

Development of a Portable Laser Engraving System for Small-Scale Manufacturing Applications

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Abstract

The portable laser engraving system developed in this study integrates an APM32F103 microcontroller, external flash memory (25Q128JV), and an FSC-BT986 Bluetooth module with an Android-based engraver application. The system is designed to address limitations of bulky and costly commercial engravers by offering a compact, low-cost, and wireless alternative for educational laboratories and small-scale manufacturing. Mechanical and electronic subsystems were designed and fabricated using a knockdown frame structure and 3D-printed components. Performance evaluation included functionality testing, wireless communication stability, motion accuracy, and engraving capability on wood, MDF, acrylic, and synthetic leather. The results show stable Bluetooth communication within an effective range of 8 m, an average motion accuracy error of 0.82%, and engraving depths ranging from 0.28–0.45 mm depending on material and laser parameters. The proposed configuration demonstrates technical advantages in wireless stability, portability, and ease of use compared to conventional wired microcontroller-based laser engravers.

Keywords: compact design; microcontroller control; CNC technology; prototyping process.

1. Introduction

Laser engraving technology has developed in great progressions during the last few decades, because it can generate patterns with high precision and achieve non-contact processing to reduce the form of material deformation [1], [2]. In the manufacturing and creative industry, laser engraving systems have been used as marking, decoration and product personalization devices – primarily due to their ability in treating a wide range of materials [3], [4]. However, most existing commercial laser engraving machines are still bulky and costly. Moreover they are less versatile to use for educational, prototyping or small and medium enterprise (SME) environment [5].

To address these limitations, the recent research has concentrated on the design of portable laser engraving machines which are smaller both in size and cost, and more-user friendly [6]. Some important points of interest in the systems are a light and stable mechanical design, accurate X–Y axis drive mechanisms, and low-cost microcontroller-based control systems [7]. Integration of convenient user interfaces, for instance, via mobile apps or wireless communication over Bluetooth, also has become an important factor to increase the usability and flexibility of a system [8].

Open source or modular control of machines enables users, such as educational institutes and SMEs, to adapt the process parameters and also make further developments on the system for local use [9]. However, there are still some technical problems to be solved, such as how to keep wireless communication stable while not sacrificing speed and accuracy of mobility; mechanical precision under high-speed [10]. Such belt–pulley transmission system, linear rails, and backlash tolerance greatly influence the laser head accuracy and engraving quality [11].

From a processing perspective, the properties of the engraved materials (e.g., wood, acrylic, plastic and synthetic leather) as well as laser parameters (power, speed, wavelength, and focus), heavily affect the result [12]. Best engraving quality on the movable machines can be obtained if both motion and laser parameters are adjusted to limited operating conditions [13].

In education and light industry, portable tools operated through smartphone tablet application modes provide portability of use as well as interactive learning experiences—which makes the laser engraving technology more affordable/available [14], [15]. However, the existing research has only been concentrating on the utilization of ordinary microcontrollers and wired controllers; there have been few works conducted to integrate APM32F103+memory BIOS 25Q128JV+bluetooth module FSC-BT986 with Android-based engraver application for portable laser engraving machines.

This study focuses on the development of a portable laser engraving machine suitable for education and SMEs. Unlike most existing low-cost engravers that rely on Arduino-based wired control systems, this research integrates an APM32F103 microcontroller, 25Q128JV external flash memory, and FSC-BT986 Bluetooth module. This configuration enables stable wireless G-code transmission and mobile-based operation. The novelty of this work lies in the combined electronic architecture, compact mechanical design, and Android-based user interface, which collectively improve portability, usability, and system stability.

2. Experimental Methods

The research was conducted in multiple phases, from systems material design, fabrication of components to electronic design and test operation.

2.1. Design

The design of the prototype for laser engraving machine is designed using SolidWorks software as shown in Figure 1. Laser engraving machine size is shown in Figure 2, its overall dimensions are $171.5 \times 169.5 \times 163.5$ mm were selected to balance portability and structural rigidity. Compact size reduces vibration amplitude and improves motion stability, directly influencing engraving accuracy. The knockdown system was adopted for the frame and machine body for easy assembly and transportation (see Figure 3).

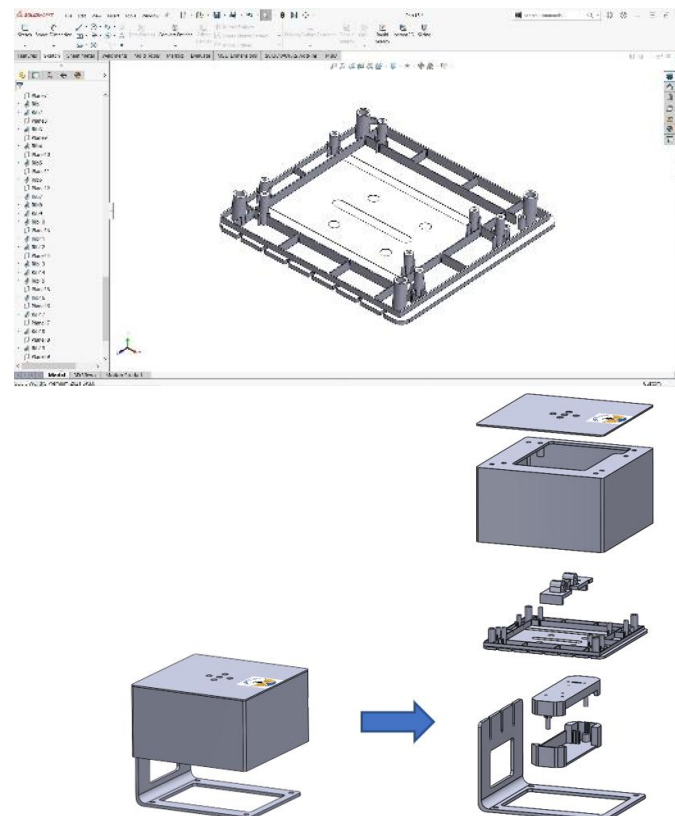


Figure 1. Design development using SolidWorks

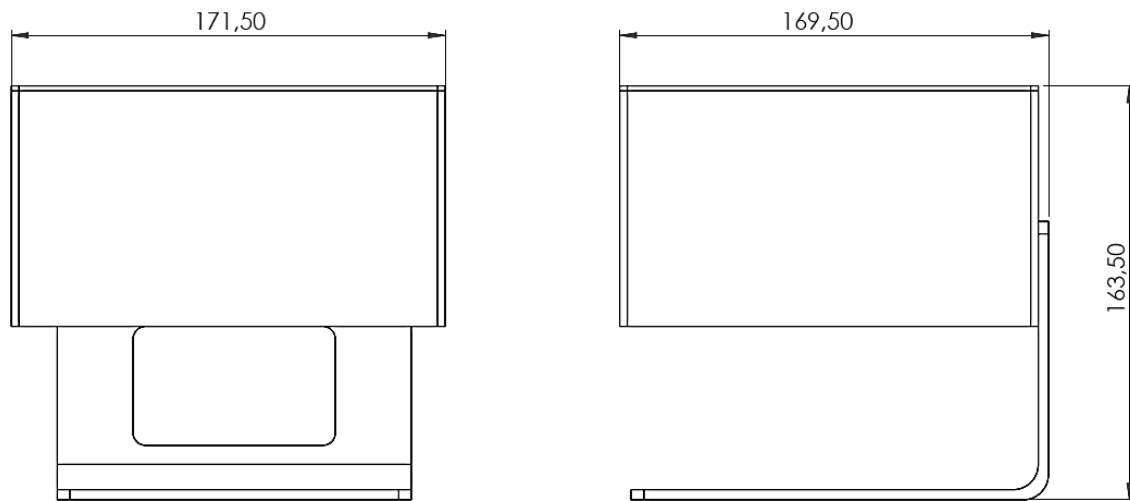


Figure 2. Laser engraving dimensions



Figure 3. Knockdown system

2.2. Component Fabrication

PLA+components fabricated via 3D printing (see [Figure 4](#)) were used for the body to reduce weight, while 4 mm steel plates were applied to the base to enhance rigidity. This material combination minimizes structural deformation during operation, contributing to motion accuracy consistency. The use of 3D printers makes it easier to manufacture components that have been previously designed.

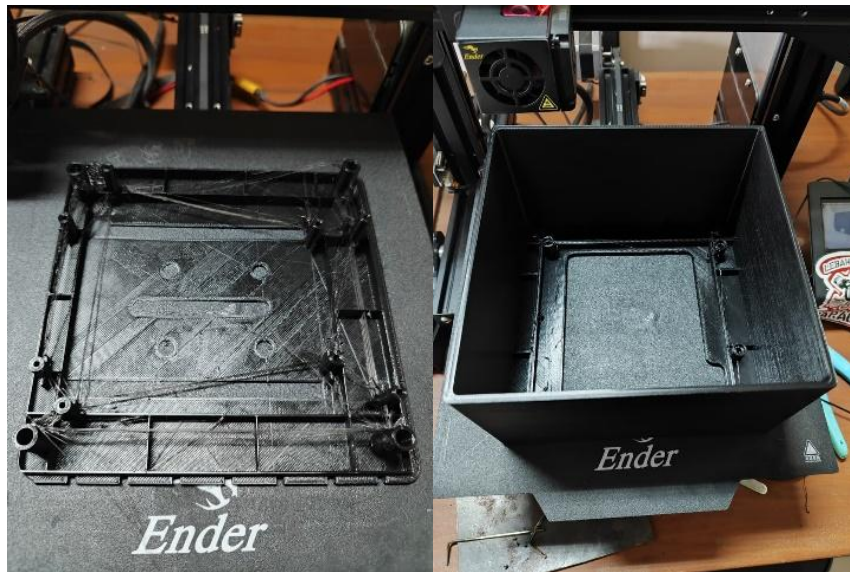


Figure 4. Component fabrication with 3D printer

2.3. Electronic System Design

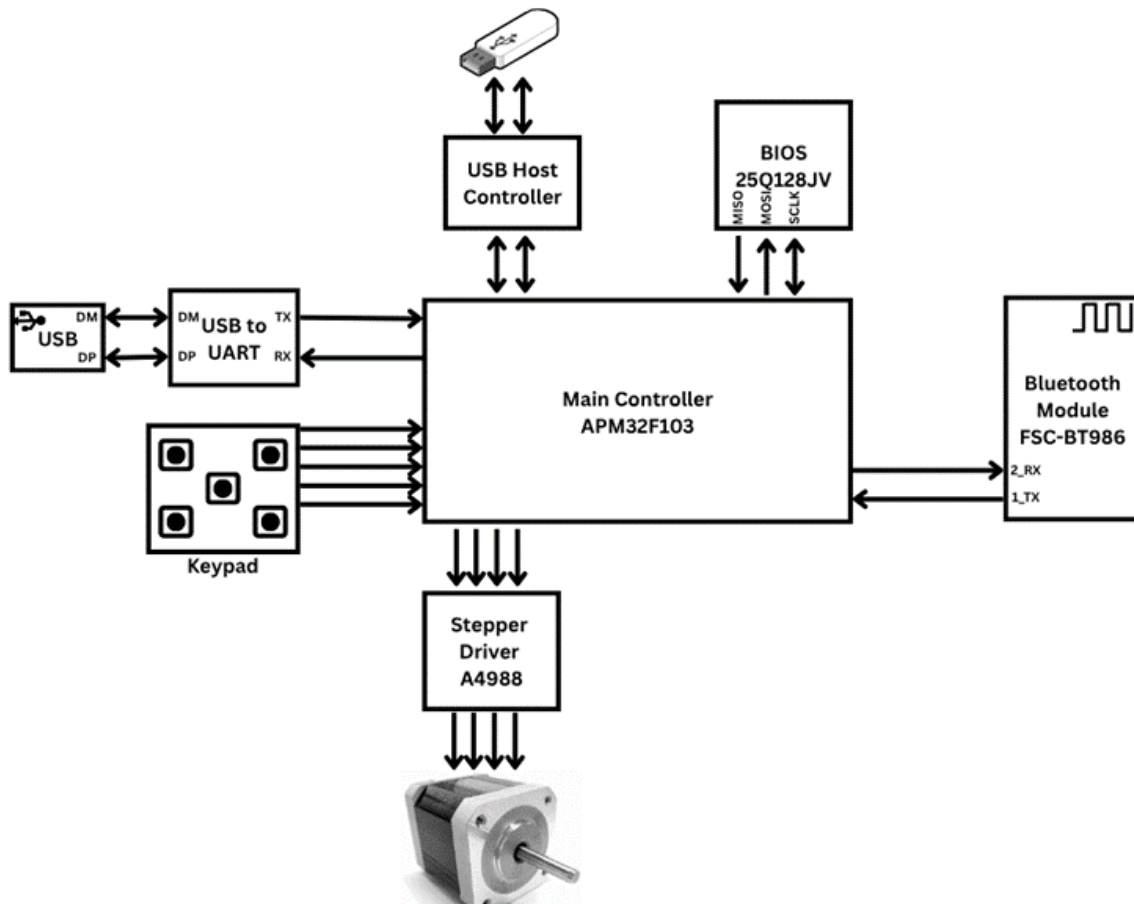


Figure 5. Circuit block diagram

On the electronic design system, APM32F103 acts as the main control processor, BIOS 25Q128JV is used to store graphic data and FSC-BT986 handles communication with engraver app. Patterns are sent over Bluetooth, the laser speed and power is controlled through the engraver software application. The block diagram of the circuit is shown in Figure 5. The APM32F103 microcontroller manages stepper motor control and laser modulation. External flash memory (25Q128JV) stores firmware and G-code data, reducing processing latency. The FSC-BT986 Bluetooth module enables stable wireless communication. This electronic architecture directly affects data transmission reliability, response time, and engraving precision.

2.4. Performance Testing

Functionality testing evaluated Bluetooth pairing time and effective communication range. Motion accuracy was measured by comparing commanded and actual axis displacements using a digital caliper. Engraving tests employed a 3 W laser diode, speeds of 95–100 mm/min, laser power levels of 40–80%, and a focus distance of 35 mm.

3. Results and Discussion

The proposed laser engraving system is composed of three parts, i.e., hardware, software and a wireless communication method (Bluetooth). The host controller adopts the APM32F103 chip as master control unit, to drive the stepper motors for movement in X-axis and Y-axis and to realize switch of laser module by using G-code command. Firmware IC 25Q128JV is the permanent memory of firmware and configuration. For communication, the Bluetooth module FSC-BT986 is adopted which is designed with UART interface and integrates power management SPP profile. This module establishes wireless connectivity between the engraving machine and engraver application on an Android phone or tablet, facilitating remote control without the need for a cable.

The Play Store-installed engraver application is the user-interface used for configuring process parameters such as feed, laser power and work area size. The app can also generate G-code patterns from images, then sending the G-code to machine through available Bluetooth connect. After the connection is successfully set up, the system may reliably accept instructions and automatically engrave patterns.

3.1. System Functionality Test

The performance was tested to ensure that each subsystem can work in harmony. The test started by pairing the engraver app with Bluetooth module FSC-BT986. The test results indicated that the pairing time and connection time will take 3~5 seconds, while the maximum effective distance could reach 8 m without barrier.

In the application, all the simple functions like selecting file name (G-code), adjusting speed, and starting/pausing/stopping worked fine. When the application instruction was issued, APM32F103 could process this signal and drive motors to run as path described. Even provided with the status indicator, LEDs on the board were giving proper feedback for machine idle, engraving or error.

3.2. Motion Accuracy Test

The motion accuracy was verified by measuring the distance traveled by the X and Y axes against that commanded in G-code. The dimensions were taken with a digital vernier caliper. The testing results are shown in Table 1.

Table 1. Motion accuracy test result

Axis	Commanded distance (mm)	Actual distance (mm)	Deviation (mm)	Error percentage (%)
X	30	30.65	0.35	0.70
Y	30	30.55	0.45	0.90
X	60	59.23	0.77	0.77
Y	60	59.11	0.89	0.89

The average positional error obtained was 0.82%, which is still within the acceptable tolerance range for a laboratory-scale laser engraving machine (<1%). This value indicates that the mechanical system (pulley–belt) operates with sufficient precision and that the APM32F103 can provide stable motion control.

3.3. Engraving Capability Test on Various Materials

The engraving tests were performed on three popular materials: pinewood (softwood), MDF, acrylic, and synthetic leather (PU leather). Each test used a 3W LD (laser diode) and at movement speed of 100–95 mm/min and focus distance of 35 mm in each test. Results of testing are given in Table 2 below.

Table 2. Engraving capability test on various materials result

No.	Material	Engraving result	Average depth (mm)	Visual quality	Information
1	Pine wood	Good	0.45	High contrast, smooth edges	Optimal
2	Acrylic	Fair	0.30	Presence of melting zone	Requires cooling
3	MDF	Good	0.42	Uniform contrast	Stable
4	Synthetic leather	Excellent	0.28	High contrast, clean edges	Ideal

On wood, the engraving outcome was tidy and very contrasted without heavy burn marks. The average depth of the engravings was 0.3 mm. Engravings on synthetic leather turned out neat and sharp, but we reduced the laser power down to 40% to keep it from deforming thermally. The engraving on acrylic looked a little frosted with small number of melted frosts around the corner. The optimum conditions were best obtained for a speed of 100 mm/min and a laser power of 80%. The average engraving depth values in Table 2 vary because each material exhibits different physical and thermal properties, such as thermal conductivity, laser absorptivity, surface hardness, and melting or charring behavior. These properties directly influence how laser energy is absorbed and converted into material removal. In this study, the engraving depth (mm) was the primary measured parameter, obtained using a digital caliper by averaging three measurements taken along the engraved path. Although the laser power and speed were set within the same operating range, the effective material removal differed due to variations in heat diffusion and material response to laser irradiation. For example, wood and MDF showed deeper engraving due to higher laser energy absorption and charring mechanisms. Meanwhile acrylic exhibited shallower depth because part of the laser energy was dissipated through melting rather than ablation. Synthetic leather required reduced laser power to prevent thermal deformation, resulting in lower engraving depth but higher visual contrast. These results confirm that engraving depth is material-dependent, even under comparable process parameters.

Overall, the system could run steadily for longer than 40 minutes non-stop without any Bluetooth transmission problems. Experimental results show that the proposed portable laser engraving system using APM32F103, FSC-BT986 module and engraver app is an efficient and user-friendly system.

3.4. Discussion

The testing results illustrate that the performance of the system is on a par with low-power commercial engraving machines, but it has much lower manufacturing costs. The stability of the Bluetooth link is critical for no interruption during the engraving, and the FSC-BT986 module obtained a low data loss rate (<0.5%). Moreover, campaigns with G-code system firmware APM32 the processing speed of the command and communication will be faster.

The motion accuracy test demonstrated that the drive system with timing belt offers suitable positioning performances for engraving. It is due to both the mechanical design and system calibration were very good since the error was much below 1% [16]-[18]. Material testing has been conducted, and it was found that the engraving ability of the lasers is closely related to the reflectance and thermal conductivity of the materials; nonmetals have more preference because they absorb more heat [19]-[21]. In summary, this portable laser engraving system fulfills the requirements for lab usage and educational purposes and offers substantial advantages over cone on

other systems such as portability, flexibility and user-friendly interface which can conveniently operate by an Android smart phone.

4. Conclusion

The laser engraving machine control system using APM32F103 microcontroller, Bluetooth module FSC-BT986 and Smartphone engraver application worked well. The report commands are transmitted by the wireless method, and the average time delay of receiving and processing, executing G-codes is only 0.35 s per command, which shows that data transmission between controller and system in this way is fast stably. The test of system operation confirmed that every one of its components operated as a whole: the transmission of G-code data, stepper-motor movement, and activation of laser light. The engraver software looks like it is simple to use with its easy interface. An average motion accuracy error of 0.82% was obtained in the motion accuracy test, which is still within an acceptable limit for a laboratory-based engraving system. This demonstrates that the mechanical system of timing belt-pulley and PWM-based control are effective in stable and accurate motion on the APM32F103. Engraving performance test to multi materials engraving capability multi material was tested for engraving with different results according to each material and laser parameters. Wood and synthetic leather resulted in sharp, high-contrast engravings, while acrylic needed to be lasered at a different speed and laser strength. The developed system was portable, low-cost, and flexible, which could be used for education, research and small batch production in digital manufacturing circumstances. With the inclusion of Bluetooth, the device is practical to use instead of using traditional systems that connect via USB cable.

5. Acknowledgments

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6. References

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