LABORATORY CNC MACHINE FOR EDUCATION OF STUDENTS IN CONTROL SYSTEMS ENGINEERING∗

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Abstract. *Modern states seek to build a society based on knowledge, and in this sense, the IPA project ADRIA HUB aims to connect students, universities and companies into a single entity in which each party realizes many benefits. Practical part of this project consists of the pilot projects related to the improvements in the woodworking industry. For the purpose of the project realization, a specific laboratory CNC machine was designed and implemented by the Laboratory for Modeling, Simulation and Control Systems at the Faculty of Electronic Engineering in Niš. CNC machine, presented in this paper, is now actively used in laboratory work. Students have the opportunity to gain practical knowledge and master the techniques of controlling this machine as part of their studies in Control Systems Engineering.*

Key words: *ADRIA HUB, CNC machine, education, control system engineering*

1. INTRODUCTION

IPA project "Bridge technical differences and social suspicions contributing to transform the Adriatic area in a stable hub for a sustainable technological development", with the Faculty of Electronic Engineering in Niš as one of the participants, tend to promote the development of the knowledge society through strengthening the relationship between the business community and universities. More details about ADRIA HUB project, its goal and work packages are given in Section 2.

Final part of the project realization includes validation via implementation of pilot projects related to the real world technological problems in woodworking industry by

connecting faculties, students, and appropriate companies. Laboratory for Modeling, Simulation and Control Systems at the Faculty of Electronic Engineering in Niš seized that opportunity to design and construct specific laboratory CNC machine to be used not only for the realization of the project but also for education of the students of Control Systems Engineering study program. Laboratory CNC machine, its design, construction, main parts and functionalities are described in details in Section 3.

Section 4 describes how designed CNC machine can be used in education of Control Systems Engineering students through laboratory work as a part of mastering various techniques of control. The integrated controller is easy to access and program and provide practical verification of designed programs. Introduction course in CNC machine has the aim of specialization in the following professional competences: preparing machine for work and its maintenance, handling CNC milling cutter in manual mode, and handling CNC milling cutter in automatic mode. Machine can be used in the implementation of laboratory teaching in several courses (PLC, SCADA systems, System identification Process control, Telecontrol).

2. IPA PROJECT ADRIA-HUB

The relationship between the business community and universities is crucial for the development of any country. The knowledge society is based on the availability and application of knowledge in all areas of life. Universities, as the main sources of knowledge, and industry, as the largest consumer of that knowledge are the two pillars of this kind of society. Academic institutions have two tasks related to their role: research in order to create a new knowledge and education in order to expand existing knowledge.

Promoting the development of the knowledge society is the main objective of the IPA project "Bridge technical differences and social suspicions contributing to transform the Adriatic area in a stable hub for a sustainable technological development", with the acronym ADRIA HUB. The project includes a total of 23 partners from 5 countries in the region, including the Faculty of Electronic Engineering in Niš, and is funded by the IPA Adriatic CBC Programme [1].

The main objective of the project is the creation of transnational network of higher education institutions and entrepreneurial organizations in the Western Balkans, in order to give support to universities to align education and develop research based on the needs of the economy. The secondary goals of the project are: to design a platform for the recruitment of highly qualified personnel, to create a database of scientific research services offered by universities in the Adriatic area, and to help transformation of knowledge into innovation [2]. This system provides the benefit of each of the participants: students invest their CV and competences, and in return receive employment opportunities; universities can adjust their plans and programs based on market analysis and to offer companies their R&D capacities; companies can search databases and employ qualified personnel as well as obtain solutions of competent university experts for their problems.

In this regard, the main activities of the project are:
- Adapting existing models for storing information about graduates and their competencies. To this end, goal is to build an innovative ICT platform for connecting graduates from all countries participating in the project with the requirements of the companies from the same countries for qualified personnel.

- Development of an integrated platform for classification of the research and development offer as well as the efficient transfer of technology. In that way, project unifies R&D offer of universities from participating countries and makes the experience and knowledge of university experts available to the companies and their needs. It also enables the exchange of experiences and ideas between the experts from different faculties. At the same time, after examining market needs, universities get an opportunity to adjust their curricula to these needs.

The project consists of the following work packages (WP): Cross-border coordination and project management, Communication and dissemination, Transnational education and development of ICT platform for graduates, Collaboration with the industry and the development of ICT Platform for R&D services, Exploitation of ICT platform for the development of technological knowledge, Transforming knowledge into innovation and technical evaluation.

The realization of the project is validated through the implementation of the technology pilot projects of importance to the industry. Specifically, the project results are being tested through solving several real problems in the wood industry by connecting faculties, students, and appropriate companies. In this regard, Laboratory for Modeling, Simulation and Control Systems at the Faculty of Electronic Engineering in Niš designed and realized specific CNC machine for laboratory environment which can be used not only for realization of the project but also for education of the students of Control Systems Engineering study program. It should be mentioned that CNC is not new in education of engineering students and there are several papers on that subject [3-5].

3. LABORATORY CNC MACHINE

For the purpose of the project realization and future education of students, a laboratory CNC machine in Fig. 1 was designed and implemented. The working area of the machine is 800x600mm. Basically, machine is a 3D milling cutter, whose functions are processing wood, printing MDF (Medium Density Fiberboard) electronic circuit boards, and cutting small density materials such as polystyrene. For coordinated movement of the tool, PLC (Programmable Logic Controller) in the category DVP-PM *Series Motion Controller*, manufactured by DELTA company, is used. Specified controller can control route, direction, size and speed of the shift of the working parts of machine. To define the mutual position of the tool and the object of processing we usually use rectangular Cartesian coordinate system X, Y, Z. Each axis represents the independent support motion, translational to the directions of coordinate axis or rotational around them. The main drive of the machine is the SPINDLE motor for tools, manufactured by AREL. The strength of this three-phase motor is 1.4 kW with maximum speed of 20000 rpm. Within the machine we can also find two identical servomotors with power of 0.4 kW and speed 3000 rpm for tools positioning. Speed regulation is achieved through frequency converters VFD-EL (manufactured by DELTA) with frequency range 0.1-600Hz. The machine can also be used as a power scraper. In this case, for the process of scraping two extra movements (longitudinal and transverse) i.e. two controlled axes on a CNC lathe (X, Z) have to be used.
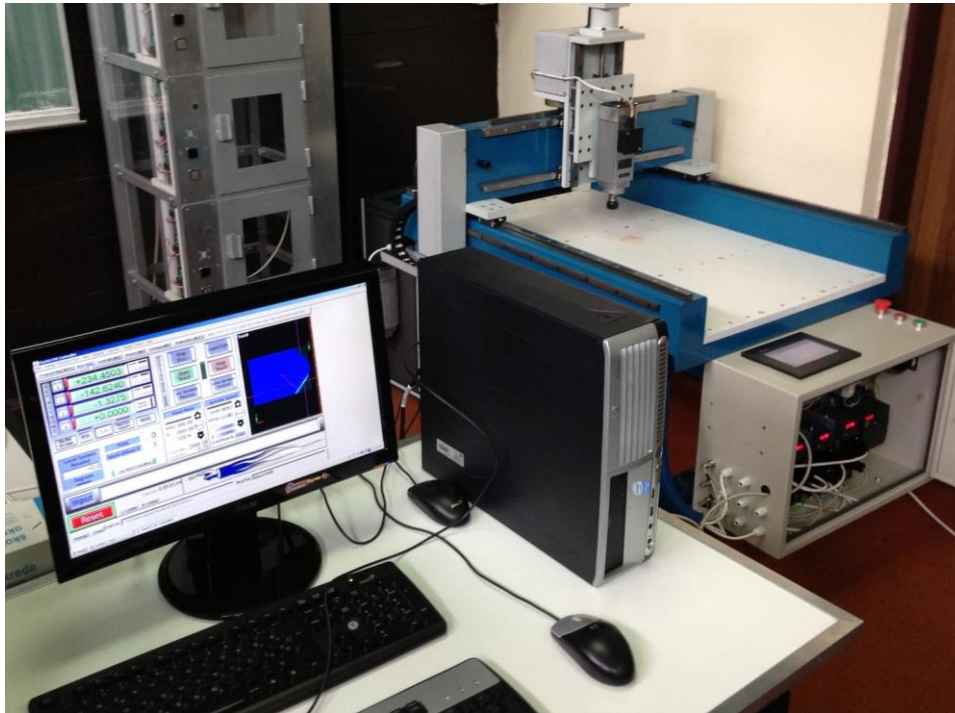
Fig. 1 Laboratory CNC machine

Machine part of the CNC machine has four characteristic points that are of elementary importance during processing of materials. These are:

- Reference point − a limit point of the working space, used for establishing a measurement system of the machine.
- Zero point of the coordinate system of the machine.
- Zero point of the processing selected by user.
- Starting point from which the tool starts processing in the programme mode.

After defining characteristic points, the next task is to form the driver program. Elementary machine control can be generalized through the following steps:

1. Start of the program
2. Loading the coordinate system
3. Loading data about the tool
4. Turning spindle on, defining the rotational speed and the speed of auxiliary movement
5. Positioning tool by working trajectory on each axis from the starting position to defined position
6. Processing of the working materials
7. Completion of processing
8. Positioning the tool to the starting position
9. End of the program

The entire device is based on the programming in the G code. That code is symbolic and commonly used to control the processing operations of computer numerically controlled (CNC) machines. G codes are supported by the modern design systems (CAD programs). This means that after the implementation of the project task in e.g. AUTO CAD we can easily perform synchronization of the final project and control logic of the CNC machine by using the G code. Machine receives the necessary coordinates and measured values required for processing and, after that it can perform material processing.

Laboratory model of CNC machine is controlled in software package Mach3 as 6-axis CNC machine controller. Mach3 operates on Windows platforms and can be used to control the motion of motors by processing G-Code. Mach3 is customizable software with many purposes: generating G-Code by simple wizards, translating M-Codes and macros in VBScript, multiple relay control, manual pulse generating, touch screen control... Some of functionalities of Mech3 CNC Controller are illustrated in Figures 2, 3 and 4.

Designed CNC machine can be used for implementing pilot projects in woodworking industry related to WP6 of ADRIA HUB project (Transforming knowledge into innovation and technical evaluation). Some of the relevant pilot projects are:

- Suppressing the occurrence of low frequency vibrations.
- Automatic balancing of used woodworking tools.
- Use of white light to measure the microscopic parameters of the wood surface.
- Design of an optimization algorithm for CNC machine tool path.
- Research on alternative production materials.
- Design of optimization algorithms for nesting of "panel squared parts".
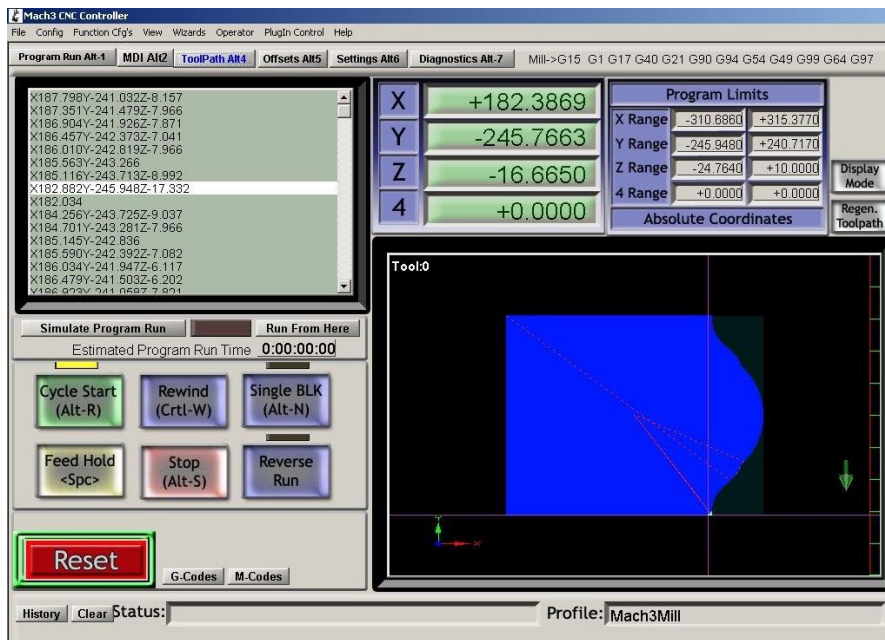- Developing algorithms for wide images drawing (engraving).
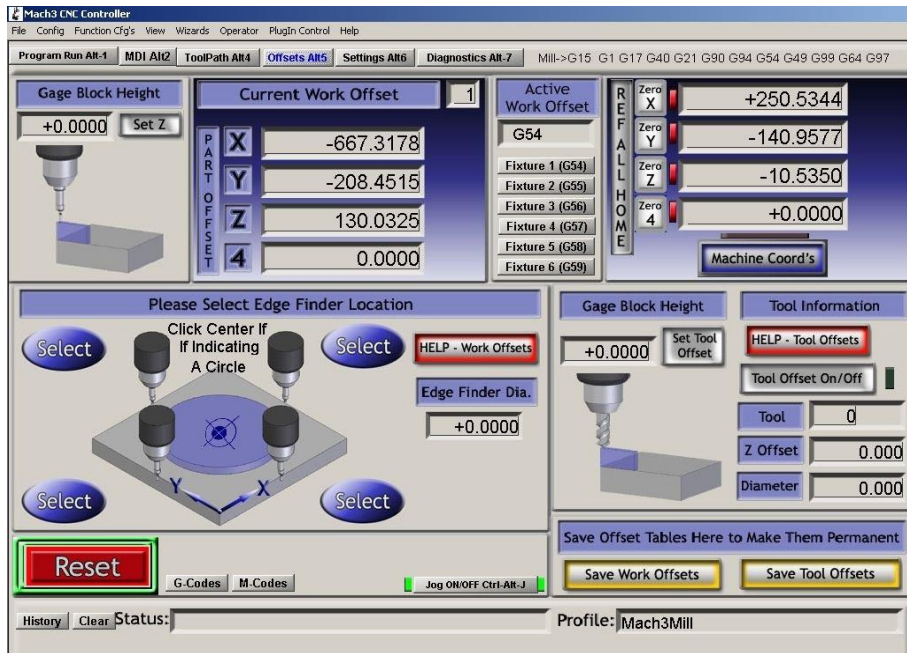

Fig. 2 Mach3 software – window ToolPath
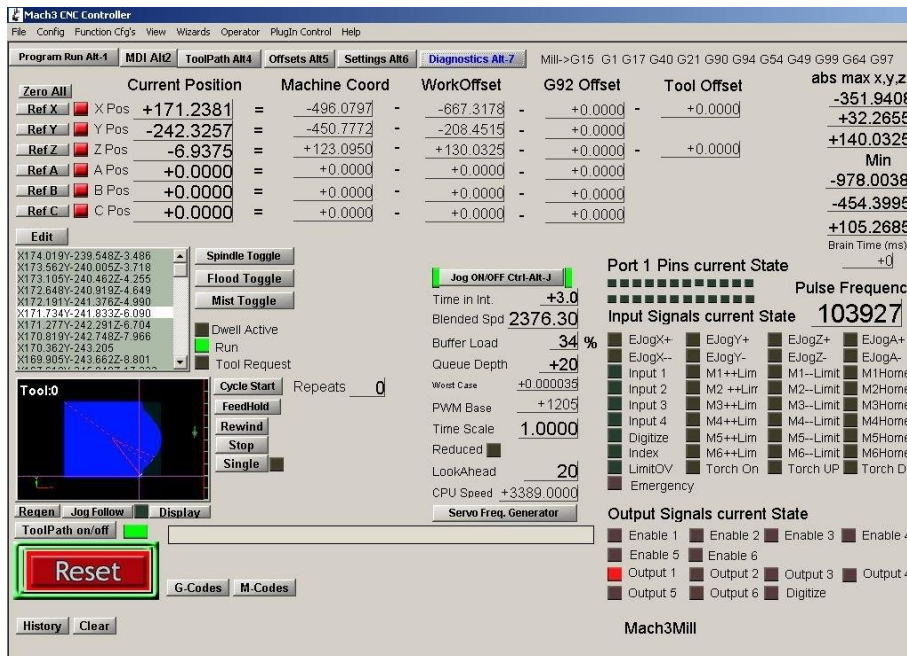
Fig. 3 Mach3 software – window Offsets

Fig. 4 Mach3 software – window Diagnostics

4. CNC MACHINE FOR EDUCATION OF STUDENTS

Presented CNC machine can be actively used in laboratory work as a part of educational process for students of Control System Engineering studies. Students have the opportunity to gain practical knowledge and master various techniques of control. The integrated controller is easy to access and program and provide practical verification of designed programs. Security features of the device are at a high level so that the risk of injury due to improper use is minimized. Another advantage is the on-line control, where the students, after the implementation of their programs, can, during the process of the machine work, perform certain corrections and changes (speed of the control characteristic points, frequency). The existing PLC can be also integrated into SCADA system. In this way the device can be used in the implementation of laboratory teaching in several courses (PLC, SCADA systems, Process control, Telecontrol).

The entire education process is organized with the aim of specialization in professional competences: preparing machine for work and its maintenance, handling CNC milling cutter in manual mode, and handling CNC milling cutter in automatic mode. Students must, first of all, be aware of the need for applying the defined procedure of technological processes. Potential errors may result in bad final products, damaged tools, machine or even an injury at work. Students' training in handling CNC machine is organized within four blocks of laboratory exercises:

1. Introduction – occupational safety and safety measures

During the exercises, students should get familiar with the basics of occupational safety in the laboratory. The most common types of accidents and injuries at work that may occur will be explained, as well as safety tips for operating the machine. The most common causes of accidents during work with the CNC machine can be: contact with the moving parts, impact of the exploded tools and materials, mechanical failure on the machine related to the incompetence of users.

2. Preparing the machine for work and maintenance

Within these exercises, students should be trained to maintain workplace and equipment. Within the exercises, students will receive training that consists of:
- Cleaning the processed objects after removal from the machine, and, if necessary, protection of objects against corrosion.
- Cleaning the machine and work area.
- Checking the oil level and lubrication of sliding parts.
- Checking and replacing the coolant, filters and tanks.

3. Handling CNC machine in manual mode

Upon completion of the exercise, students should be able to set working materials and tools in working position on the basis of technological specification. They will learn how to control the milling cutter in manual mode through the following tasks:
- Introduction to the technological documentation where students perform an analysis of schematics of simple work pieces and plan for clamping the cutting part.
- Practicing of dimensional measurements on different working objects.

- Preparation of CNC machine where students practice individually the setting of prepared tools. After that, students practice setting, centering and clamping the processing materials.
- Manual movements of tool carrier in the direction of X, Y and Z axes where these movements are performed using the buttons on the control panel. During the exercise, students change speed and degree of displacement of the tool carrier.

4.   Handling CNC machine in automatic mode and programming

The aim of these exercises is that students perform verification of compliance of the prerequisites for the work of the machine in automatic mode. They are required to know how to successfully read, write and modify program code as well as to successfully operate CNC milling cutter in automatic mode. Within this block of exercises, students will learn how to implement the simple programs, main and auxiliary functions within the program. They will also see different situations where it is necessary to interrupt and stop the operation of CNC machine. After processing of the work piece is finished, students have to analyze the results and find possible mistakes during operation. Realization of this block implies set of laboratory exercises designed in such a way that students adequately acquire basic knowledge about the processing different materials using CNC machines: drawing letters and different shapes, shaping geometrical bodies, drilling holes, hollowing out different surfaces on metal and wood plates.

All these exercises will be starting point for including CNC machine in laboratory work of several courses of the study program Control Systems. Within the course Process Control, CNC machine will be one of the mandatory devices for mastering practical control. The machine will be also used in the context of the courses System identification where students will have to mathematically describe dynamics of the machine and perform its simulation in Matlab. Different control algorithms will be designed through the course Regulation of Electrical Machines and Drives. Further, students will have to design machine control using PLC devices of different manufacturers. Within the course SCADA Systems, students will make SCADA environment for monitoring and control of CNC machine and processing materials from a remote computer.

5. CONCLUSION

Laboratory for Modeling, Simulation and Control Systems at the Faculty of Electronic Engineering in Niš designed and constructed specific laboratory CNC machine with two purposes. One is to participate in implementation of pilot projects related to the real world technological problems in woodworking industry as part of realization of IPA project ADRIA HUB. Second is to improve practical laboratory work for students of Control Systems Engineering study program. This paper first gave some details about the project, its goal and work packages. Then, laboratory CNC machine, its design, construction, main parts and functionalities were described as well as its possible applications in education of students.

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