexible Training

Due to different flexible units designed and used by the project partners a lot of specific training modules have been prepared during the project. Furthermore teachers and researchers in different fields of automation processes can impart their expert-knowledge. In the following Fig. 3 a summary of the prepared modules is given. Note that also an estimated duration for each module was proposed.

Module	Hour
CNC Manual Programing (milling + turning)	8
CNC Cam Programing (milling + turning)	8
Robotics basic	8
Robotics advanced	6
Quality management	4
Optical measurement systems	4
Process control	6
Machine control and embedded systems I	6
Machine control and embedded systems II	6
Safety basic	5
Safety advanced	3
Design I	6
Design II	6
Economics and organization	8

Figure 3: Training modules overview

The red colored part in the figure indicated the modules prepared at CUAS which are described in the next section.

IV. Training Modules at CUAS

In this section the specific training parts, which have been given at CUAS are described in details. Basically the training modules where presented to two different target groups. First of all pupils and undergraduate students have been trained, secondly the same topics where presented to teachers in terms of a train the trainer program. It has to be mentioned that the main objective of the second training program was only to instruct our partners about our specific contents and pedagogical methods. This is important because all students are trained in different topics by trainers from all partners. During the project it turned out however that an arbitrary exchange of teachers would need intense and time consuming teaching procedures.

The main focus in all cases was to explain the proposed topics by the FlexCell device. In particular at our location four modules have been trained: robotics, image processing, profibus and statistical process control (SPC). The training program for the modules robotics and SPC are described in details, whereas for the remaining modules just a summary is given.

A. *Robotics*

Due to the fact that the industrial robot represents the main part of the FlexCell a teaching module “Robotics” is seen as very important. In flexible automation controlling a robot is one of the essential technical tasks an engineer has to cover [7]. On the other hand robotics includes a lot of different sophisticated problem-settings. In details we mean for example analysis of robots dynamical behavior, trajectory planning and robot control. Most of them need some prior technical knowledge or at least some “technical feeling”. Furthermore there is usually the need of an advanced mathematical background if the participant of a training program has to understand and solve robotics tasks in details. In addition some general conditions related to the training program had to be fulfilled:

- The pupils came from different schools in Austria and Slovenia.
- The schools are vocational schools.
- The pupils participated the third year (high school).
- Each training module was given within 4 hours.
- Participants got detailed materials for further discussions in class, no pre-education by the teachers was given.

Furthermore all the contents in class as well as all lecture notes have been presented or prepared in English. Due to the fact that our participants – mostly pupils – did not have the desired knowledge we proceeded in the following way. First of all the main tasks robots in a flexible automation process have to perform are discussed and explained by the FlexCell device, e.g.

- General task description
- Basic elements: joints, coordinates
- Prepare the task for the robot: Trajectory planning
- Make the robot move: Joint control

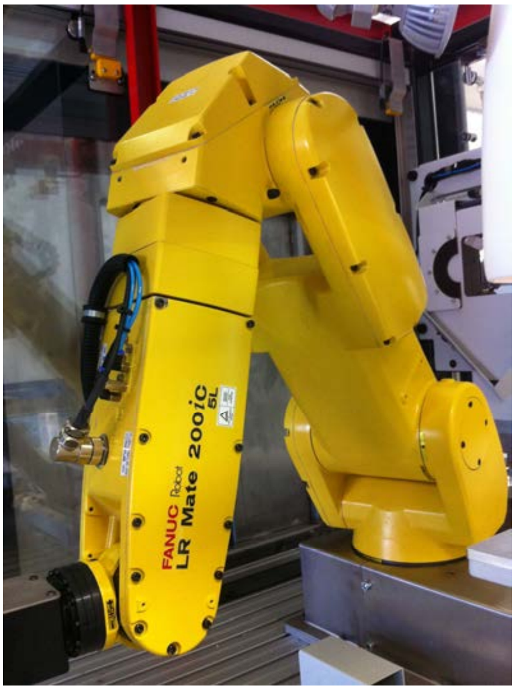

Figure 4: FlexCell Robot

At that point two important aspects have to be discussed. First some theoretical background related to robotics is necessary to understand the robots behavior. Secondly simulation tools are always used to verify a suggested performance or control of the robot. Considering the FlexCell - robot in Fig. 4 was deemed to be too difficult and but also not necessary to achieve our pedagogical goals. Hence a simpler robot-system was selected to elaborate on some selected task in details. In the following figure (Fig .5) the discussed system is given. It consists of two DC-Motors (so two joints) and a flexible link. The main task of the robot system is to command the x and y position of the tip of the robot.

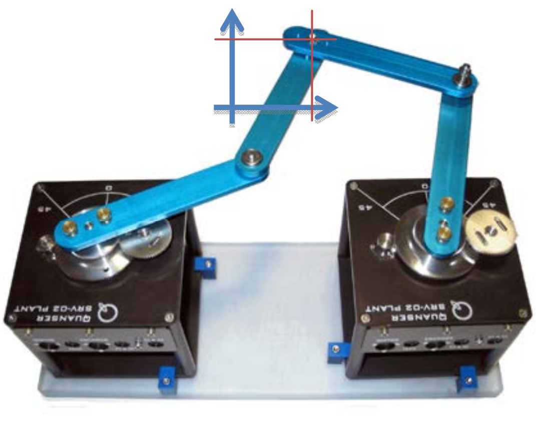

Figure 5: 2 DOF robot experiment

Hence the open tasks which are needed for the FlexCell robot can be discussed and solved in the same way at the simpler system, e.g.

- Kinematic model and dynamic model of a robot
- Control of a joint
- Simulate the robots movement
- Implement the controller to a real word system

In all of our courses MATLAB/SIMULINK is a standard tool for simulation of robotic systems and also for implementation of different control concepts at real world experiments. Deriving and discussing the mathematical model was the first step. Instead of deriving the mathematical model using analytical methods – which have not been well known to the pupils – an experimental setup using SIMULINK given in Fig. 6 was used to get the required data of the system, e.g. gain and time constants. Thereby black box models and suitable system responses (e.g. step response) have been considered. The determined parameters have been associated to the selected black box model (second order system) that describes the dynamic behavior of the joints.

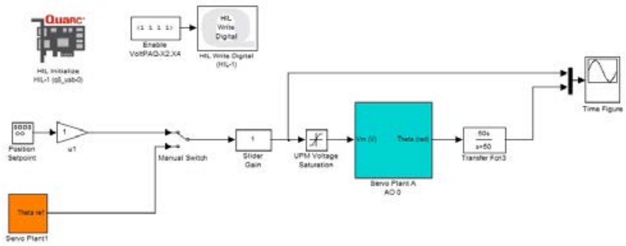

Figure 6: Experimental Setup

The same environment was taken to explain the need of a feedback concept (Fig. 7) and to discuss standard controllers like PID-controllers.

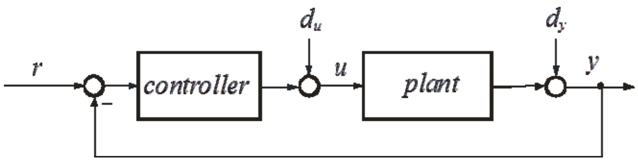

Figure 7: A feedback system

The next step was to control the two joint individually by experimentally found controller. Thanks to the used environment the result from our real world system (robot) are directly shown in class. To control the tip of the robot the connecting links have to be considered. So both the kinematic and inverse kinematics of the robot could be introduced and explained quite naturally. Implementing the kinematic models and performing the control of the tip finalized the robotics training session.

B. Profibus

The third part- profibussystem [3] contained the communication between the stages. Therefore a profi bus is used, which coordinates the communication in the FlexCell. The teacher was talking about the needs and the advantages of the use of a bussystem in an automation process. Furthermore was presented how the protocol is built, which information and messages are included and how the access to the data is managed. A big point was also the safety integrity. There are many norms and requirements for which application the bussystem is used. The profi bus is authorized up to SIL3 (safety integrity level).

C. *Image processing*

The topic of the fourth part was image processing [4]. Due to that the measurement process is done by cameras, the presentation was about how cameras could be used for such an application. One point was to discuss how a picture has to be manipulated so that this information can be evaluated. Therefore the questions about how a colour can be described and which patterns are useful were discussed.

D. *Statistical Process Control*

In addition to robotics and image processing, quality management is an essential part of educational program. Nowadays nearly in every modern industrial enterprise a quality management system is installed and make use of statistical methods to guarantee best possible stability of the manufacturing line. Very common is the concept of "Statistical process control" (SPC) [5,6]. In this section the application of SPC to FlexCell is demonstrated and described.

Experimental setup: after installing and calibrating the optical measurement system, a set of 50 work pieces was produced and measured. Fig. 8 shows three characterized feature sizes of the sample

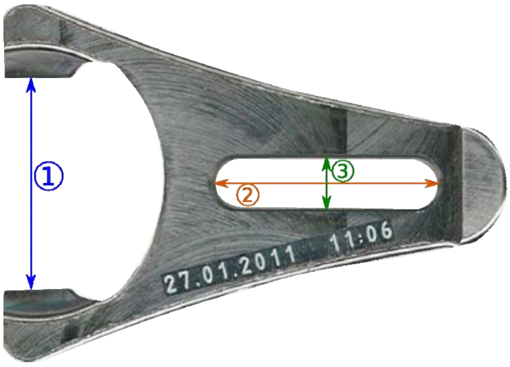

Figure 8: Work piece and measurement points

In Fig. 9 the dataset of feature size 1 (blue arrow) is represented as a cumulative frequency plot for all work pieces.

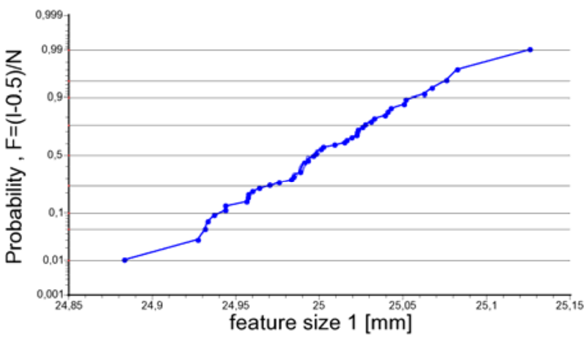

Figure 9: Probability plot of dataset

It is clearly seen from Fig. 9 that the readings are gaussian distributed as expected for a stable production since there is a linear curve in the probability graph. Therefore the prerequisites for the implementation of SPC are fulfiled. Now the upper control limit (UCL) and the lower control limit (LCL) are required for the control chart and can be obtained by the formulas

$$UCL = \bar{x} + 3s \tag{1}$$

and

$$LCL = \bar{x} - 3s \tag{2}$$

In the presented case it is UCL = 25,14 mm and LCL = 24,86 mm. The associated control chart is shown in Fig. 10.

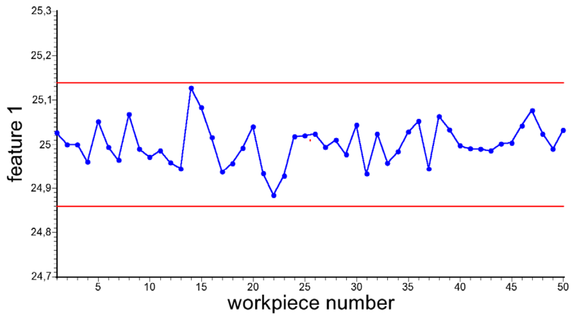

Figure 10: Control chart of stable production

An additional set of 50 work pieces was fabricated. But this time the dimensions were varied intentionally for didactic reasons. The purpose of the variation was to simulate production problems and to check, if the fully automated system is able to detect these problems. The basic criterion for an unstable production is the violation of the control limits. The probobility that these limits are exceeded randomly is only 0,26%. Therefore a violation is interpreted as an instability of the overall process. In this case the production is stopped immediately and a message pops up to the operator. Corrective actions must be taken by the responsible process engineer. Besides the work piece is placed to the scap slot.

In Fig. 11 the violation of the control limits are automatically detected and clearly marked by the software.

Figure 11: Control chart of unstable productio

V. Discussion and Outlook

In this paper the project FlexCell, which combines various disciplines of industrial automation, like robotics [7], image processing and analysis and CNC-based manufacturing has been described in details. Main focus was to present the essential training modules given at CUAS in Villach.

It has been shown that the device can be successfully used for teaching pupils and students of different levels of education. Furthermore the process will help technical staff of small and medium-sized companies to create modern solutions for their own process automation tasks. An industrial robot represents the central part of the construction. Therefore robot handling and programming is of particular importance in the training modules. Additionally the great relevance of quality management in any industrial process is clearly manifested in the training program of the project.

Figure 12: Training session in Villach

It is important to mention that the manufacturing process is of course not limited to the considered items described in the paper. It can be used to build and to analyze different CNC-based production lines, especially for small-batch production. Furthermore the proposed process device can easily be extended to additional tasks that have to be considered in an adapted or even new automation process.

Fig. 12 shows one of the training sessions given at Villach. Pupils participating at the training program gave very positive feedback to the presented sessions. Most of them pointed out that the combination between basic theoretical knowledge and practical demonstration was well balanced.

The project is continued in the way that both the knowledge - related to the designed automation devices - as well as the training program is extended to education institutions in Turkey and Croatia.

Acknowledgment

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References

[1] www.flexcell.eu

[2] J. Love, *Process Automation Handbook: A Guide to Theory and Practice,* Springer, 2007

[3] J. Weigmann, G. Kilian, *Decentralization with PROFIBUS DP/DPV1: Architecture and Fundamentals*, Wiley-VCH, 2004

[4] T. Klinger, *Image Processing with LabVIEW and IMAQ Vision*, Prentice Hall, 2003

[5] J. S. Oakland, *Statistical Process Control*, Taylor & Francis, 2007

[6] T. Stapenhurst, *Mastering Statistical Process Control: A Handbook for Performance Improvement Using Cases*, Butterworth Heinemann, 2005

[7] B. Siciliano, O. Khatib, *The Handbook of Robotics*, Springer, 2008

[8] C. Madritsch, C. Ungermanns, T. Klinger, W. Werth, *An Innovative Industrial Automation System Showcase for Quality Management and Statistical Process Control Lectures*, MIPRO 2012, Croatia, 2012