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PROCEEDINGS

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DESIGN AND IMPLEMENTATION OF A LOW-COST CNC LASER ENGRAVING MACHINE FOR UNIVERSITY LABORATORIES

Duong Dinh Tu*, Mai The Anh, Ho Sy Phuong, Le Van Chuong, Ta Hung Cuong, Vu Van Thanh, Le Thi Thu Uyen

Department of Automatic Control, Institute of Engineering and Technology, Vinh University, 182 Le Duan Street, Vinh City, Nghe An Province

*E-mail: *duongdinhtu@vinhuni.edu.vn*

Abstract. This paper proposes a low-cost design for a two-axis CNC laser engraving machine that provides similar functionality to high-cost industrial systems. The proposed design is suitable for university laboratories due to its accessibility, small size, ease of use, low manufacturing cost, and transportability. The machine is based on an Arduino platform and uses a high-watt burning laser module to engrave 2D and grayscale images on paper, plastic, and wood. The dimensional, dependency, and coordinate tests were conducted to verify the validity of the machine. Finally, pilot experimentation was carried out on cardboard composites, plastic, and wood.

Keywords: *Laser Module, Arduino, Stepper Motor, G-code, GRBL.*

I. INTRODUCTION

Laser marking is a widely used process in various industries, including manufacturing, automotive, and aerospace. However, the high cost of commercial laser marking machines has limited their accessibility for many educational institutions, particularly those with limited budgets. This paper presents the design and implementation of a low-cost CNC laser marking machine based on Arduino specifically tailored for educational purposes. Our machine is capable of marking a wide range of materials, including metal, plastic, and wood, and can be easily customized to meet the specific needs of different educational programs. By providing an affordable and accessible solution for laser marking, we hope to enable more educational institutions to incorporate this cutting-edge technology into their curricula and enhance their students' learning experience. Additionally, using Arduino in our design allows students to learn about microcontroller programming and its applications in real-world scenarios.

II. RELATED WORK

In recent years, the high cost of commercial CNC machines has limited their accessibility for many educational institutions, particularly those with limited budgets. As a result, low-cost solutions have become increasingly popular.

Kumar et al. [1] designed and manufactured a portable laser engraving cutter using Arduino CNC, which is produced at a more affordable price than CO2 laser cutting machines. The design uses Laser Diode modules with 500 mW power with 450 nm wavelength and stepper motors controlled by a microcontroller called Arduino CNC Shield Driver. All design sketches were done on SolidWorks software. Reza et al. [2] focused on the drafting aspect of the industry and described the design and construction of microcontroller-based plotters. They used three motors to obtain a range of motion on three translational axes X, Y, and Z. Both

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Kumar et al. and Reza et al. used CAMotics software to generate Gcode and Arduino IDE to program the microcontroller.

Peixoto et al. [3] proposed using Raspberry Pi 3 or the platform Arduino as an example of the control unit for technical training in Portugal. The paper by Antunes et al. [4] describes the development of a laboratory-based prototype for a diamond wire CNC stone-cutting machine at UMinhoLabs. Quatrano et al. [5] also built a low-cost CNC machine using a discarded 3D printer and Arduino Mega 2560 as the control unit. The objective of this design is to construct an affordable CNC machine capable of precision machining various shapes and sizes of objects.

Overall, these case studies have demonstrated that low-cost CNC machines can be designed and manufactured using open-source software and low-cost devices such as Arduino microcontrollers. These solutions offer an affordable and accessible option for educational institutions to incorporate CNC technology into their curricula, providing students with valuable hands-on experience in this field.

III. HARDWARE DESIGN AND IMPLEMENTATION

3.1. The block diagram of the system

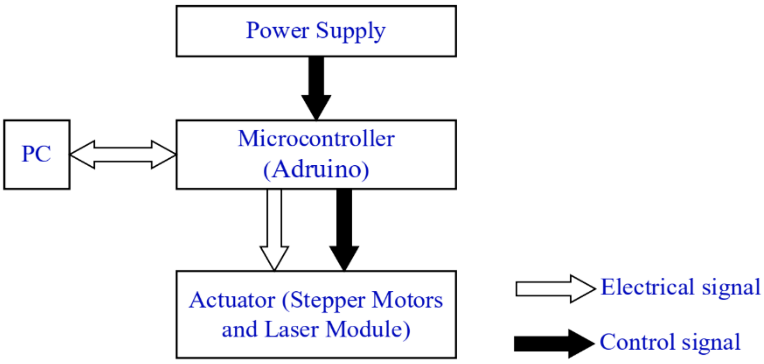

Fig. 1. *The block diagram of the system.*

The block diagram of the system is presented in Fig. 1, which illustrates the components of the system, including the power supply block, microcontroller block, and actuator block. The power supply block is responsible for providing a 12 V power supply to the laser diode, which utilizes a maximum of 3 V in forward bias conditions. Additionally, the 12 V power supply is consumed by two stepper motors utilized in the movement of the laser. The microcontroller block consists of an Arduino microcontroller that receives control signals from the computer and sends those control signals to the actuator block. Finally, the actuator block includes the stepper motors and laser module, which perform the task of moving the laser module and engraving on the material.

3.2. Hardware device selection

The power supply used in our system is a 12 V honeycomb source with the following specifications: input voltage of 180 V - 240 V, operating frequency of 47 ~ 63 Hz, power of 60 W, output voltage of 12 V, maximum current of 5 A, adjustable voltage of ± 10 %, efficiency

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of ≥ 85 %, working temperature range of -20 °C to 60 °C, and size of 110×78×H36 mm. This power supply is readily available in the market at a cost of approximately 150,000 VND;

The CNC shield V3 is an expansion board for the Arduino UNO R3 that is utilized to control mini CNC machines. The board consists of four trays for plugging in A4988 stepper motor control modules, allowing it to control up to three axes (X, Y, Z) and an optional fourth axis on mini CNC machines. The CNC shield V3 is compatible with GRBL, open-source software used to control mini CNC machines, and supports up to two terminal sensors per axis. Additionally, it features coolant control when the machine is running and uses stepper motor control modules to reduce costs when replacing or upgrading. The power supply voltage for the CNC shield V3 ranges from 12 V to 36 V. The market price of the CNC shield V3 is approximately 100,000 VND;

The NEMA 17 stepper motor is a high-precision motor that is suitable for applications requiring large loads and precision, such as mini CNC machines, robot arms, and SCARA robots. It features an integrated reduction gearbox with a ratio of 3969/289, which increases traction and motor accuracy. The motor has an all-metal gearbox for high durability and stability, making it a reliable option for various applications. The NEMA 17 stepper motor has the following specifications: 1.8° stepper rotation (200 steps/revolution), current 1.7 A, torque 2.2 N.cm, rotor inertia 54 g.cm^2, step angle accuracy of ± 5 % (full step, no load), motor mass of 280 g, body length of 40 mm, frame size of 42×42 mm, shaft diameter of 5 mm, and shaft length of 23 mm. The market price of the NEMA 17 stepper motor is approximately 170,000 VND;

The laser diode engraving module is a device that utilizes a laser diode to engrave or mark various materials, including wood, acrylic, leather, and more. The module comprises a laser diode, a driver circuit, and a focusing lens. The laser diode emits a high-intensity laser beam that is focused by the lens to create a small point of light. By moving the module across the surface of the material, the laser can create intricate designs or text. The laser diode engraving module has the following specifications: wavelength of 450 nm, working voltage of 12 V, working current of ≤ 2 A, power of 3500 mW, fan heat dissipation, and size of 33×33×H75 mm. The market price of this device is approximately 750,000 VND;

The GT2 pulley 5 mm is a type of pulley that is commonly used in 3D printers and other precision machinery. It is designed to work with GT2 timing belts, which have teeth that fit into the grooves of the pulley to provide accurate and reliable motion control. The GT2 pulley is made from high-quality materials, such as aluminum or steel, and is available in various sizes and tooth counts to accommodate different applications. It features a tooth profile that is optimized for low backlash and high torque transmission, making it ideal for precise movements. The market price of this device is approximately 20,000 VND;

The frame for the CNC laser engraving machine is made from profiled aluminum, a material that offers several advantages such as lightweight, resistance to rust, high strength, good bearing capacity, and high aesthetics. The aluminum profile used for the CNC laser engraving machine has the following specifications: material - aluminum 6063-T5, size of 20×20 mm, width between two slots 6 mm, size for X axis 370 mm, size for Y axis 315 mm. The market price for a 6-meter-long aluminum profile is approximately 80,000 VND.

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The physical connection diagram of the system is shown in Fig. 2.

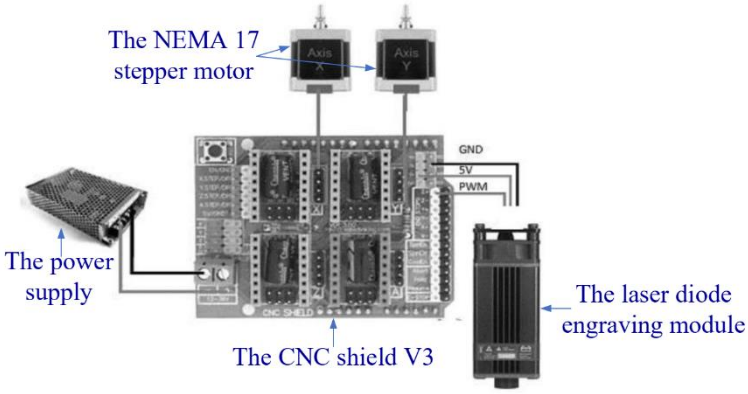

Fig. 2. *The physical connection diagram of the system.*

3.3. Mechanical modeling of the system

The structure of the laser cutting machine has been designed and modeled using SolidWorks software (Fig. 3). Prior to the implementation of the hardware for the actual laser cutting machine, all parts of the machine will be produced. This design will be further modified through iteration and simulation to achieve a final design that is stable and realistic. Any necessary modifications will be made through simulation and testing to ensure that the final design is optimized for stability and performance.

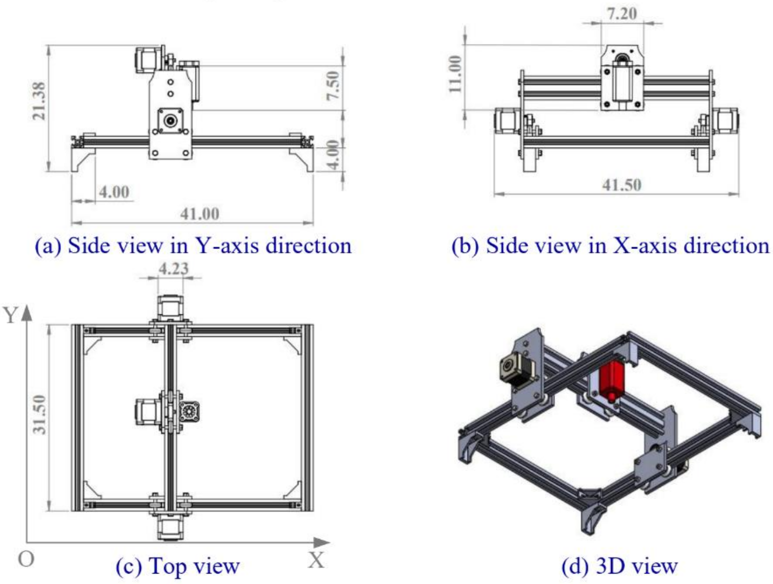

Fig. 3. *Mechanical modeling of the system in SolidWorks software.*

3.4. System crafting

The hardware of the system is implemented as shown in Fig. 4. The total cost for hardware implementation is about 1,700,000 VND.

(a) Top view (b) Side view (c) Panoramic view

Fig. 4. *Finished CNC laser engraving machine.*

IV. SOFTWARE IMPLEMENTATION AND SYSTEM OPERATION

The software implementation steps for CNC laser engraving machines involve the following: (1) load the GRBL library for Arduino UNO R3: download the GRBL library and add it to the Arduino IDE software. Then, upload the GRBL library to open it and load it into the Arduino UNO R3 board through the COM interface between the computer and the Arduino; (2) create G-code with Inkscape software: this software allows graphic images to be in vector form, making it easy to resize them without losing quality; (3) control interface for CNC laser engraving machine by Benbox software: load G-code graphics files into this software and proceed with laser engraving. By following these implementation steps, CNC laser engraving machines can be programmed and operated with precision and efficiency. The operating process of the system is shown in Fig. 5.

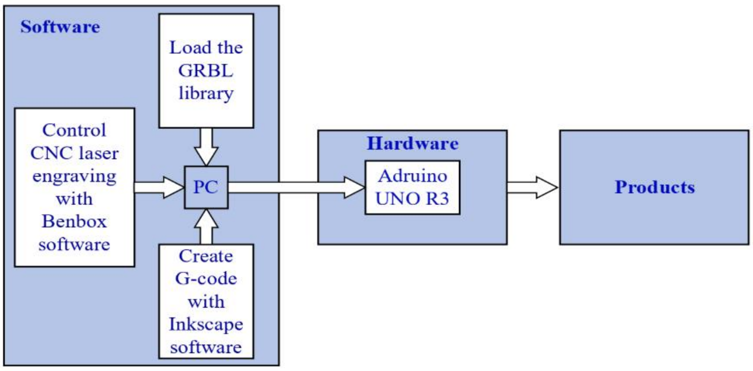

Fig. 5. *The operating process of the system.*

V. RESULTS

The results of this study demonstrate the successful development of a CNC laser engraving machine capable of producing high-precision, high-quality engravings on a variety of materials. The machine was capable of engraving complex designs with intricate details. The machine was tested on a range of materials including wood, plastic, and cardboard composites,

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and was found to produce consistent and accurate results across all materials. The use of a closed-loop feedback system ensured precise positioning of the laser beam, resulting in engravings with sharp edges and minimal distortion. An example of a product engraved on a wooden surface is shown in Fig. 6.

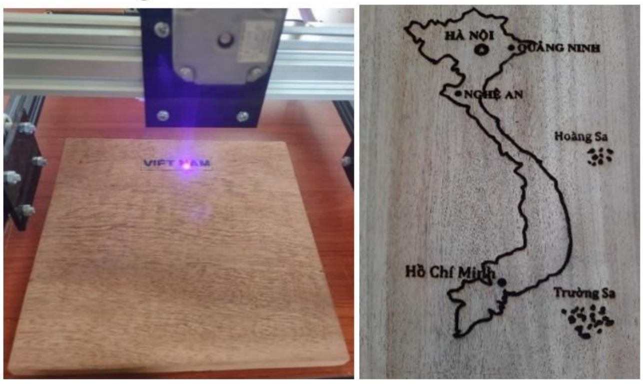

Fig. 6. *A product of a CNC laser engraving machine engraved on a wooden surface.*

Advantages: The CNC laser engraving machine developed in this study is cost-effective and economically feasible, with a total build cost of approximately 1,700,000 VND. The use of laser technology allows for high precision and fine detail in engravings. The machine's chassis is designed with an aluminum profile, resulting in a lightweight design that is easy to move from one place to another. Additionally, the machine is user-friendly and does not require any specialized skills to operate. The laser beam is suitable for a wide range of materials, including wood, plastic, cardboard, and foil, making it a versatile tool for many applications.

Disadvantages: The machine is limited to working in the two-dimensional plane of the X and Y directions and is not suitable for processing highly hard or high melting point metals. Additionally, engraving on highly reflective metals can be difficult due to the reflection characteristics of the material.

VI. CONCLUSION

In conclusion, the development of a low-cost CNC laser engraving machine represents a significant advancement for university laboratories. The machine's affordability and user-friendliness render it an accessible tool for both students and researchers, whereas its exceptional precision and versatility render it suitable for a broad spectrum of applications. The use of laser technology allows for fine detail and consistent results across a variety of materials, while the lightweight design and user-friendly interface make it easy to move and operate. Overall, this CNC laser engraving machine offers an affordable and effective solution for university laboratories seeking to expand their capabilities in the field of laser engraving.

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