Using open source software CNC controllers and modular multi-axis mechanical structure as integrated teaching environment for CAD/CAM/CAE training

R E Breaz¹, S G Racz¹, C E Girjob¹, M Tera¹ and C Biriș¹

¹ Lucian Blaga University of Sibiu, Faculty of Engineering, Victoriei, 10, Sibiu, 550024, Romania

Email: radu.breaz@ulbsibiu.ro

Abstract. Open source CNC controllers, such as Linux CNC are used more and more because they are open source projects and consequently are available for free. Moreover, these controllers are highly customizable, and their capabilities are close to the commercial solutions. The paper presents how using Linux CNC controller and a modular structure of a multi-axis CNC machine-tools, built by a commercial company, an integrated environment for training students in implementing CAM techniques was developed. Aside the CNC controller and the machine-tool, a CAM software package was used for programming complex machining operations. The kinematic model of the machine was built, for the user to be able to simulate, in a realistic way the multi-axes machining operations. The integrated teaching environment enable the users to be trained in CNC programming for three to five axes machining operations. Advanced programming strategies, such as tool center point management (TCPM) can also be tested.

1. Introduction

CNC machine-tools are the backbone of the modern manufacturing industry, as the most used technological equipment. Even if additive manufacturing is spreading fast, subtractive manufacturing will keep its ground for a long time to come. Moreover, hybrid solutions of CNC machine-tools are launched on the market, which encompass both additive and subtractive manufacturing capabilities.

Being able to implement CNC machine-tools in modern manufacturing systems, in conjunction with the use of CAD/CAM/CAE techniques is a competence of the greatest importance for mechanical, manufacturing, and industrial engineers. Thus, CNC training is provided for students in technical universities all over the world as core activity within many subjects form the curriculum.

CNC training, from a state-of-the-art point of view should be regarded as the integration of CAD/CAM/CAE techniques in a machining environment based upon CNC machine-tools. 3-axis and 5-axis milling machining centers are the core of the modern CNC machine-tools [1, 2].

However, commercially available CNC machine-tools, particularly 5-axis machining centers are very expensive and their use for training purposes in technical universities could be problematic due to cost-related issues.

The approach presented in this paper is based upon the use of a modular, low-cost 5-axis machining center, specially developed for training, and controlled by means of an open-source CNC software controller.
2. Hardware CNC controllers vs. software CNC controllers
Commercially available CNC multi-axes CNC machining centers are controlled by means of hardware CNC controllers, specifically developed for a certain class of machines. Hardware CNC controllers are based upon the specific hardware embedded on the machine and consequently are not configurable. In opposition, as presented in figure 1, open source software controllers [3-5] are designed to be highly configurable and to be integrated with any kind of hardware modules existing on a CNC machine-tool.

![Figure 1. Differences between hardware and software CNC controllers](image)

Hardware CNC controllers are fitted with specifically designed Human-Machine Interface (HMI). Usually in the form an operator panel, the HMI has hardware buttons and knobs for each specific function. Designed to provide the user with ease of access and ergonomics, these HMI’s are far superior to the ones provided by the open source software controllers which are usually PC-based. It means that usually no buttons and knobs are available for the user and every function is implemented at the level the computer keyboard and mouse.

Moreover, CNC hardware controllers are fitted with a lot of supplementary capabilities, such as machining simulation, collision control, tools management, depending on the vendor and on the price the user is willing to pay for them. The software CNC controllers are fitted with a reduced set of capabilities, strictly necessary for controlling the machining process on the CNC machine-tool. However, modern CAM software packages can compensate the reduced set of capabilities of the software CNC controllers by providing them off-line.

Hardware CNC controllers are supporting various NC programming systems (such as ISO 6983 G-code, Heidenhain TNC and many others) depending on the manufacturer, while software CNC controllers are usually supporting only ISO 6893 G-code programming system.

3. CNC machine-tool and CNC controller
The main objective of the research was to develop a low-cost, yet effective integrated layout for CNC training, in the form of a CNC milling machining center.

A 3-axis CNC industrial machining center, figure 2a, developed by General Numeric company from Brașov was fitted with two supplementary rotary axes [6,7], to increase its technological capabilities. The rotary axes unit (figure 2b) consists of two ISEL specialized modules, DSH-S (tilting) and RDH-S (rotary). The unit is based upon harmonic drive manufactured by ISEL. Linux CNC [8] software controller was used to control the machine. Being a software CNC controller made the operation of adding two supplementary axes a simple one, due to the high configurability of the
controller. The operating panel of the machine, PC-based HMI, (figure 2c) consists of a PC using Linux as operating system.

All machine axes are fitted with servomotors and consequently all motion control systems on each axis are closed-loop ones, a fact which guarantees high machining accuracies.

The machine was designed by General Numeric company in a modular, reconfigurable way, a fact which made the task of adding supplementary modules an easy one.

The machine frame and some other structural elements were designed and manufactured in house by the company, while the servomotors, transducers, transmission systems, other actuating and control modules were purchased from specialized vendors (especially ISEL company).

![Image of the modular 5-axes CNC milling machining center, the rotary axes unit, and the operator panel.]

**Figure 2.** The modular 5-axes CNC milling machining center (a); the rotary axes (B, C) unit (b); the operator panel (c).

### 4. Integrated teaching environment

The CNC milling machining center was designed as an integrated teaching environment. The main objective was to provide the students the necessary training to implement CAD/CAM/CAE techniques in machining systems, figure 3.

Training in the field of CAD techniques is facilitated by making the 3D model of the machine, which was necessary for developing its kinematic model [9]. Moreover, for each part machined on it, the students must build the 3D model of the part, which furthermore will develop their abilities in using CAD techniques.
Training in the fields of CAD/CAM/CAE techniques

The core of the integrated teaching environment is intended to be the training in the field of CAM techniques. The students will program the machine, using dedicated CAM software packages to machine parts by means of 3D operations (which require only the use of X, Y, Z linear axes) and by means of 4&5 axis machining operations (which requires the use of both linear and rotary axes). The students will be also trained to develop specific post-processors for Linux CNC software controller in every CAM software package used to program the machine, Is it here to mention that there are no limitation for the CAD/CAM software packages to be used in conjunction with the machine.

Training in the field of CAE techniques will be ensured be configuring the hardware modules of the machine using Linux CNC and studying and compensating the machining accuracy. It is her to be noticed the fact that the students will also be trained to build the kinematic model of the machine, which is required for realistic simulation of 4&5 axes machining operations, figure 4.
Advanced CAM techniques such as realistic toolpath simulation, TCPM (tool center point management) and collision control (implemented by developing the kinematic model of the machine [9]) could also be studied and implemented by using the integrated teaching environment.

The part presented in figure 5a was subject to an application for the post-graduate students (at master studies. It is here noticeable the fact that the part requires 4&5 axes operations to be machined (figure 5b).

The model of the part was provided by Sonnek Engineering company, form Șura Mică, Sibiu county.

An example of the machined part is presented in figure 6.
5. Conclusion
A complex research and teaching program which involved the development of an integrated teaching environment for CAD/CAM/CAE techniques was presented in this work. The main steps of building a 5-axes CNC milling machining center in a modular manner, in co-operation with an industrial company as the core of the teaching environment was introduced.

By using the integrated teaching environment presented in this paper, students are trained in designing and modeling individual parts and assemblies (CAD techniques), in programming CNC machine-tools using specialized software packages (CAM techniques) and in analyzing the complex kinematic of the machine-tool by building its kinematic model (CAE techniques). Consequently, the main objective enounced in the beginning of this paper, training the students to be able to implement CNC machine-tools in modern manufacturing systems, in conjunction with the use of CAD/CAM/CAE techniques, can be fulfilled by means of the proposed integrated teaching environment.

The main training directions and actions facilitated using the proposed integrated teaching environment to train the engineering students were also highlighted. An example of an application which involves the machining of a complex part on the proposed CNC machine-tools is also presented in the paper.

6. References
[1] Bologa O, Breaz R E, Racz S G and Crenganiş M 2016 Procedia Comput. Sci. 91 184–92
[2] Bologa O, Breaz R E, Racz S G and Crenganiş M 2016 Procedia Comput. Sci. 91 683–89
[3] Tianliang H, Chengrui Z, Riliang L and Peng L 2009 Int. J. Adv. Manuf. Technol. 40(5) 541–552
[4] Park S, Kim S.-H and Cho H 2006 Int. J. Adv. Manuf. Technol. 27, 788-796
[5] Sperling W and Lutz P 1996 Robot Manuf. 6 613–620
[6] Suh S-H and Lee J-J 1998 J. Manuf. Sci. Eng. 120(1) 120-28
[7] Chen Z C, Dong Z and Vickers G W 2003 Comput. Ind. 50 319–31
[8] *** http://www.linuxcnc.org/
[9] Chicea A L, Breaz R E and Bologa O 2015 Applied Mechanics and Materials 809-810 1004-09

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