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A Budget-Friendly CNC Laser-Cutting Machine

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***Abstract*—This CNC laser cutting machine can process up to three units per minute while ensuring high precision. The system combines mechanical and electronic components that are optimized for efficiency, featuring an Arduino-based control unit and a tailored G-code generation method to streamline workflow and reduce material waste. Notable features include a sturdy structural framework, automated calibration, and a flexible control system guaranteeing accuracy and repeatability. Furthermore, the research investigates methods to lessen the environmental impact of laser cutting by fine-tuning operational parameters. This machine is especially well-suited for educational settings and small-scale manufacturing, offering a cost-effective alternative to high-priced industrial CNC systems. Future efforts aim to enhance automation, incorporate AI-driven predictive models for improved cutting precision, and refine component selection for better performance.**

***Index Terms*—CNC, laser cutting, automation, G-code, digital manufacturing, predictive modeling.**

I. Introduction

Digital manufacturing has revolutionized the fields of design and production, mainly through the use of Computer Numerical Control (CNC) machines. These machines facilitate processes such as cutting, engraving, and machining with increased precision and efficiency. However, commercial CNC machines are often expensive, limiting their accessibility to small businesses, independent creators, and educational institutions. This barrier restricts students and professionals from engaging in hands-on learning and innovative digital fabrication.

To address this challenge, there is a growing demand for affordable and accessible alternatives that enable broader access to CNC technology. This project focuses on designing and constructing a cost-effective CNC laser cutting machine that maintains high performance and accuracy, achieving a production rate of three pieces per minute. Our machine is specifically designed to cut Christmas-themed figures, including a Christmas tree, a candy cane, and a star, ensuring precision and repeatability while remaining financially feasible. The space of the working area depends on the size of the pieces, and the optimal material for cutting is a 3 mm balsa wood sheet.

II. State of the Art

Laser cutting has become a key technology in advanced manufacturing because it can achieve precise and high-quality cuts in various materials. This document reviews the main recent contributions in the field, citing technological advances, predictive models, and applications.

Regarding the fundamentals and emerging technologies, the work presented at the ”7th Annual International Conference on Materials Science and Engineering” [1] highlights fundamental developments in materials science and their application in laser cutting, providing a framework for understanding the required properties in materials processed by this technique. In addition, recent research addresses strategies to control contamination during laser cutting, highlighting solutions that reduce emissions and improve environmental sustainability [3]. On the other hand, a review by Bogue [4] emphasizes the flexibility and precision offered by these technologies in industrial processes such as automatic assembly.

The impact of cutting parameters has been the focus of attention. Studies such as those of Vincenzo Tagliaferri et al. [5] investigated the influence of materials and process parameters on cut quality, highlighting the importance of selecting appropriate operating conditions. In parallel, significant advances in predictive models based on neural networks have allowed for more accurate prediction of cut quality. For example, Kusuma and Huang [6] used vibration signals and deep neural networks to analyze the laser cutting of silicon steel sheets. Similarly, Nguyen et al. [7] used convolutional neural networks to predict the width of the kerf in thin materials, demonstrating the effectiveness of machine learning techniques in this field.

Combined methodologies like those developed by Yang et al. [9] integrate the Taguchi method with neural networks to build robust predictive models in experiments with CO2 lasers. Likewise, Alizadeh and Omrani [8] incorporated robust analysis to optimize process parameters, achieving optimal models in CO2 laser cutting.

In terms of materials, the research of Wouters et al. [19] analyzes the microstructural changes induced by laser cutting and their impact on mechanical properties. This knowledge is the key to adjusting processes and minimizing unwanted effects on parts. In addition, mathematical approaches such as those of Mahrle and Schmidt [16] provide tools to model and optimize complex processes in laser cutting.

III. Main Contribution

This study introduces an innovative and low-cost CNC laser-cutting machine designed to meet the needs of small and medium enterprises or educational institutions. The machine was built at a total cost of 266.21 dollars, including electrical and mechanical components, making it more affordable than commercial alternatives, with a price range of 500 to 6,000 dollars. This low cost makes the machine-accessible to users with limited budgets, such as small businesses and schools. In addition, its design includes a robust mechanical structure and an automated piece-loading system, which improves operational efficiency and precision. Comparative studies have shown that low-cost CNC systems properly optimized can achieve performance metrics similar to those of high-end industrial machines. For example, affordable systems have been reported to achieve kerf widths (cutting precision) of less than 0.1 mm, a level of precision that competes with more expensive equipment [5]. The stability and rigidity of the mechanical structure are also critical factors in achieving high accuracy, an aspect that was prioritized in the design of this machine [16].

To optimize the cutting process, GRBL Firmware was used, which is a widely recognized software for controlling CNC machines. This software allows the adjustment of key parameters such as position on the balsa wood, cutting speed, laser power, and other variables to achieve the best results. During testing, it was shown that the machine could cut three pieces of 3 mm balsa wood in 40 seconds, a competitive speed compared to other low-cost CNC systems [2, 6]. This performance is consistent with studies highlighting the importance of optimizing parameters such as laser power and cutting speed to improve cut quality and reduce material waste by up to 20%. The testing process included iterative adjustments of the parameters to identify the optimal configuration for each material, ensuring that the machine can adapt to a wide range of cutting needs.

The machine developed in this study combines high productivity, precision, and versatility, making it a valuable tool for educational and industrial applications. With a cutting rate of three pieces per minute, the system maintains high precision, making it suitable for small-scale manufacturing. This capability is comparable to other systems reported in the literature, emphasizing the importance of balancing speed and accuracy in laser cutting [5, 16]. In addition, the machine proved to adapt to different materials, such as balsa wood and acrylic, expanding its range of applications. Previous studies have shown that laser cutting systems can achieve high-quality cuts in various materials, including metals and polymers, by adjusting parameters such as laser power and gas pressure [19]. This adaptability is a key advantage of our system, as it allows for use in multiple contexts without significant modifications. Validation tests confirmed that the machine can achieve precise and efficient cuts, supporting its viability for practical applications in educational and small industrial settings.

IV. Materials and Construction

The CNC Laser Cutting Machine was built using mechanical and electronic components carefully selected to ensure precision, affordability, and ease of assembly. For the mechanical structure shown in Fig. 1, the base (1) was constructed from 8mm MDF, providing a sturdy and lightweight foundation. Linear Rails (2) (MGN15H) were used to guide the movement of the X and Y axes, ensuring smooth and accurate motion. GT2 pulleys and toothed belts (4) were employed to transfer motion from the NEMA 17 stepper motors (5) to the axes, allowing precise cutting head control. Stainless steel screws and bolts (3, 6, and 7) of various sizes were used to assemble the frame, ensuring durability and stability during operation. A detailed list of the mechanical components and their specifications can be found in Table 1. The design prioritizes simplicity and modularity, making it easy to replicate and modify for different applications.

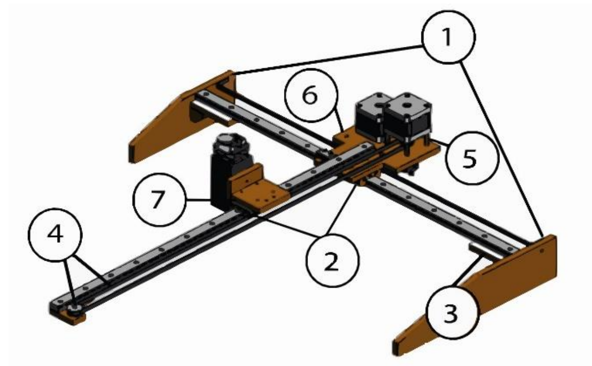

Fig. 1: CNC machine assembly utilized in the laser cutting system.

TABLE I: Mechanical Components and Specifications

Component	Specification
Base	8 mm MDF
Linear Rails	MGN15H
Pulleys	GT2
Belts	GT2 toothed
Screws and Bolts	Stainless steel, various sizes

On the electronic side, the machine is controlled by an Arduino UNO equipped with an ATmega328P microcontroller, which runs the GRBL firmware for CNC control. A GRBL-compatible CNC shield was used to interface the Arduino with the stepper motor drivers (A4988), which support micro stepping up to 1/16 for smoother motion. The NEMA 17 stepper motors, with a steep angle of 1.8°, provide the necessary torque for precise movement. A 500 mW, 405 nm laser module was chosen for cutting and engraving tasks, powered by a 12V, 5A power supply. Limit switches (250V, 5A, 1NO + 1NC) were installed on each axis to ensure safe operation by preventing the machine from exceeding its mechanical limits. The Arduino controls the laser module via PWM signals, allowing for adjustable power output to suit different materials and cutting requirements. The complete list of electronic components and their specifications is provided in Table 2.

TABLE II: Electronic Components and Specifications

Component	Specification

Arduino UNO	ATmega328P Microcontroller
CNC Shield	GRBL Compatible
NEMA	17 Motor, 1.8° step, 2 A
Drivers	A4988, Microstepping up to 1/16
Laser Module	500 mW, 405 nm
Power Supply	12V, 5A
Limit Switches	250v , 5A, 1NO + 1NC

The electronic configuration of the CNC machine is shown in Fig. 2. In this figure (1) is the central controller, interpreting G-codes through GRBL firmware, allowing translating software instructions into precise machine movements. (3) are the motors, controlled by A4988 drivers, which ensure the proper movement of the X and Y axes with micro stepping up to 1/16, optimizing precision in each operation. (5) operates with pulse width modulation (PWM), adjusting its power according to the requirements of the material being worked, whether engraving or cutting. (2) ensures a stable power supply for all electronic components, preventing fluctuations that could compromise performance. Additionally, the system includes (4), which protects the machine and facilitates initial configuration by delimiting the operating ranges.

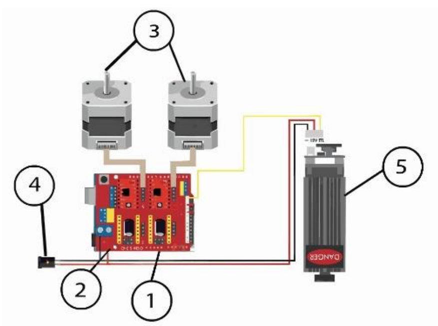

Fig. 2: Electronic configuration of the assembled CNC.

The LT- 20W-A laser module used in this project has a laser output power of 20 W (optical power of 4 W) and operates at 12V with a current range of 1.4 A to 1.8 A. It has a wavelength of 405 nm and an adjustable focus range of 0.787 [in] to 1.378 [in], making it suitable for both engraving and cutting tasks. The module has overvoltage protection and a plug-in control line interface (XH2.54-3P connector), ensuring safe and reliable operation. For a comprehensive overview of the laser module's specifications, refer to Table 3.

TABLE III: LT-20W-A Laser Specifications

Parameter	**Specification**
Laser Output Power	20 W US
Optical Power	4 W US
Electrical Power	12 V, 1.6 A (1.4 A - 1.8 A)
Wavelength	17.717 in
Material	Aluminum Alloy
Laser Color	Blue
Power Adjustable	5V PWM Compatible
Driver Protection	Overvoltage Protection

Adjustable Focus	0.787 in - 1.378 in
Interface	XH2.54-3P Connector
Application	Engraving/Cutting
Control Line Installation	Plug-in
Operating Temperature	32.0 - 158.0 ˚F
Package List	1 x Laser Head, 1 x 31.5 in 3-pin cable
Module Size	1.378 × 1.378 × 3.921 in
Module Weight	5.15 oz

To assembly the machine, the MGN15H linear rails were meticulously installed on the base to ensure precise alignment and prevent displacement. NEMA 17 stepper motors were securely fastened to reinforce MDF supports. These motors were then connected to GT2 pulleys and belts to transmit motion to the machine's axes. The laser module was mounted on a movable platform equipped with an adjustable support, allowing for precise manual focusing of the laser beam onto the processed material. The electronic integration phase involved connecting the Arduino UNO to the CNC shield, A4988 drivers, and the power supply, resulting in a fully functional system. Finally, calibration and initial configuration tests were conducted to optimize the machine's performance. This included adjusting the tension of the belts and fine-tuning the laser power. These steps ensured that the machine could operate with precision and stability, meeting the design specifications. After all mechanical and electronic components were joined, the machine was tested several times to validate the system's perfect functionality. Fig. 3 shows the finished CNC laser-cutting machine.

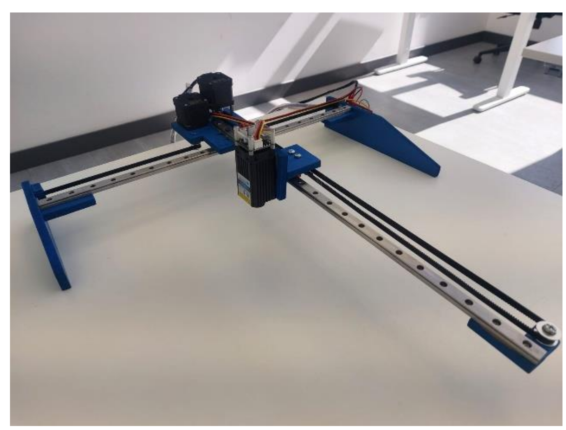

Fig. 3: Complete assembly of the CNC laser-cutting machine.

V. G-CODE GENERATION

G-code generation was accomplished using Inkscape, a versatile vector graphics editor. A specialized plugin, specifically designed for laser engraving applications, was utilized within Inkscape to convert the design into a series of machine-readable G-code instructions. This plugin facilitated the translation of the vector graphics into a format that the CNC machine could understand and execute. Fig. 4 shows an example of the G code generation using Inkscape.

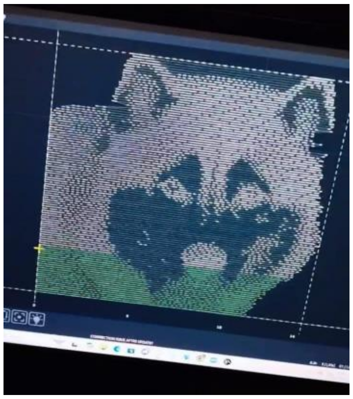

Fig. 4: Example of G code generation.

The generated G-code files were subsequently uploaded to LaserGRBL, a popular open-source software application designed to control CNC machines, particularly those equipped with lasers. LaserGRBL provided a user-friendly interface for managing G-code files, monitoring machine operations, and adjusting real-time parameters. Fig. 5 shows the G code uploading flowchart to the system.

Crucial parameters such as cutting speed and laser power were carefully adjusted within LaserGRBL based on the material's specific characteristics. These parameters significantly influenced the quality and efficiency of the engraving process. For instance, higher laser power was typically required for cutting thicker materials, while lower power and slower speeds were often necessary for intricate engravings.

Finally, the laser focus was manually adjusted to optimize the engraving quality. Proper focus ensured that the laser beam was concentrated at the correct point on the material, resulting in clean cuts and precise engravings. This step often required careful observation and iterative adjustments to achieve the desired results.

This G-code generation and machine control approach provided a flexible and efficient method for executing laser engraving operations on the CNC machine.

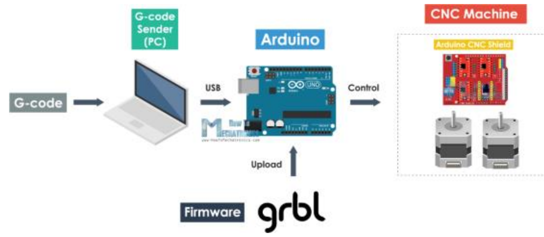

Fig. 5: G code uploading flowchart.

VI. MACHINE TESTS AND VALIDATION

To test the system and validate its correct functionality, several experiments were developed to cut 3 mm thick balsa wood with dimensions of 2.5 x 4 cm; Several settings were tested to optimize power, speed, and cutting time. The goal was to achieve precise and clean cuts on three shapes: a star (A), a candy cane (B), and a tree (C).

In experiment A, the parameters were set as power 70% and cutting speed 150 mm/min. The result was a broad but incomplete cut; the laser didn't fully penetrate the material. The low speed caused excessive burning, widening the edges without properly separating the shape. This result is reflected in Table 4, where some cuts were not fully completed.

TABLE IV: Cutting Test Results

Shape	Cut (Yes/No)	Time (s)
Rod	Yes	10.15
Rod	Yes	8.34
Rod	Yes	10.87
Rod	No	7.22
Rod	Yes	10.41
Tree	Yes	9.56
Tree	Yes	10.62
Tree	Yes	8.77
Tree	No	7.88
Star	Yes	10.03
Star	Yes	9.25
Star	Yes	8.66
Star	No	10.49
Star	No	7.14

For experiment B, the power was increased to 90% and the speed to 250 mm/min. This produced a narrower cut with less burn, but the higher speed made it harder for the laser to follow the shape precisely, leading to incomplete or misaligned cuts. Some edges weren't fully detached, affecting the final quality. As shown in Table 4, some cuts were only partially completed despite improved speed settings.

Finally, in experiment C, the power was adjusted to 85% and the speed to 200 mm/min. This setting created a perfect balance, allowing the laser to make clean and precise cuts without distorting the shapes. The cutting time was optimized, and the pieces were separated neatly without excessive charring. This was the most efficient setup, ensuring sharp edges and an accurate result, as evidenced by the successful cuts shown in Table 4.

The results obtained in these tests are more evident in Fig. 6, in which it is possible to see the evolution of the cutting process for the three objects. Also, Table 5 shows the summary of the results obtained, in which it is possible to conclude that the CNCN cutting machine has a correct operation with a parameters laser distance of 2.5 cm, laser power of 85%, and cutting speed of 200 mm/min.

Fig. 6: Cutting test A, B y C.

TABLE V: Cutting Tests on Rod, Tree, and Star

N	D(cm)	P(%)	Vel(mm/min)	T(s)	Cut?
1	2	70	150	70,15	Only marked
2	3	90	250	42,10	Partially cut
3	2.5	85	200	43,22	Cut correctly

VII. CNC LASER CUTTING COSTS

The proposed low-cost CNC laser cutting machine was designed and constructed in the UIDE mechatronics lab. For this reason, the cost associated with the design and assembly can be reduced. The costs associated with the mechanical and electronic components are shown in Table 6. As shown in this table, the total cost of the system is 266.21 dollars, which is accessible for small and medium enterprises, schools, and students.

TABLE VI: CNC laser cutting cost

Quantity	Description	Total (USD)
2	Nema 17 motor	32.00
2	Linear rails 500mm MGN15	87.98
1	GT2 pulleys and toothed belts	16.99
1	M3 screw spacer kit	5.00
1	Nut and bolt kit M6 M5 M4 M3	8.00
1	A4988 V3 CNC engraver board	8.00
1	Arduino Uno	16.00
2	DRV8825 stepper motor driver	7.50
1	4000mW laser engraving module	49.99
1	12V 10A 60W power supply	24.00
1	8mm MDF for the structure	10.00
3	Bell-type cable (per meter)	0.75
	Costo total	**266,21**

VIII. CONCLUSIONS

After conducting multiple tests, we could fine-tune the laser cutting parameters to achieve clean and precise results. The combination of optimized power and speed settings allowed us to produce three pieces per minute while maintaining good quality, demonstrating that a low-cost CNC laser cutter can deliver professional-level results when adequately calibrated.

One of the biggest advantages of this machine is its affordability. Compared to commercial CNC systems, which can be expensive and out of reach for small businesses, this setup provides an accessible alternative without compromising on precision. This makes it particularly valuable for small and medium-sized enterprises (SMEs) that need a cost-effective solution for custom manufacturing.

Additionally, the flexibility of using an Arduino-based control system gives users more freedom to modify and adapt the machine to different needs. Unlike proprietary software that can limit customization, this open-source approach empowers users to refine their workflows, making the system highly adaptable for various materials and applications.

For small entrepreneurs, having access to an affordable CNC laser cutter can be a game-changer. It allows them to create custom products, prototypes, and even small production runs without requiring a significant initial investment. This accessibility can foster innovation, helping local businesses grow and compete in the market.

This CNC laser cutter proves that high precision and efficiency are achievable even on a limited budget. Its potential impact on education, small businesses, and independent creators makes it a valuable tool for anyone exploring digital manufacturing without breaking the bank.

Accurate cuts remained challenging because the project needed repeated modifications of power and speed settings. Performance was affected by both material restrictions and the need to calibrate hardware at the beginning. Future development will concentrate on automation of calibration procedures and incorporation of AI predictive models and component optimization to enhance the cutting outcomes and operational efficiency.

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