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CNC SIMULATOR BASED ON LINUXCNC CONTROL AND PROGRAMMING SYSTEM

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Abstract: *This work presents a CNC simulator that was created based on the need to design and form a working environment within which training of operators and programmers of CNC machines will be carried out in an economically profitable way. The CNC simulator is based on a Raspberry PI 5 microcomputer and LinuxCNC open-source software system intended for control and programming of CNC machines and industrial robots. The LinuxCNC software system was configured according to the set requirements and current needs. With the control system configured in this way, two working environments were formed that are currently used in the realization of laboratory exercises of the teaching process of the higher education institution. In the framework of the paper, the created working environments are described, and in the conclusion, the observations obtained by analyzing the results achieved using the CNC simulator are presented.*

Keywords: *LinuxCNC, Raspberry PI, CNC machine programming, Virtual CNC machine, Complex CNC machine*

1. INTRODUCTION

With the rapid development of the industry, the need for CNC machine operators and programmers is increasing. Training for the operation and programming of CNC machines, in addition to the theoretical part, also includes practical work in which the acquired theoretical knowledge is applied. Regardless of whether the training of personnel is carried out within the production plant or within institutions that have personnel qualified to conduct training, the following problems arise: i) the need for CNC machines intended only for training, ii) the risk of injury during training, iii) the possibility of causing significant damage to the equipment, etc. Following the example of well-known brands such as HAAS and FANUC (Figure 1), the authors of this paper have developed their educational simulator, which they have called “CNC EduSim”.

Figure 1. CNC simulator: a) HAAS [1], b) FANUC [2]

The developed and built CNC EduSim simulator, in addition to being significantly more affordable, also has features that branded simulators do not have, which will be discussed in the following text.

2. DESCRIPTION OF THE EDUCATIONAL SIMULATOR

During the development of CNC EduSim, a prototype simulator was first built. The goal was to create a simulator with minimal investment, based on which the justification for further development and construction of a larger number of simulators would be established. After testing the built prototype, it was determined that the simulator can be used for educational purposes and that it fully meets all needs.

On the built prototype of the simulator, certain defects were observed that disturbed comfortable work. Also, when working on the prototype, one did not fully get the impression that one was working on the control unit of a CNC machine. After removing the defects and redesigning the housing, several simulators were built, which are shown in Figure 2.

Figure 2. CNC EduSim simulators built

The developed and built CNC simulators are primarily intended for the training of operators and programmers of CNC machines. For this reason, during the development, care was taken to ensure that CNC EduSIM meets the set requirements, such as:

· to look like commercial simulators or the control panel of an industrial CNC machine,

· to have external connections that improve the functionality of the simulator,

· that it can be used for training operators and programmers for CNC machines of different purposes and structures (CNC lathes, three-axis CNC milling machines, multi-axis CNC milling machines, CNC wire-cutting machines ...),

· to be able to simulate tool movements based on G-code programs that are manually written or generated using one of the available CAD/CAM software systems,

· to be able to simulate tool movement based on parametric G-code programs,

· to be able to simulate the operation of a CNC virtual machine during the machining process, which is driven by identical control signals as the real machine,

· that it can be easily adapted to new requirements.

The developed CNC EduSim (Figure 3) consists of a touch screen, an alphanumeric keyboard, and a series of switches and ports.

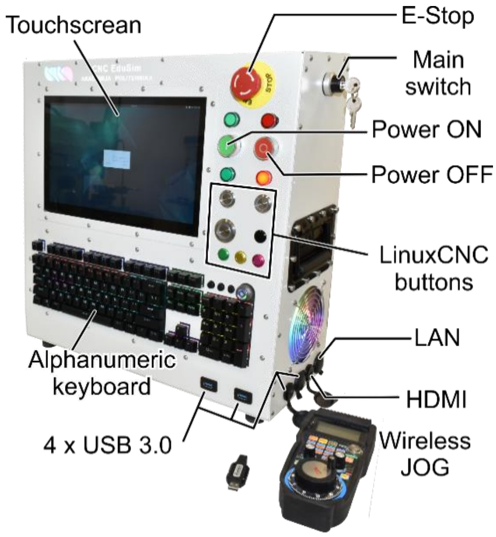

Figure 3. CNC EduSim - switches, buttons, and ports

Buttons and switches are divided into two groups. The first group consists of buttons and switches that provide power to the simulator, as well as turning it on and off. By turning on the simulator, the LinuxCNC software control system for CNC machines is started [3]. The second group consists of keys that facilitate work in the LinuxCNC software control system and are intended for starting, pausing and stopping the loaded G-code program, for initializing the machine, software turning on and off the machine (Machine ON/OFF).

CNC EduSim has a total of four USB-3.0 ports designed to transfer the G-code of the program from the USB memory to the simulator and vice versa. Also, USB-3.0 ports are used to connect peripheral hardware (computer mouse, handwheel-JOG, etc.) to the simulator. In addition to the USB-3.0 port, CNC EduSim has an HDMI port for an additional monitor or projector, as well as a LAN port for connecting the simulator to the Internet.

The above components were used in order to fully utilize the capabilities of the Raspberry Pi-5 microcomputer [4]. All components shown in Figure 3 (switches, buttons, connectors, monitor and keyboard) are connected to the microcomputer RaspberryPi-5 (RPI-5) directly or through other electrical components such as relays and USB 3.2 HUB HAT (Figure 4). Also, LinuxCNC 2.9.4 Raspberry Pi5 Debian operating system [5] is installed on the RPI-5, which represents the control and programming system of CNC EduSim.

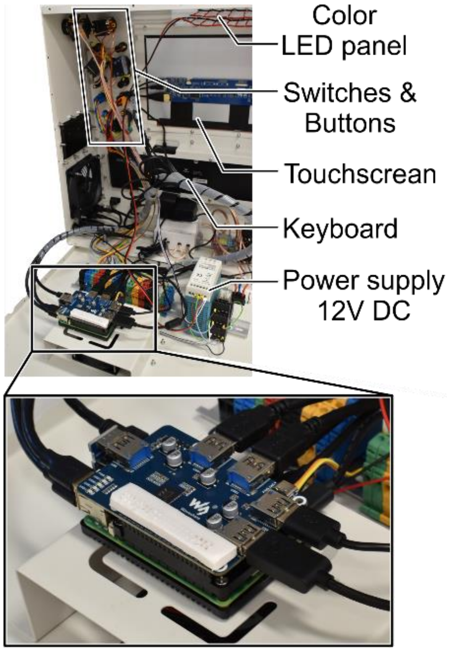

Figure 4. Raspberry Pi 5 + USB 3.2 HUB HAT

2.1 Linuxcnc control and programming system

The main advantage of LinuxCNC compared to other control systems is that it has an open architecture system that can be freely accessed and configured according to one's own needs. Therefore, LinuxCNC can be used for:

control of CNC machines intended for conventional machining (turning, milling, grinding),

control of CNC machines intended for non-conventional machining methods (plasma cutting, laser cutting, wire cutting),

control of industrial robots with serial, parallel and hybrid kinematics.

Taking into account the set requirements for CNC EduSim and the previous experiences of the author [6-8], the LinuxCNC software control system has emerged as a solution that will meet all current and future requirements.

2.2 Working environment for education on cnc edusim simulators

Considering that the CNC EduSim simulators are intended for the education of both programmers and operators of CNC machines, two working environments have been prepared for their use.

The working environment for training CNC machine programmers is shown in Figure 5. The working environment includes a sufficient number of CNC EduSim simulators, which will ensure smooth, comfortable and independent work for each training participant. Also, the working environment includes a simulator for a qualified demonstrator who conducts training. As shown in Figure 5, during the training the demonstrator uses the previously mentioned simulator prototype, while the course participants use improved and redesigned versions of the simulator.

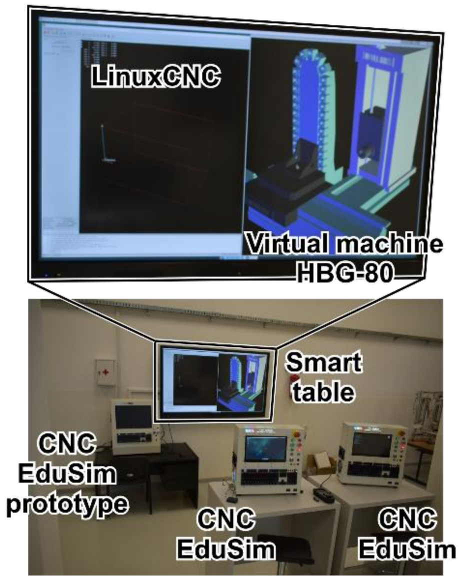

Figure 5. A working environment for training

CNC machine programmers on CNC EduSim. Apart from the primary goal that the participants of the training acquire the knowledge necessary for successful programming of CNC machines, a secondary goal was also imposed during the formation of the working environment. As the need for the training participants to get a feel for the operation of the CNC machine during the execution of the prepared G-code program was highlighted, the secondary goal of the training was also defined. In order to successfully achieve the secondary goal, using the capabilities of the LinuxCNC software control and programming system, a virtual machine is configured in the Python 3D graphics environment on each CNC EduSim simulator. Figure 5 shows a virtual LOLA HBG-80 CNC milling machine, which represents a Digital Twin machine, i.e. a virtual machine that, according to the loaded G-code program, fully simulates the operation of a real machine [9]. In addition to training CNC milling machine programmers, CNC EduSim simulators are configured so that they can also be used to train CNC lathe programmers. Examples of tool motion simulation according to G-code programs prepared for a CNC lathe are shown in Figure 6.

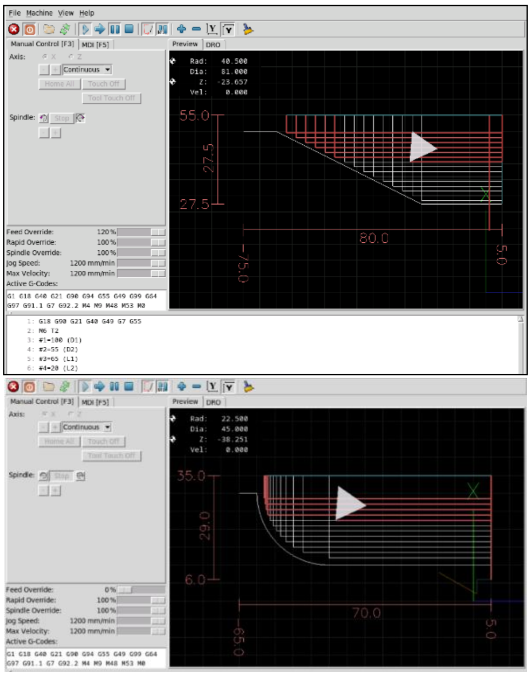

Figure 6. CNC EduSim – tool path simulation according to G-code programs prepared for CNC lathe [10]

As mentioned, CNC EduSim simulators are also intended for the training of CNC machine operators, and in accordance with that, a trial working environment was formed (Figure 7).

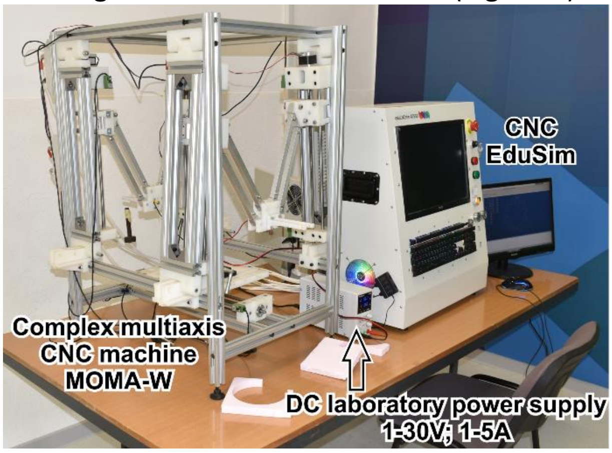

Figure 7. Work environment for training CNC operators

The working environment from Figure 7 consists of a CNC EduSim simulator, a laboratory power supply and a complex multi-axis machine tool MOMA-W, which is also the subject of current research by the author of this paper. The complex machine MOMA-W [11] is intended for cutting foam materials with a red-hot wire. The MOMA-W machine tool consists of two independent parallel mechanisms connected to each other by a wire. Each of the mechanisms used has two degrees of freedom, and the movements of the platforms of the mechanisms ensure translational movements of the wire (tool) in two directions as well as rotational movements around two axes. The mechanism of the MOMA-W machine tool has extremely complex kinematics. Also, the mechanism of the MOMA-W machine tool cannot be characterized either as a mechanism with parallel kinematics or as a mechanism with hybrid kinematics, and for this reason the mechanism is characterized as a complex mechanism, which is where the name of the machine comes from. The wire that connects the platforms of the used mechanisms and is used to cut the foam materials is heated by the laboratory power supply, and the entire environment is intended for training operators to work on WEDM (Wire Electrical Discharge Machining) CNC machines. According to the dimensions, the complex machine tool MOMA-W can be characterized as a table machine that can be used not only for education but also for research purposes.

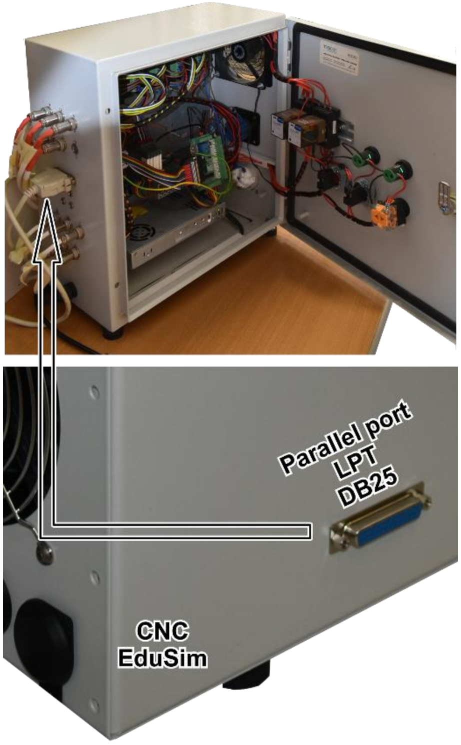

Figure 8. Electro-energetic system of the complex multi-axis machine tool MOMA-W

In addition to the equipment shown in Figure 7, the working environment also includes the electro-energetic part of the control system, which is connected to the CNC EduSim simulator via a parallel port (Figure 8).

The electrical subsystem contains stepper motor drivers (5 X TB6600), appropriate power supplies (12V-DC, 24V-DC), components used for automation realisation (switches, buttons, relays, etc.) and external connections for stepper motors and drive axle sensors. The electric-energy subsystem was developed and built so that, in addition to controlling a complex machine, the MOMA-W tool can also be used for other desktop machines that have a maximum of five drive axes. In other words, the electro-energetic subsystem can be used to control five-axis CNC machines as well as five-axis industrial robots whose motors and sensors are compatible with the aforementioned electrical components.

Figure 9 shows a gear made on a complex multi-axis MOMA-W machine. By creating gears, but also other parts of simple or complex geometry, where G-code programs written by hand, generated using available CAD/CAM systems and parametric programs [11] were used, it was confirmed that the created environment fully meets all the needs for successful training of CNC machine operators.

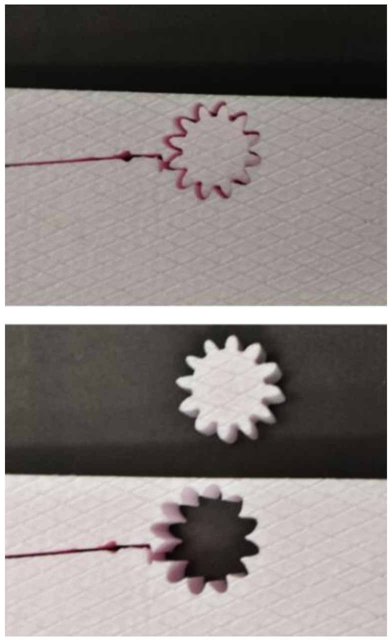

Figure 9. Gear made on a complex multi-axis machine MOMA-W

2.3. Forthcoming improvements of cnc edusim and formed working environments

As already mentioned, LinuxCNC is an open architecture software system and can be modified and adapted to current needs. LinuxCNC has predefined graphical interfaces (Axis, Mini, TkLinuxCNC) through which CNC machines and all peripheral equipment are managed. The predefined interfaces fully support all the functions that control units of branded CNC machines have, such as initializing the machine, zeroing the workpiece, loading, starting and stopping the program, Manual Data Input-MDI, tool change, turning on and off the cooling and lubrication system, etc. The disadvantage of the LinuxCNC software system is that the graphical environments mentioned do not resemble the graphical interface of any branded CNC machine, so during training it's not possible to get full feeling that you are working on a specific CNC machine. In order to eliminate this shortcoming, one of the directions for further improvements is the creation of appropriate graphical interfaces like the QtDragon interface is (Figure 10) [12].

Figure 10. LinuxCNC QtDragon graphical user interface

Another direction of improvement relates to the development and construction of desktop educational CNC machines in order to improve the education of CNC operators. In the first step, the CNC machines that each production plant owns, i.e. a CNC lathe and a three-axis CNC milling machine, would be built. With the mentioned CNC desktop machines, during the CNC operator training, it would be possible to master all the necessary procedures that are performed before, during and after the machining process on a specific CNC machine. This primarily refers to basing and clamping the preparation, defining the coordinate system of the workpiece, tool measuring, loading and starting the prepared program, finishing the part, measuring and controlling the manufactured part, etc. The next steps would be: development and construction of a four-axis CNC milling machine, development and construction of a five-axis CNC milling machine, development and construction of a four-axis lathe (XYZC).

3. CONCLUSION

Based on the many years of work experience of the author of this paper and on the basis of the perceived opportunities for improving teaching processes at the Faculty of Mechanical Engineering of Belgrade University and the Academy of Applied Studies Polytechnic, also in Belgrade, the initial idea for the construction of a CNC simulator appeared. After defining the goals and expected outcomes of using the CNC EduSim simulator, one simulator prototype was first built, and then five more fully functional simulators. The prototype and three more redesigned CNC EduSim simulators are located in the laboratory for CNC technologies and conventional machining in Zemun. Two redesigned simulators are located in the Požarevac, where the Academy of Applied Studies Polytechnic also has its own classrooms. CNC EduSIM simulators are widely used for the implementation of exercises in the following subjects: CNC machine programming, Computer aided design CAM, parametric programming of CNC machines, programming of CNC systems I and programming of CNC systems II. Also, to an increasing extent, CNC EduSim simulators are used when preparing final papers for basic and master applied studies. With the goals achieved so far and the results achieved, the assessment is that the built CNC EduSim simulators fully met expectations. In terms of education, comparing the knowledge of students from the period when simulators were not used with the acquired knowledge of students who worked on the CNC EduSim simulator, a significant difference is observed, which justifies the construction of the simulator. After the implementation of the described improvements, the plan is to commercialize the CNC EduSim simulators and offer them to secondary and vocational schools at an affordable price.

In addition to educational purposes, CNC EduSim is also used in the scientific research work of the author of this paper. Primarily, the CNC EduSim simulator is used to configure the control system of CNC machines of various configurations with an emphasis on machines with parallel and hybrid kinematics. Further research work will be directed towards the development of reconfigurable control for a specific group of CNC machines, and the results will be published in appropriate scientific journals and conferences.

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