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Improvements of Educational Process of Automation and Optimization Using 2D Plotter

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Abstract: The paper presents development and application of Computerized Numerical Control (CNC) type laboratory-scale positioning tool *2D Plotter* for both, education and research. Presented device was built in order to provide an effective tool for solving two types of automated tasks, the precise positioning control in planar space, e.g. plotting of vector graphics, and illustrative extremum seeking for two-dimensional functions using brightness map and moving light sensor. Since the device is intended mostly for educational purposes, its construction is easily reproducible and low-cost. *2D Plotter* will directly take place in courses focused on automation, process control, and optimization. Its properties also determine its utilization in remote experimentation. The paper presents potential tasks that can be effectively solved in educational process using the device.

Keywords: Control education; Optimization; CNC machinery; Plotter.

1. INTRODUCTION

The main goal of control engineering education is to prepare students for their future positions in industrial practice to ensure safe and optimal production. It is merely important to prepare young engineers for real situations that often do not directly corresponds to those they have learned on the theoretical basis. Therefore, the main responsibility of educators is to provide students appropriate practical training on real engineering equipment and also to motivate them to participate in practical projects. Common practice applied in many educational institutions is development of supplementary educational equipment, e.g. laboratory experimental devices, which allow students to apply their newly acquired theoretical knowledge, to enhance their practical skills, and to obtain an important experience that only the work on real engineering devices can offer. Another level of improvement in education methodology is the practice where students are encouraged to participate directly on the development of laboratory equipment or even they are in the leading role of the development projects.

At the Institute of Information Engineering, Automation and Mathematics (IAM), the last mentioned approach is used to help students in improving practical skills and individual solving of problems. In that case, the student is the one responsible for the project aiming and the one who needs to seek for an appropriate solution of problems which arise during the development phase. Moreover, in this approach students adopt the practices in searching technical and scientific literature, investigating similar exiting works and creating their own unique solutions. This also prepares them for their possible future career in research, where all these qualities are necessary. This methodology also reaps the benefits of an interesting phenomena where students develop the education equipment for students. As a result, developed experimental devices are often better designed for the needs of students than those developed by teachers. This phenomena comes from the fact that students are able to judge their own needs and empathize with other students, applying their experience with usage of existing laboratory equipment. Moreover, newly developed educational tools can offer students more intuitive usage and learning value.

The use of positioning tools (plotters, CNC machines, robotic arms, etc.) is very popular in control engineering education (Ungermanns and Werth, 2013). Educational institutions that are directly focused on mechanical engineering often use a full-scale industrial equipment such as CNC mills (Fisher and Hofmann, 2007; Max et al., 2015), both in the practical and theoretical way. These machines allow students to train their practical skills on the machinery similar to that in manufacturing. On the other hand, these machines are very expensive and many universities rather develop their own cheaper solutions as a supplementary aid for laboratory training. This is mostly used in institutions primarily focused on control education. Simple devices such as plotters are especially suitable for education in mechatronics and mechanical engineering (Camposaragna et al., 2006). Different education-oriented works often use a different control equipment for machine tools operation. These include the programmable logic controllers (Rata and Rata, 2015), embedded systems (Shaer et al., 2015) and others. An important task in machinery control is to ensure the optimal operation.

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Especially, optimization of trajectories is one of the commonly solved problems in practice (Mannava et al., 2012).

In this work the machine tool *2D Plotter* for numerical control is introduced. The main objective of its construction was to support the research and teaching of courses focused on control system design and optimization. The *2D Plotter* can be used either as a tool for plotting and engraving tasks or as an illustrative experimental device for seeking extrema in optimization methods using the detection of brightness gradients.

2. MOTIVATION TO *2D PLOTTER* DEVELOPMENT

The developed *2D Plotter* is based on the *Computerized Numerical Control* (CNC) machine principles. CNC machines are widely used in production industry and can be of various types, sizes, and principles of operation. The main common property of CNC machines is that they can perform very precise multi-axis positioning control. In many cases they are used in manufacturing of components for mechanical systems such as engines, or in production of electronics where strict precision standards are applied. In order to construct, configure and program positioning machines for industrial usage, highly qualified persons are required. Young control engineering professionals which leave universities and seek jobs in the industry need to use skills in machinery operation and control.

The main motivation for the development of *2D Plotter* arose from the need of a laboratory device on which the main problems of machinery practice can be demonstrated in a comprehensible and illustrative way. The main objectives of device's design were:

- to provide as simple construction as possible while preserving the standard functionality of common positioning machines;
- to ensure the high level of modularity and ability to physically reconfigure the device for different educational purposes;
- to provide easy-to-use but featureful control environment that students are most familiar and comfortable with;
- to keep the development costs within the range acceptable for educational institutions even with limited financial resources;
- to use open source platforms and publicly available construction kits in order to retain reproducibility of the solution.

The *2D Plotter* handles two main tasks. Firstly, it is able to plot figures in the form of the vector-defined graphics. In this functionality, user can design its own figure to be plotted and than transfer it to the instructions for machine's positioning controller. These instructions are in the form of G-code, a universal machinery language for multi-axis movements. Second task for which the device is designed is the physical simulation of gradient-based optimization methods. In this setup the device serves as an effective tool to visualize the optimization algorithms for educational purposes. In extremum seeking, the *2D Plotter* is equipped with the light sensor (photo-resistor) and a tablet is attached to the base of device. The contour map of two-dimensional function is displayed on a tablet's screen in a grey scale. The extermum seeking involves the algorithm-based movement of light sensor over the screen in order to detect the gradients of function and find its local minima and maxima. Visualizing this task on a real laboratory device helps to better understand the principles and different methods of optimization. Obviously, both of these tasks can be handled in the education process in very valuable way. Particularly, the *2D Plotter* can be very useful in the courses oriented on the machinery control, automation, and optimization.

Further development of the *2D Plotter* will be focused on the implementation of the user-friendly web-based interface so that the device can fully take a part in the remote laboratories provided Remote Laboratory Management System (RLMS) WebLab-Deusto at IAM. Since use remotely operated experiments via the Internet has tradition at the IAM (Kalúz et al., 2015), one of the ideas for the future is incorporation of *2D Plotter* into the base of remote laboratories.

3. DEVICE DESCRIPTION

3.1 Mechanical Construction

The CNC-based prototype *2D Plotter* was developed in several steps. First step was to design suitable construction for the device. Next task was to design electronic communication between the control units, sensors and actuators. The design of the construction was determined by the main goals, i.e., user-friendly handling and budget limitations. Therefore we tried to minimize the overall size and weight of the *2D Plotter* to simplify its utilization. This allows the device to become a portable piece of educational equipment that can be easily transferred between laboratories. The portability of the device also brings possibilities to promote the control engineering education in secondary schools and other institutions that prepare students for practice and higher education.

Figure 1 shows the overall physical construction of *2D Plotter*. The device has following structural, operational and electronic parts:

- *Main frame* – The main construction that holds the device together and allows the attachment of sensors, actuators and electronics is build on the OpenBeam platform [1], an extruded aluminum framing system brought to the public by a successful campaign at Kickstarter. The OpenBeam provides a modular aluminum frames of different lengths and various types of brackets. This allows to build almost any kind of mechanical construction.
- *Motors* – The *2D Plotter* uses two main types of motors to operate. For the movement in the planar space two NEMA 17 stepper motors were used. These motors provide satisfying parameters for fluent operation of device. The holding torque of motors is 0.44 N m that is sufficient for both types of tasks that the device is designed for. The control precision of motors is 1.8° per step which makes 200 steps per revolution. To increase the control precision in axis movements, the motors are controlled by electronic

[1] `http://www.openbeamusa.com/`