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Design and Fabrication of CNC Milling and Laser Engraving Machine

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ABSTRACT

CNC milling and laser engraving are advanced machining processes used for precision manufacturing. CNC milling removes material using rotating tools, ideal for creating complex shapes in metal, plastic, and wood. Laser engraving uses a high-powered laser to etch surfaces with accuracy, making it perfect for marking and customization. Both technologies offer speed, precision, and versatility, playing a vital role in modern manufacturing.

1. INTRUDUCTION

CNC milling and laser engraving are widely used manufacturing processes that offer precision and automation. **CNC milling** involves cutting and shaping materials using computer-controlled rotating tools.

Laser engraving, on the other hand, uses a focused laser beam to etch designs onto surfaces without physical contact. It is commonly used for marking, branding, and artistic customization on materials like wood, acrylic, and metal.

1.2 SCOPE OF THE CAPSTONE PROJECT

- **Improve Build Quality and Modularity:** It has an improved aluminium frame that offers **more stability and longevity than previous generations.** Users can change individual parts, such the spindle motor or laser module, thanks to the modular architecture.
- **Improved Control Mechanism:** An improved GRBL control system is integrated into the machine, providing smoother operation and increased precision. In contrast to previous iterations, has an offline controller **that enables users to control the machine without a constant computer connection**
- **Increased Compatibility of Materials:** Due to limited spindle power and router bit compatibility, older versions frequently had trouble with specific materials. In order to address this, a greater variety of materials are supported, such as PCB boards, wood, acrylic, and soft metals.
- **Improved Safety Features:** To solve the safety issues with previous versions, safety features like an emergency stop button and improved heat control have been added. By avoiding overheating during extended usage, these enhancements reduce the possibility of mishaps and increase the machine's longevity.
- **Higher Precision and Reliability:** Higher precision and reliable results are provided by the improved stepper motors and spindle, which were issues with the earlier machines. Additionally, calibration options have been improved, enabling users to attain precise and consistent performance.

2. LITERATURE REVIEW

LASER ENGRAVING

Richard G. G (1920–2005) played a significant role in the development of laser technology and optical amplification. His long legal battles to secure patents for the laser and related technologies highlighted the competitive nature of this innovation. Although the exact date of laser etching's invention is unclear, laser engraving was first introduced in 1978. Key advancements in laser technology include Einstein's theory of stimulated emission (1917), the maser concept (1951), and the invention of the CO_2 laser (1964). Over time, laser engravers have evolved to become more compact, precise, and environmentally friendly, incorporating safety features like polycarbonate windows to absorb radiation.

CNC MILLING

John T. Parsons is recognized as the pioneer of CNC machining, introducing numerical control (NC) in machine tools. CNC technology emerged during World War II, driven by the aerospace industry's need for high-precision parts. In 1952, Parsons and Frank L. developed the first CNC milling machine at Parsons Corporation in Michigan. This early machine used numerical control systems and motor-driven tools, setting the foundation for modern CNC technology. By integrating digital programming and positioning tools, CNC machining revolutionized manufacturing, allowing for greater automation and accuracy.

3. CAPSTONE PROJECT WORK

3.1 CAPSTONE PROJECT PLANNING

3.1.1 Work breakdown structure (WBS)

A hierarchical chart or diagram known as a work breakdown structure (WBS) divides a task or project into smaller, easier-to-manage parts. It is a project management tool used to plan and arrange the different tasks or components of a project. The work breakdown structure (WBS) breaks the project up into smaller, easier-to-manage components known as work packages. After then, these work packages are further divided into more manageable and actionable tasks or activities.

3.2.1 Key Levels in the Work Breakdown Structure (WBS)

- **Project Planning:**
    1. Research: Investigate required components, market options, and feasibility of designs.
    2. Decision Making: Define key decisions (machine specs, suppliers, software choice).
    3. Purchasing: Acquire necessary parts, materials, and tools.
- **Build Phase:**
    1. Controller setup
    2. Motor Driver Installation: Set up motor driver for controlling the motors.
    3. Extruder Driver Installation: Install extruder driver for filament feeding.
    4. Controller Integration: Assemble the main controller that links motors and extruder.
    5. Frame Construction.
- **Programming:**
    1. 3D Software Setup
    2. Install 3D Printing Software: Install slicing software (e.g., Cura, Prusa Slicer).
    3. Configure Settings for Printer: Input specifications such as bed size, extruder type, etc. Stepper Motor Testing: Test motors for correct movement.
    4. Controller Software Setup
    5. Compile Firmware: Configure and compile firmware for the machine's controller. Motor and Axis Control.
- **Delivery/Final Assembly:**
    1. Final Assembly.
    2. Assemble Extruder to Frame: Mount the extruder on the assembled frame.
    3. Attach Wiring to Motors and Controller: Wire up the motors and other components to the controller.
    4. Troubleshooting.
    5. Address Wiring Issues: Resolve any power or connectivity issues.

SL NO	REGISTER NUMBER	STUDENT NAME	WORK ASSIGNED	ROLES
1	499ME22012, 499ME22025	Nagamani. N Vishal. S	Documenter	Group Lead
2	499ME23304, 499ME22020, 499ME22006	Narasimha. A Shiva Shankar. K. S Karthik. B	Desing And Fabrication , Purchase Of Parts	Desing And Fabrication Team
3	499ME23303, 499ME22013	Likith Kumar. M Charan. P	Literature And Market Survey	Survey Team

Table: Work break down Work Distribution

3.1.2 Time Line Schedule

Making a timetable for an upgraded three-axis GRBL CNC Milling And Engraving Machine. The complexity of the machine, component availability, and production procedures are only a few of the variables that affect CNC engraving machines. Phases of design, prototyping, testing, and production are typically included. A ballpark figure might be:

1. **Planning and research**: This phase involves defining the project scope, objectives, and technical requirements. Research focuses on material selection, component specifications, software compatibility, and cost analysis
2. **Methodology and objective:** The methodology involves a step-by-step approach, including design, component selection, assembly, software integration, testing, and optimization.
3. **Market survey:** The market survey focuses on analysing existing CNC milling and laser engraving machines, identifying key features, pricing, and customer demands. It evaluates the latest industry trends, competitor products, and technological advancements to determine the best components and software.
4. **Implementation With assembly**: The implementation phase involves assembling and integrating the CNC Milling & Laser Engraving Machine. The mechanical frame is first constructed using aluminium extrusions and guide rails for stability.
5. **Testing**: The testing phase ensures the CNC Milling & Laser Engraving Machine functions accurately and efficiently. Initial checks include verifying electrical connections, stepper motor movements, and spindle/laser activation.
6. **Reporting:** The reporting phase documents the entire CNC Milling & Laser Engraving Machine development process, including design, assembly, testing, and performance analysis.

SL NO	TASK	ESTIMATED TIME	START WEEK	END WEEK
1.	Planning and research	2 Week’s	Week 1	Week 2
2.	Methodology and objective	3 Week’s	Week 3	Week 5
3.	Market survey	4 Week’s	Week 6	Week 9
4.	Implementation With assembly	4 Week’s	Week 10	Week 13
5.	Testing	1 Week’s	Week 14	Week 14
6.	Reporting	2 Week’s	Week 15	Week 16

Table : Time Line Schedule

3.1.3 COST BREAKDOWN STRUCTURE

A comprehensive list or breakdown of all project-related expenses is called a cost breakdown structure. It contains an exhaustive list of every part, subpart, and related expense needed to finish a project. To create an accurate budget and spot possible costs, a cost breakdown structure helps to better understand the costs of every component of a project or product.

COMPONENT	**COMPANY NAME**	**QUANTITY**	**PRICE**
Frame And Mechanical Parts	**Trinamic**	**1 set**	**12,880rs**
Stepper Motor	**Robokits ind**	**4 no's**	**3,220rs**
Spindle Motor	**GRBL**	**1 no**	**4,293rs**
Control Board	**-**	**1 no**	**5,152rs**
Offline Controller	**SKU Laser's**	**1 no**	**1717rs**
Laser Module	**-**	**1 no**	**4,293rs**
Router Bits And Accessories	**-** **-**	**2 set's**	**1717rs**
Miscellaneous Hardware	**-**	**1 no**	**859rs**
RAW Materials (Wood, Acrylic Board)		**3-4 set's**	**2,500rs**
Total Estimated Cost			**39,852rs**

Table : COST BREAKDOWN STRUCTURE

3.1.4 Capstone Project Risks Assessment

TECHNICAL RISKS:

- Hardware Malfunction
- Software Issues
- Material Compatibility

OPERATIONAL RISKS:

- User Error
- Project Delays

FINANCIAL RISKS:

- High Initial Investment
- Maintenance Costs

SAFETY RISKS:

- TOOL BREAK
- OVER HEATING

OBJECTIVE

The objective of a CNC Milling and Laser Engraving Machine is to enable precise cutting, engraving, and machining of various materials with high accuracy and efficiency. It automates manufacturing processes, reduces material wastage, and enhances productivity for industries like manufacturing, signage, and custom product design

1. Understand CNC Machine Operation

2. Customization and Creativity
3. Material Versatility and Experimentation
4. Skill Development and Prototyping
5. Efficiency and Innovation
6. Offline Controller Utilization
7. Safety and Maintenance

Design Specification

3.3.1: System Design Selection:

A 3-axis Cartesian coordinate system was selected for the CNC router's design in order to enable accurate milling, engraving, and carving processes. The X, Y, and Z axes of the machine will be driven by stepper motors and either ball or lead screws

Important Aspects of the Selected Design

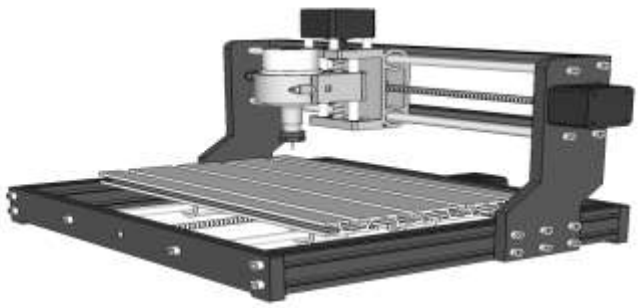
Frame: Made of mild steel or aluminium, the frame minimizes vibration while operating while offering strength.

Spindle Motor: Various materials can be sliced, engraved, and carved using this high-speed motor.

Controller: A microcontroller or CNC controller that decodes G-code and manages the motions of the machine, such as GRBL

Ball Screws/Lead Screws: Used for translating rotational motion from stepper motors into linear motion for precise control of each axis.

Bearings and Guide Rails: The carriage moves smoothly in the X, Y, and Z directions thanks to linear motion guide rails.



Methodologies

1. Research and Planning
2. Design and Programming
3. Machine Setup and Calibration
4. Testing and Optimization
5. Material Selection and Process Evaluation
6. Production and Prototyping
7. Safety, Maintenance, and Documentation

Technology

CNC milling is a precise machining technique that removes material from a workpiece using computer-controlled movements. The machine translates CAD design files into G-code, guiding cutting tools along multiple axes—typically 3-axis or 5-axis—for intricate designs. High-speed rotating tools like end mills and drills shape materials based on spindle speed and feed rate, making CNC milling essential in manufacturing, automotive, and aerospace industries. Similarly, laser engraving uses high-intensity laser beams (CO2, fiber, or Nd: YAG) to vaporize material for detailed designs.

DETAILS OF SOFTWARE PRODUCTS

1. Easel Software for G-Code Generation

2. Candle GRBL Software for CNC Milling

3. Light Burn Software for Laser Engraving

Easel is a cloud-based software by Inventible for generating G-code in CNC milling, offering an all-in-one solution for designing, creating toolpaths, and controlling CNC machines. It features intuitive design tools, automatic G-code generation, a simulation mode for previewing cuts, a material library with preset settings, and real-time CNC machine control.

Candle is an open-source GRBL controller software designed for CNC milling, providing an intuitive interface to control machine movements, send G-code commands, and monitor operations. It features real-time CNC control, G-code execution, a 2D visualization preview, and adjustable spindle and feed rate settings, ensuring optimized cutting.

Light Burn is a powerful laser engraving and cutting software that offers an all-in-one solution for designing, editing, and controlling laser machines. It features vector and raster design tools, image tracing, optimized G-code generation, and layer control for precise engraving depth and speed.

DETAILED DESCRIPTION OF COMPONENTS/ SUBSYSTEM

Controller Board & Electronics: The controller board runs on GRBL 1.1 firmware with an ATmega328P microcontroller, controlling NEMA 17 stepper motors via A4988 or DRV8825 drivers. It operates on a 24V 5A power supply and supports USB and offline controller connectivity.

Frame & Structure: The frame & structure is made from aluminium and plastic, providing a lightweight yet stable design. It features a 300 x 180 x 40 mm work area, suitable for small projects. Linear guide rails with bearings ensure smooth movement of the cutting head, while the lead screw-driven motion system enhances precision.

Stepper Motors & Motion System: The Stepper Motors & Motion System includes three NEMA 17 stepper motors, controlling movement along the X, Y, and Z axes with precision. Lead screws and anti-backlash nuts minimize play, ensuring accurate positioning. Some models use a pulley & belt system for smoother motion.

Work Bed & Clamping System: The Work Bed & Clamping System is made from MDF or aluminium, offering a 300mm x 180mm work area with a Z-axis height of 40mm. It features pre-drilled mounting holes for easy attachment of clamps, ensuring stability during engraving and milling. The clamping system includes metal clamps, T-slot nuts, and screws to hold materials securely.

Power Supply & Wiring: The operates on a 24V, 5A power adapter, ensuring stable performance for the stepper motors, spindle, and controller board. The wiring system connects the stepper motors, spindle motor, and limit switches to the GRBL-based controller board, allowing smooth communication and precise control.

Limit Switches & Safety Features: The limit switches prevent over-travel of the spindle, protecting both the machine and workpiece from damage. They are placed at the ends of the X, Y, and Z axes, triggering a stop when the machine reaches its movement limits. The homing function enables the CNC to return to a predefined starting position automatically, improving repeatability and accuracy.

Software & Control: The user a combination of software tools for control, engraving, and G-code generation. Candle (GRBL Controller Software) is primarily used for CNC milling and engraving, providing a simple interface to send G-code commands and manually control movements. Laser GRBL is specialized for laser engraving, allowing image-to-G-code conversion and precise laser power adjustments.

Spindle Motor & Power: The comes with a 775 spindle motor, running at 10,000-12,000 RPM, suitable for engraving and light milling on materials like wood, acrylic, and PCB. For more demanding applications, it can be upgraded to a 500W or brushless spindle, allowing for deeper cuts and better performance on harder materials like aluminium.

CNC Router Bits & Cutting Tools: The a variety of router bits and cutting tools, each designed for specific applications. End mills are general-purpose tools used for cutting, carving, and shaping materials like wood, plastic, and acrylic. V-bits are ideal for engraving fine details, such as lettering and intricate designs.

Laser Module: The CNC 3018 Pro supports 5W-15W laser modules, allowing precise engraving on wood, acrylic, leather, and other soft materials. The laser is controlled using Laser GRBL software, which enables image-to-G-code conversion and real-time power adjustments.

Theory of Assembly

The assembly of a flexible CNC milling and laser engraving machine integrates mechanical, electrical, and software components to enable both subtractive (milling) and non-contact (laser engraving) manufacturing. The goal is to ensure accuracy, stability, and seamless switching between milling and laser operations. Key assembly steps include constructing the mechanical frame, installing linear rails and lead screws, mounting stepper motors, assembling the control board, connecting electronics, attaching the spindle and laser module, configuring the power supply, and setting up software.

Mechanical Assembly

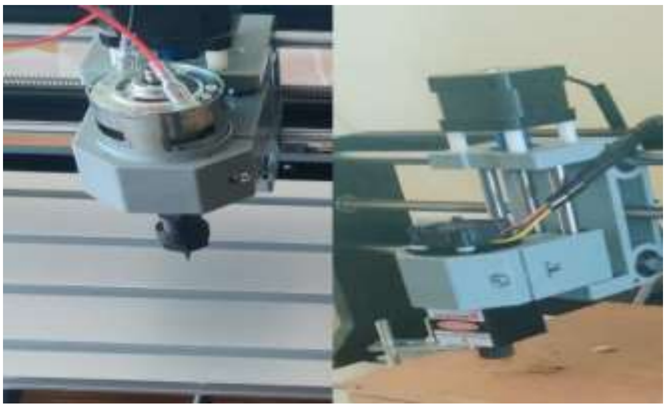
The process begins with assembling the mechanical frame, ensuring a stable and level foundation using an acrylic or aluminium base. Vertical supports are attached to hold the gantry, which moves along the X and Y axes. Linear rails and bearings are installed for smooth movement, followed by securing lead screws or belts for precise motion. The stepper motor system is mounted on all axes, with couplers connecting motors to lead screws and limit switches installed for safety and homing functionality.

Electronics and Control Board Assembly

A GRBL-based control board is secured to the frame, with stepper motor drivers wired for precise axis control. The electronics wiring involves connecting motors, limit switches, and peripherals to the controller board while ensuring neat cable management using chains and zip ties. The power supply (typically 24V) is installed with proper insulation and grounding, providing regulated voltage for the controller, motors, spindle, and laser module.

Spindle, Laser Module & Software Configuration

The CNC milling spindle is mounted to the Z-axis bracket with a secure clamp, while the laser module is attached using a quick-release mount for easy interchangeability. The software setup involves installing GRBL firmware for motion control, using Candle for CNC milling and Light Burn for laser engraving. Calibration settings such as step/mm values, homing, and spindle/laser power adjustments ensure smooth machine operation.



Power Supply & Connectivity Check

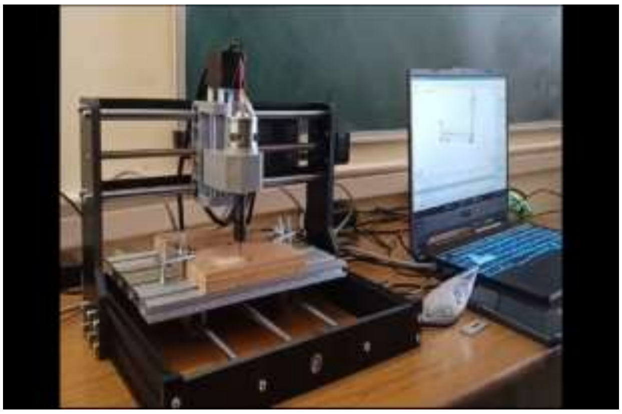
A stable 24V power supply is essential for motors, the laser module, and the control board. Proper connectivity ensures smooth operation, and testing Pulse Width Modulation (PWM) control helps regulate laser power effectively. Checking voltage consistency and current flow prevents system failures during CNC milling and laser engraving.

Structural & Mechanical Analysis

The frame rigidity and vibration levels must be tested to ensure minimal movement during machining. A dial gauge or accelerometer helps measure vibrations. Axis precision and alignment should be verified using a dial indicator to ensure smooth X, Y, and Z-axis movement. The spindle and laser head should be perpendicular to the work bed for accurate cutting and engraving. Load testing assesses the machine's capability to cut various material thicknesses at different speeds and power levels.

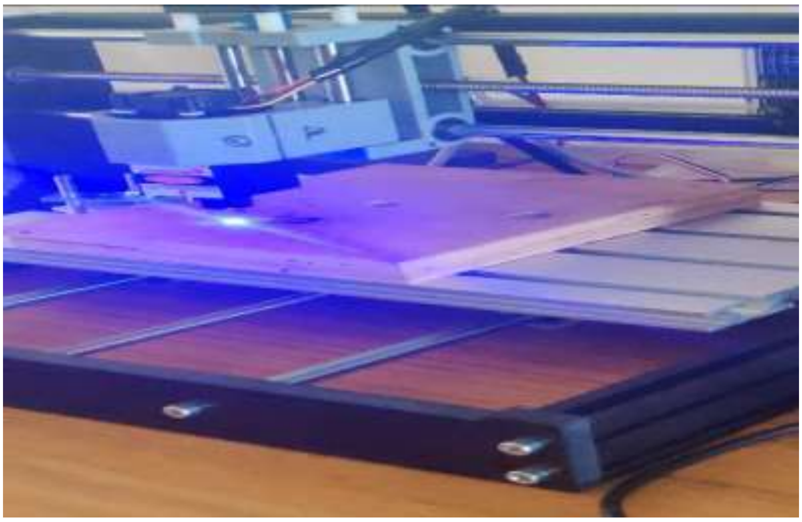
CNC Milling Performance Testing

Optimizing cutting speed and feed rate is critical for different materials like wood, acrylic, and aluminium. Spindle RPM, feed rate, and depth of cut must be fine-tuned for best results. The surface finish and accuracy of milled parts can be assessed using a surface profilometer to measure roughness and precision.



Laser Engraving Performance Testing

To achieve high-resolution engraving, beam focus and spot size must be adjusted by testing different focal distances and lens configurations. Material engraving tests on wood, leather, acrylic, and metal help determine optimal power levels, ensuring sharp edges, proper burn depth, and high contrast for clear engravings.



Software & G-code Testing

Before actual operation, G-code simulation and dry runs should be conducted using software like Candle, Fusion 360, or Laser GRBL to verify motion paths. Performing dry runs (without activating the spindle or laser) ensures that tool movements follow the intended design, preventing errors during engraving or milling.

FINANCIAL CONSIDERATIONS

When planning the CNC Milling & Laser Engraving Machine, several financial aspects were considered, including material costs for the aluminium frame, stepper motors, spindle, laser module, and power supply. Software costs were factored in, with GRBL being open-source but design software like Fusion 360 and Inkscape potentially requiring licenses.

Bill of material (BOM)

Here is a detailed cost breakdown of the components:

Component	**Quantity**	**Estimated Cost (INR)**
CNC Frame (Aluminium)	**1 Set**	**5,000rs**
Stepper Motors (NEMA 17)	**3**	**3,200**
Spindle Motor (775 or 500W)	**1**	**4,293**
Laser Module (5W-15W)	**1**	**12,447**
GRBL Controller Board	**1**	**2,152**
Power Supply (24V, 5A)	**1**	**1,500**
Linear Rails & Lead Screws	**3**	**2,000**
Work Bed (Aluminium or MDF)	**1**	**1,500**
Router Bits	**10+**	**1,000**
Wiring & Connectors	**Various**	**1,000**
Software (CAD/CAM)	**Open-Source or Licensed**	**1,000**
RAW Materials (Wood, Acrylic Board)	**Various**	**3,000**
Total		**38,092**

Table 9.1: Cost Break Down Structure

CONCLUSION

The CNC Milling & Laser Engraving Machine project successfully demonstrates the integration of precision machining and automation for engraving and cutting various materials. By carefully planning material selection, software integration, and cost optimization, we have developed a functional and efficient system. The project not only enhanced our understanding of CNC technology but also provided hands-on experience in design, programming, assembly, and troubleshooting. With future improvements, such as higher-powered lasers and better spindle motors, this system can be further optimized for industrial and commercial applications. Overall, this project showcases the potential of CNC and laser engraving in modern manufacturing and prototyping