Journal Publication of International Research for Engineering and Management (JOIREM)
Volume: 04 Issue: 5 | May-2026
ISSN (O) 3107-6696

Implementation of a Wi-Fi Enabled CNC Plotter Using ESP32 and Smartphone Interface

A. P Amit Nigam[1], Amrita Roy[2], Srotoswini Sen[3]

Narula Institute of Technology

---***---

Abstract - The advancement of embedded systems and wireless communication technologies has significantly transformed automation and manufacturing processes. Computer Numerical Control (CNC) machines have become essential in industries for achieving high precision, repeatability, and automation in fabrication and drawing applications. However, conventional CNC systems often require bulky desktop computers, wired communication, and expensive controllers, limiting their portability and affordability for educational and small-scale applications. To overcome these limitations, this research presents the design and implementation of a Wi-Fi enabled CNC plotter using the ESP32 microcontroller integrated with a smartphone-based control interface.

The proposed system utilizes the ESP32 microcontroller as the primary control unit due to its integrated Wi-Fi capability, low power consumption, and cost-effectiveness. Stepper motors controlled through motor driver modules provide accurate movement along the X and Y axes, while a servo motor controls the pen lifting mechanism. The system employs GRBL firmware to interpret and execute G-code instructions generated from vector graphics and CAD software. A smartphone application serves as the wireless user interface, enabling users to upload designs, control machine movement, and monitor operations remotely over a Wi-Fi network.

The research focuses on the hardware architecture, software integration, wireless communication mechanism, and motion control techniques involved in the CNC plotting system. Experimental testing was conducted to evaluate plotting accuracy, communication reliability, response time, and operational stability. The developed prototype successfully demonstrated smooth and accurate plotting operations with reliable wireless connectivity. The implementation reduced wiring complexity and improved system portability while maintaining satisfactory performance for educational, hobbyist, and lightweight industrial applications.

The study concludes that ESP32-based wireless CNC systems offer an efficient and economical alternative to conventional CNC controllers. The proposed system contributes toward the development of IoT-enabled smart manufacturing and automation technologies by integrating wireless communication and mobile-based control into CNC applications.

Keywords: CNC Plotter, ESP32, Wi-Fi Control, Smartphone Interface, GRBL Firmware, IoT, Embedded Systems, Automation.

1. Introduction

1.1 Background

Automation has become one of the most important technological advancements in modern engineering and manufacturing industries. Computer Numerical Control (CNC) technology is widely used for automated machining, engraving, plotting, drilling, and cutting operations. CNC machines operate based on pre-programmed instructions known as G-code, enabling precise and repeatable motion control.

Traditional CNC systems usually depend on desktop computers and wired communication interfaces such as USB or serial communication. These systems are often expensive, less portable, and complicated for beginners or educational users. With the growth of embedded systems and Internet of Things (IoT) technologies, wireless communication-based automation systems are becoming increasingly popular.

Journal Publication of International Research for Engineering and Management (JOIREM)
Volume: 04 Issue: 5 | May-2026
ISSN (O) 3107-6696

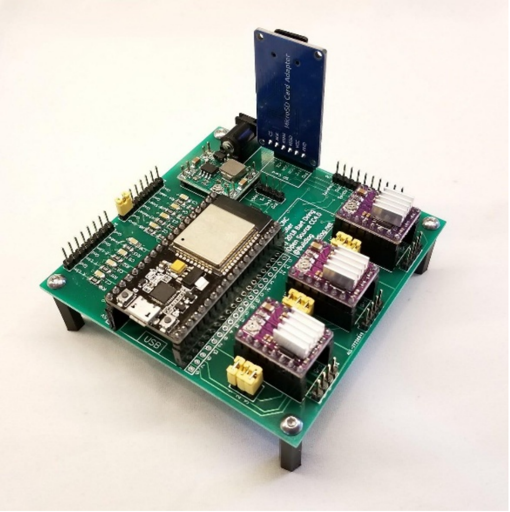


Figure 1: Developed Wi-Fi Enabled CNC Plotter Prototype

The ESP32 microcontroller has emerged as a powerful solution for embedded automation due to its built-in Wi-Fi and Bluetooth capabilities, dual-core processing architecture, and low-cost implementation. These features make ESP32 highly suitable for wireless CNC control systems. By integrating ESP32 with GRBL firmware and a smartphone interface, CNC machines can be operated remotely without requiring continuous computer connectivity.

1.2 Problem Statement

Conventional CNC plotters face several challenges:

- Dependence on wired communication
- Limited portability
- High implementation cost
- Complex setup procedures
- Requirement of dedicated computer systems

Educational institutions, hobbyists, and small-scale industries require a compact, affordable, and user-friendly CNC solution capable of wireless operation. Therefore, a wireless CNC plotter controlled through smartphones can provide greater flexibility and accessibility.

1.3 Aim of the Research

The aim of this research is to design and implement a low-cost Wi-Fi enabled CNC plotter using the ESP32 microcontroller and smartphone interface for wireless motion control and plotting operations.

1.4 Objectives

The primary objectives of this research are:

1. To develop a compact CNC plotting system using ESP32.
2. To implement wireless communication using Wi-Fi technology.
3. To integrate GRBL firmware for motion control.
4. To enable smartphone-based CNC operation.
5. To evaluate plotting accuracy and communication performance.
6. To reduce system complexity and cost.

1.5 Scope of the Research

This research focuses on the design and implementation of a two-axis CNC plotter capable of drawing text, geometric patterns, and vector graphics on paper surfaces. The scope includes:

- Hardware integration
- Wireless communication
- Firmware implementation
- Smartphone control
- Motion control analysis
- Performance evaluation

The project is intended mainly for educational, research, and prototype development purposes rather than heavy industrial machining.

2. Literature Review

The development of CNC machines has evolved significantly over the past few decades. Researchers and engineers have continuously worked toward improving CNC performance, reducing implementation cost, and increasing operational flexibility.

Early CNC systems relied heavily on desktop computers and industrial controllers. Although these systems provided excellent accuracy, they were expensive and difficult to operate for small-scale users. Arduino-based CNC systems later became popular due to their affordability and simplicity.

Journal Publication of International Research for Engineering and Management (JOIREM)
Volume: 04 Issue: 5 | May-2026
ISSN (O) 3107-6696

GRBL firmware enabled Arduino microcontrollers to interpret G-code instructions and perform motion control operations efficiently.

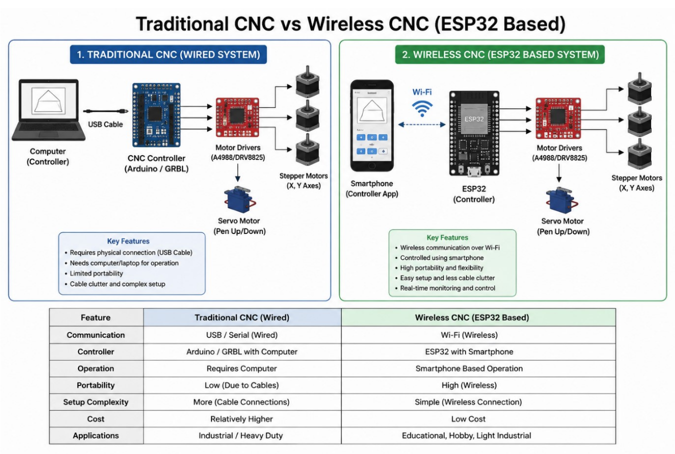
Several studies explored the implementation of low-cost CNC plotters using Arduino Uno and ATmega328P microcontrollers. These systems demonstrated good plotting accuracy but lacked wireless communication capabilities. Most designs required USB-based communication with desktop systems, restricting portability.

Recent advancements introduced ESP32-based CNC controllers. ESP32 offers integrated Wi-Fi and Bluetooth communication, enabling remote machine operation through smartphones and web applications. Researchers have successfully implemented wireless CNC systems using ESP32 and GRBL_ESP32 firmware for real-time motion control.

Studies also demonstrated the use of smartphone applications for wireless machine control. Mobile interfaces simplified machine operation by providing graphical controls, file transfer capabilities, and remote monitoring features. Wi-Fi-enabled CNC systems significantly reduced wiring complexity and improved user accessibility.

Existing literature indicates that wireless CNC systems provide several advantages including:

- Reduced hardware complexity
- Improved portability
- Remote accessibility
- Lower cost implementation
- Better user interaction



Feature	Traditional CNC (Wired)	Wireless CNC (ESP32 Based)
Communication	USB / Serial (Wired)	Wi-Fi (Wireless)
Controller	Arduino / GRBL with Computer	ESP32 with Smartphone
Operation	Requires Computer	Smartphone Based Operation
Portability	Low (Due to Cables)	High (Wireless)
Setup Complexity	More (Cable Connections)	Simple (Wireless Connection)
Cost	Relatively Higher	Low Cost
Applications	Industrial / Heavy Duty	Educational, Hobby, Light Industrial

Figure 2: Traditional CNC vs Wireless CNC

However, many existing systems still suffer from limitations such as limited plotting area, unstable communication, and insufficient motion precision. Therefore, this research aims to improve reliability and operational flexibility through optimized ESP32 integration and smartphone-based control architecture.

3. Methodology

3.1 System Design

The proposed CNC plotter system consists of both hardware and software components integrated to perform wireless plotting operations.

Major Components:

- ESP32 microcontroller
- Stepper motors
- A4988 motor drivers
- Servo motor
- Mechanical frame
- Timing belt mechanism
- Smartphone interface
- Power supply unit

Figure 3: System Architecture of the Proposed CNC Plotter

The system architecture is designed to ensure smooth communication between the smartphone application and CNC controller through Wi-Fi connectivity.

3.2 Hardware Implementation

Journal Publication of International Research for Engineering and Management (JOIREM)
Volume: 04 Issue: 5 | May-2026
ISSN (O) 3107-6696

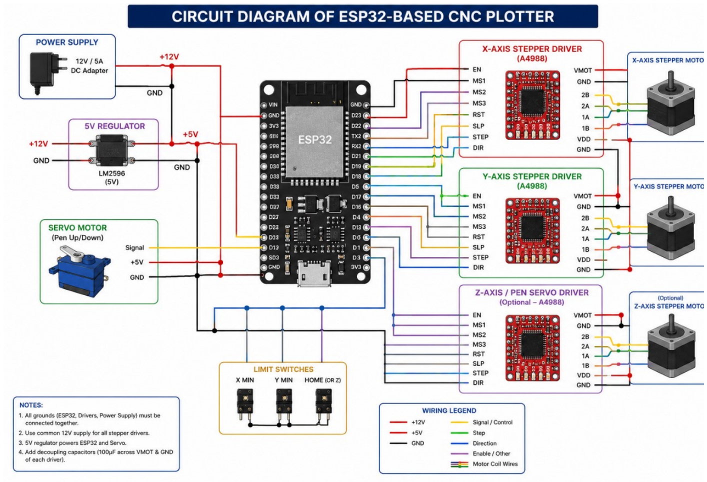


Figure 4: Circuit Diagram of ESP32-Based CNC Plotter

ESP32 Controller

The ESP32 acts as the central processing unit of the CNC plotter. It receives G-code commands wirelessly and generates pulse signals for motor control.

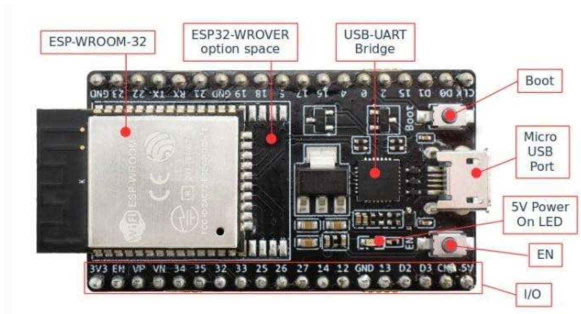


Figure 5: ESP32 Development Board Used in the System

Stepper Motors

Two NEMA 17 stepper motors are used to control X-axis and Y-axis movements. These motors provide accurate rotational movement required for plotting operations.

Motor Drivers

A4988 drivers convert low-current control signals into sufficient power required by the stepper motors.

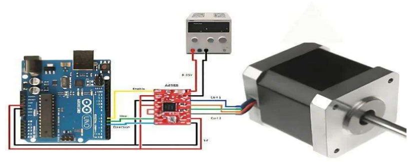


Figure 6: Stepper Motor and Motor Driver Module

Servo Motor

The servo motor controls pen up/down motion during plotting.

Mechanical Structure

The frame is constructed using acrylic or aluminum components. Belt-driven motion mechanisms provide smooth and precise movement.

3.3 Software Implementation

GRBL Firmware

GRBL firmware is installed on the ESP32 microcontroller for interpreting G-code instructions.

Smartphone Interface

A mobile application communicates with ESP32 using Wi-Fi. The interface allows:

- Manual movement control
- G-code upload
- Start/stop commands
- Monitoring operations

Figure 7: Smartphone Interface for Wireless CNC Control

G-code Generation

Designs are prepared using software such as:

- Inkscape
- LaserGRBL
- Universal G-code Sender

The designs are converted into G-code and transmitted wirelessly.

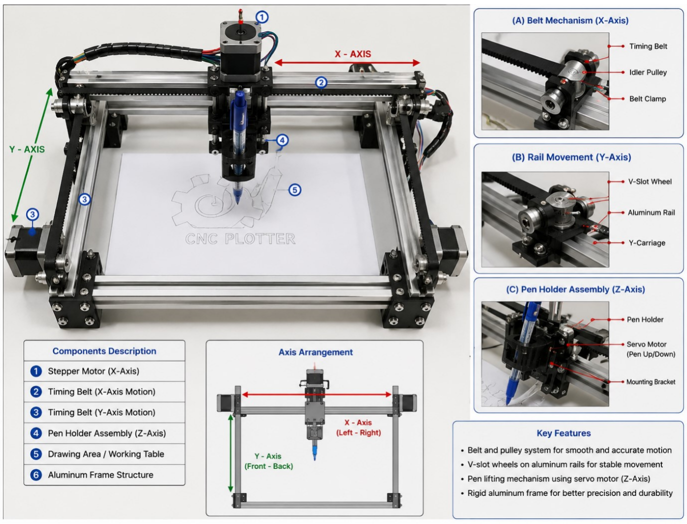


Figure 8: Mechanical Structure and Axis Arrangement

•

3.4 Working Procedure

1. Design creation using CAD software
2. G-code conversion
3. Wireless transmission to ESP32
4. G-code interpretation using GRBL
5. Stepper motor control
6. Plotting execution

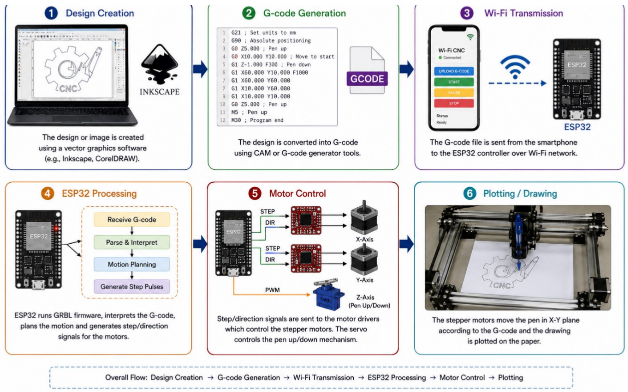


Figure 9: Workflow of CNC Plotting Operation

3.5 Experimental Setup

Testing was conducted using:

- A4 drawing sheets

Journal Publication of International Research for Engineering and Management (JOIREM)
Volume: 04 Issue: 5 | May-2026
ISSN (O) 3107-6696

- Geometric patterns
- Text drawings
- Vector graphics

Parameters evaluated:

- Plotting accuracy
- Wireless range
- Communication delay
- Motion smoothness
- Power consumption

;4.1 Plotting Accuracy

The CNC plotter successfully reproduced geometric patterns and text with satisfactory precision. Minor deviations occurred at high speeds due to belt tension and mechanical vibrations.

The average positioning accuracy observed was approximately ±0.5 mm, which is suitable for educational and hobbyist applications.

4.2 Wireless Communication Performance

The ESP32 maintained stable Wi-Fi communication within a range of approximately 15–20 meters under normal indoor conditions. Communication delay was minimal and did not significantly affect machine performance.

The smartphone interface provided smooth command transmission and responsive machine control.

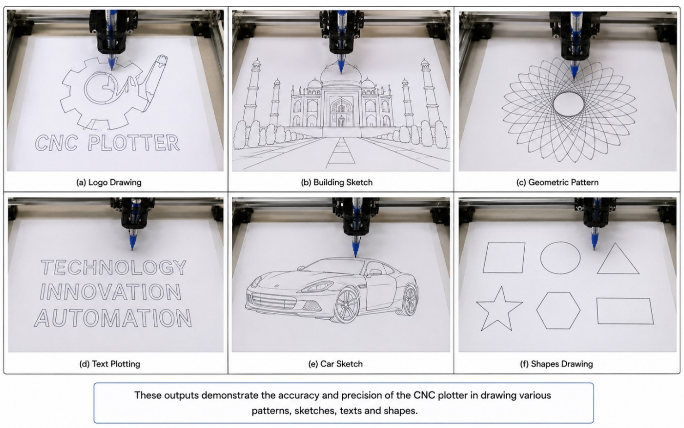


Figure 10: Output Generated by the CNC Plotter

4.3 Motion Control Analysis

Stepper motors demonstrated smooth movement during operation. Micro-stepping provided improved motion resolution and reduced vibration. The GRBL firmware effectively synchronized motor movement and interpreted G-code instructions accurately.

4.4 Power Consumption

The system consumed relatively low power compared to industrial CNC machines. ESP32's low-power architecture contributed to efficient operation.

4.5 Advantages of the Developed System

Low Cost

The implementation cost was significantly lower than industrial CNC systems.

Wireless Operation

Wi-Fi connectivity eliminated the need for wired communication.

Portability

Compact design improved portability and usability.

User-Friendly Interface

Smartphone control simplified machine operation.

  ISSN (O) 3107-6696

Journal Publication of International Research for Engineering and Management (JOIREM)
Volume: 04 Issue: 5 | May-2026
ISSN (O) 3107-6696

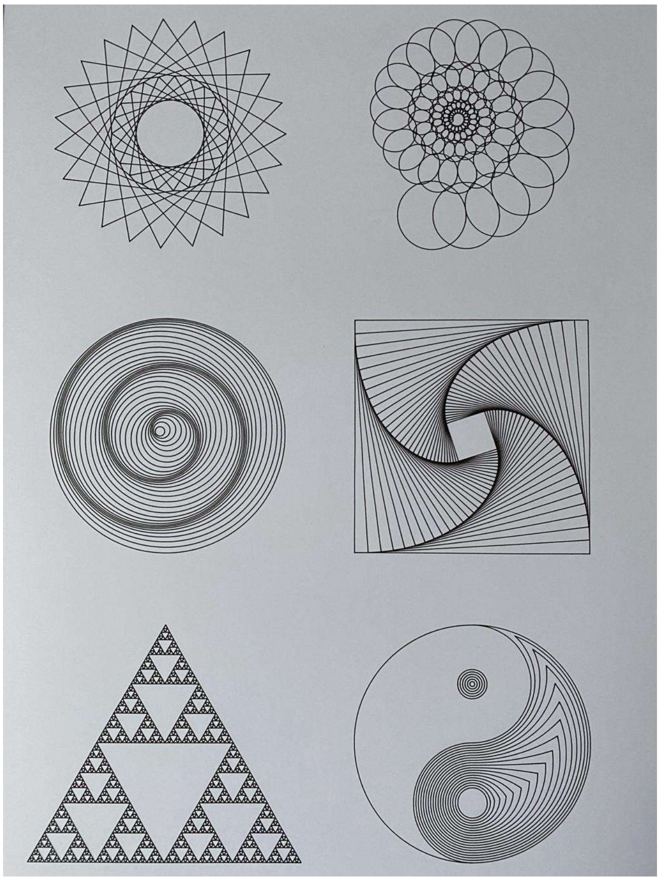


Figure 11: Output Generated by the CNC Plotter

4.6 Limitations

Despite successful implementation, several limitations were observed:

- Limited plotting area
- Moderate plotting speed
- Dependence on stable Wi-Fi network
- Reduced precision compared to industrial CNC systems

4.7 Comparative Analysis

Parameter	Conventional CNC	Proposed ESP32 CNC
Communication	Wired	Wireless
Portability	Low	High
Cost	High	Low
Ease of Use	Moderate	Easy
Smartphone Support	No	Yes
Power Consumption	High	Low

The proposed system demonstrated improved flexibility and accessibility while maintaining acceptable plotting performance.

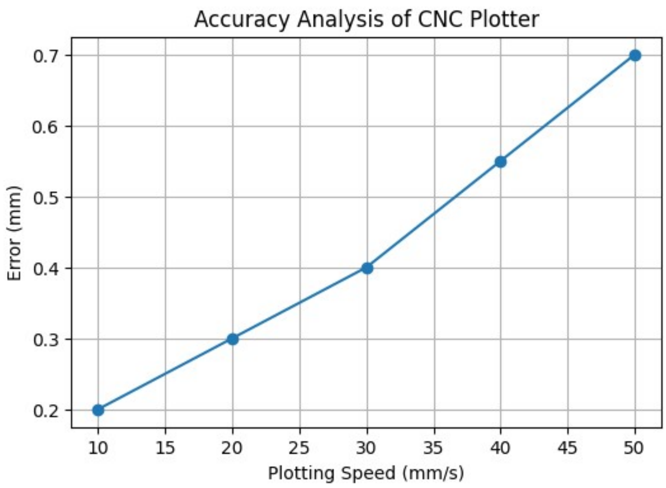


Figure 12: Accuracy Analysis of the CNC Plotter

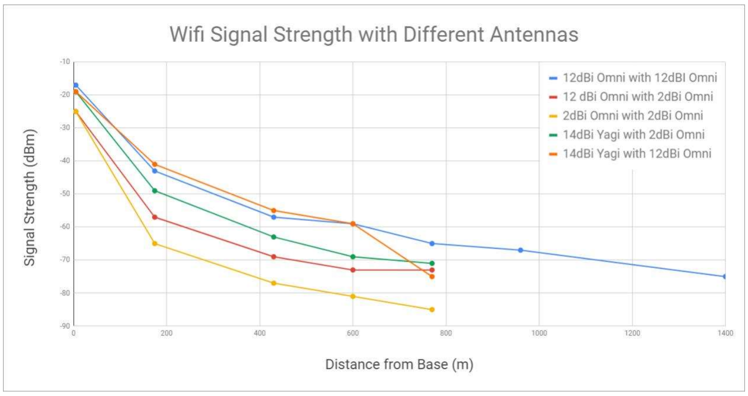


Figure 13: Wireless Communication Performance Analysis

5. Conclusion

This research successfully demonstrated the implementation of a Wi-Fi enabled CNC plotter using ESP32 and a smartphone interface. The integration of ESP32 provided reliable wireless communication and efficient motion control capabilities while reducing hardware complexity and system cost.

The developed CNC plotter achieved accurate two-dimensional plotting using stepper motor-based motion control and GRBL firmware. Wireless communication through Wi-Fi enabled remote operation and eliminated dependency on wired desktop systems. Experimental results showed stable performance, smooth motion control, and satisfactory plotting precision for educational and prototype development applications.

The proposed system offers several advantages including affordability, portability, low power consumption, and user-friendly smartphone operation. Although the system is not intended for heavy industrial applications, it represents an effective solution for students, researchers, hobbyists, and small-scale automation projects.

Future developments may include cloud-based monitoring, Bluetooth integration, AI-assisted image processing, automatic calibration, and multi-axis expansion. The research highlights the growing significance of IoT-enabled automation systems in modern embedded and manufacturing technologies.

References

1. Ashwini M S, Punith Kumar M B, and Thejesh P, “Design and Implementation of a Smart Industrial Gateway for CNC Machines Using ESP32-WROOM-32,” International Journal of Scientific Research in Science, Engineering and Technology, 2025.

2. V.W. Wankhede et al., “2D CNC Plotter Integrated with Arduino,” Journal of Microprocessor and Microcontroller Research.

3. Grbl Firmware Documentation, Open-Source CNC Motion Control Project.

4. Espressif Systems, “ESP32 Technical Reference Manual.”

5. Rahul Reddy et al., “Integration of CNC Plotting with Image Processing for Automated Drawing,” IRJAEH Journal, 2025.

6. A4988 Stepper Motor Driver Datasheet, Allegro Microsystems.

7. NEMA 17 Stepper Motor Specifications Manual.

8. FluidNC Documentation for ESP32-Based CNC Controllers.

9. Inkscape User Manual for Vector Graphics and G-code Conversion.

Universal G-code Sender Documentation.