



Esp32 Microcontroller Based Braille CNC Printer

DR.L.Umasankar M.E, Ph.D, R.Pugazhenth

Associate Professor, Department of EEE, S. A. Engineering College, Chennai, Tamil Nadu, India

PG Student, Department of EEE, S. A. Engineering College, Chennai, Tamil Nadu, India

Publication History: Received: 25.02.2026; Revised: 20.03.2026; Accepted: 25.03.2026; Published: 28.03.2026.

ABSTRACT: An ESP32-based CNC Braille printer is a tactile printing device designed to emboss Braille dots using CNC motion control. It converts digital text into raised patterns readable by touch, aiding visually impaired users. Compared to Arduino, ESP32 offers superior processing speed and dual-core performance. Built-in Wi-Fi and Bluetooth enable wireless control and remote updates. The printer uses stepper motors and servo mechanisms for precise dot placement. ESP32 supports SPIFFS for onboard Braille file storage and retrieval. Voice input integration allows hands-free operation and accessibility. Real-time text-to-Braille conversion is faster due to ESP32's higher clock rate. Arduino-based systems often require external modules for connectivity. ESP32's larger memory supports complex firmware and multitasking. The printer can be controlled via mobile apps or web interfaces. It's cost-effective and scalable for educational and assistive tech use. Open-source libraries and community support enhance development. The design promotes inclusive technology and digital literacy. It bridges the gap between IoT and accessibility solutions. ESP32 makes Braille printing smarter, faster, and more connected.

KEYWORDS: ESP32, Braille Printer, CNC Machine, Assistive Technology, Embedded Systems, Tactile Printing, IoT Automation

I. INTRODUCTION

1.1 Background

The background of the ESP32 CNC printer lies in the growing need for affordable, compact, and connected solutions for CNC (Computer Numerical Control) automation. Traditionally, desktop CNC and 3D printers relied heavily on 8-bit controllers like the Arduino, which, while accessible, limit processing performance and connectivity options. As demands for higher precision, multi-axis support, advanced G-code interpretation, and streamlined remote operation grew, microcontrollers with greater capabilities became essential. This set the stage for the ESP32's entry into the CNC ecosystem, offering dual-core 32-bit processing power and integrated wireless networking at a low cost. ESP32 microcontroller introduced a leap forward with its built-in 2.4GHz Wi-Fi and Bluetooth, rich GPIO, and flexible peripherals. Developers quickly adopted it for CNC control, leveraging its advantages to offer wireless file transfers, real-time monitoring, and web-based user interfaces for controlling machines. Custom open-source firmware, like FluidNC and Grbl_ESP32, was developed for the ESP32 to handle timing-sensitive step generation, G-code parsing, axis coordination, SD card file management, and even web hosts—all tasks that stretch beyond traditional controllers' capabilities.

Component

- 1.ESP32 devkitv1 Main controller; reads G-code, processes motion commands using GRBL firmware, and generates precise STEP and DIR signals for each axis.
- 2.CNC Shield (v3) Interface board that distributes STEP, DIR, and ENABLE signals to stepper driver sockets (X, Y, Z). Provides headers for limit switches and spindle control.
- 3.Stepper Driver (A4988 / DRV8825) Converts low-power logic pulses (STEP/DIR) from the ESP32 into controlled high-current signals to drive stepper motors. Controls direction, step size, and current.
- 4.Barrier / Level Translator (optional) Provides voltage-level matching (3.3V ↔ 5V) between ESP32 and CNC Shield if any 5V-only signals are present. Ensures signal integrity and protection.
- 5.Stepper Motors (e.g., NEMA 17) Convert electrical step pulses into mechanical rotation for motion along X, Y, and Z axes.
- 6.Power Supply (12V/24V) Provides sufficient current to drive all motors and control electronics.



7. Software (GRBL_ESP32 + G-code Sender) sender (PC or web) sends command

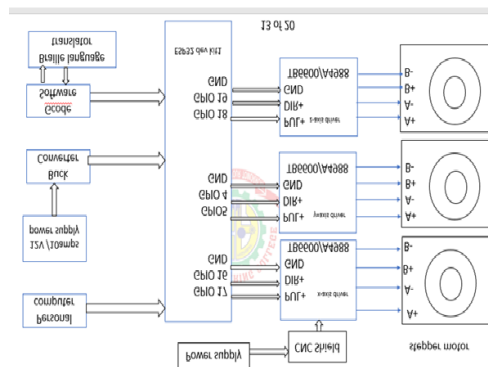
GRBL firmware on ESP32 interprets G-code commands. G-code

II. BRAILLE CNC PRINTER BLOCK DIAGRAM

The block diagram shows the working principle of a Braille CNC printer controlled by an ESP32-devkit board. First, the personal computer sends commands to the ESP32 specifying movements and operations, while the 12V power supply feeds the system through a buck converter to ensure correct voltage levels. The buck converter stabilizes and adjusts the power from 12V / 10A to a suitable voltage for driving the motors and electronics.

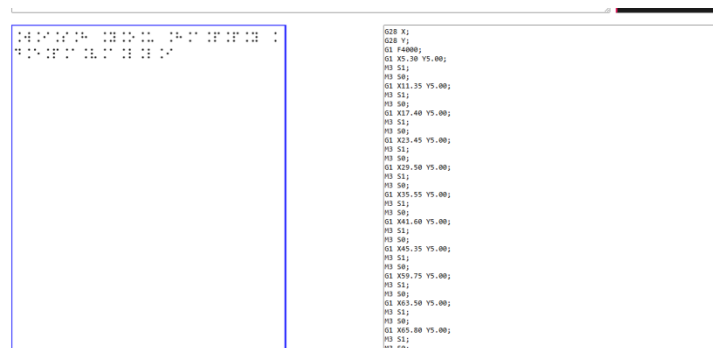
The ESP32 devkit communicates with a CNC shield, which acts as the interface between the microcontroller and the stepper motor drivers (either TB6600 or A4988). Control signals such as pulse (PUL+), direction (DIR+), and ground (GND) are sent to each axis driver. The CNC shield distributes the signals to the respective drivers of each axis (X, Y, Z), which then energize the stepper motors accordingly to move the axis.

Stepper motors convert electrical pulses from the drivers into precise mechanical movements. Each motor moves in small discrete steps based on pulse commands, with direction determined by the DIR signal. This allows the CNC printer to position the tool head accurately according to the G-code instructions generated by the G-code software running on the PC.



III. BRAILLEY TRANSLATOR FOR GCODE

An Braille is an open-source, low-cost Braille embosser project designed to make the production of Braille and tactile documents accessible to individuals, schools, and organizations. maps, and accessible content for the

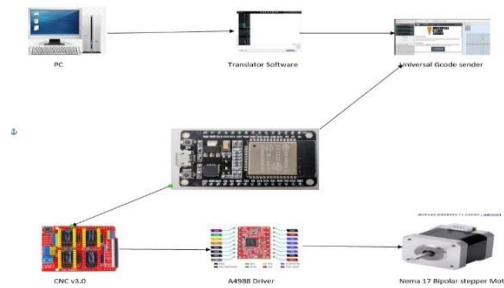


Translator software for gcode

In conclusion, battery life indicator sensors are indispensable components within Battery Management Systems, enabling precise monitoring, diagnostics, and control of rechargeable batteries. By harnessing the power of sensor technology and advanced algorithms, BMS equipped with these sensors significantly contributes to the optimization of battery performance, longevity, and safety across diverse applications and industries. As the demand for energy storage



solutions continues to rise, the role of battery life indicator sensors in ensuring reliable and sustainable power management will only grow in significance



The system operates in a sequential workflow as described below:

1. **Personal Computer:** It is communicate with Universal Gcode software control the driver and stepper motor.
2. **Translator:**Images It is convert to normal language to Braille Language
3. **Universal Gcode Software:** It is used for control the gcode command to sent the driver .
4. **CNC V3.0 Shield :** it has used to wiring the driver and Bipolar stepper motor
5. **A4988 Driver:** it is used for send the command and control the Bipolar stepper motor
6. **Bi Polar Stepper Motor :** .It is used to control the dependent of command can be receive the angle and precious movement

IV. RESULT AND DISCUSSION

The developed CNC-based Braille printer successfully produced embossed Braille characters with uniform dot height and accurate spacing that conform to standard Braille dimensions. The motion control system using stepper motors achieved smooth and repeatable movements along the X, Y, and Z axes. The embossing pin created well-defined tactile dots on thick paper, making the printed text easily readable by touch. During testing, the system consistently reproduced letters and sentences with minimal positional error, demonstrating the precision of the CNC motion mechanism.

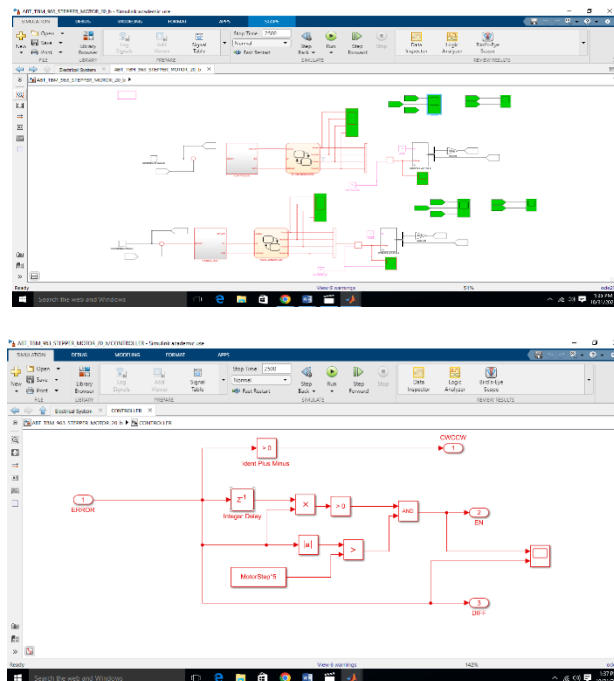


Fig 4.1 matlab input



V. RESULTS DISCUSSION:

This system is a 2-phase stepper motor driven by a pulse generator. The controller converts a position reference (reference step angle) into directional and enable pulses. Those pulses are applied to the motor driver/coil terminals as pulsated (on/off) voltages. The motor's power source is a steady DC supply (shown in the lower plot). Each pulse moves the rotor by one discrete step; many pulses produce continuous rotation. The plots show (1) the pulsating drive voltage applied to the motor and (2) the constant DC input supply that powers the driver.



Fig:4.2 step angle

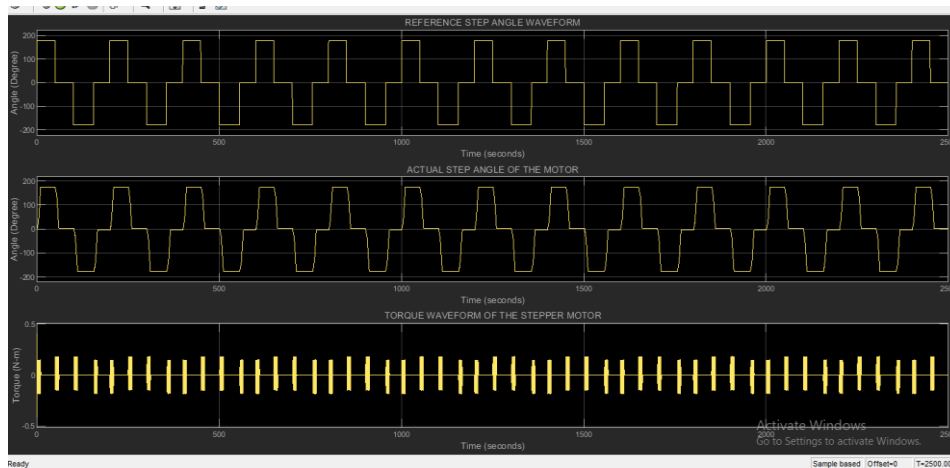


Fig : 4.3 torque of motor Waveform

Reference Step Angle Waveform (Top Plot)

This signal is the input command given to the stepper motor controller. It tells the motor how much to rotate (and in which direction) step by step. The waveform alternates between $+200^\circ$ and -200° , meaning the controller commands the rotor to move forward and backward repeatedly. The constant step height shows that each commanded step is of equal angular size — the step angle of the motor.

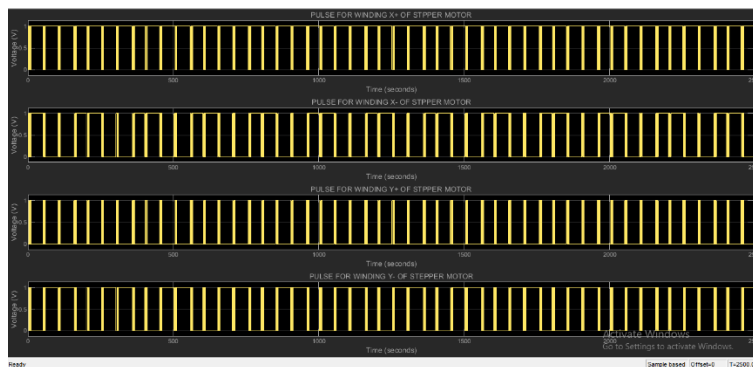


Fig: 4.4 pulse wave of x,y,z



Pulse for Winding X of Stepper Motor (Top Plot)

This represents the positive terminal excitation of Phase X (also called Phase A). The pulses alternate between 0 V and ~20 V (the motor's supply voltage). When X⁺ is high (ON), current flows through the X-phase winding in one direction. Each high pulse corresponds to energizing the winding, which produces magnetic attraction that aligns rotor teeth with the stator.

2. Pulse for Winding X⁻ of Stepper Motor (Second Plot)

This represents the negative terminal excitation for the same Phase X coil. It energizes the winding in the opposite direction of X⁺. X⁻ pulses are shifted in phase from X⁺ — when X⁺ turns OFF, X⁻ turns ON. This alternation reverses the current through the coil, reversing the magnetic polarity.

3. Pulse for Winding Y⁺ of Stepper Motor (Third Plot)

This waveform controls Phase Y⁺ (Phase B positive). The Y-phase is electrically 90° shifted from the X-phase. This phase shift is crucial—it determines the step direction (clockwise or counterclockwise). This shift creates a rotating magnetic field when combined with Phase X, which “steps” the rotor tooth to the next aligned position.

4. Pulse for Winding Y⁻ of Stepper Motor (Bottom Plot Plot)

This represents negative excitation for the Y-phase winding. Like X⁻, it is phase-shifted 180° from Y⁺. Alternates opposite to Y⁺, ensuring that at any moment, current flows in only one direction per winding pair.

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