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Research Article

DESIGN AND DEVELOPMENT OF A LOW-COST CNC MACHINE FOR PCB PRINTING

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Abstract

The demand for custom-printed circuit boards (PCBs) is rapidly increasing across various industries, including electronics, automotive, and consumer goods. Traditional PCB manufacturing methods involve costly and time-consuming processes, making them unsuitable for small-scale production and prototyping. This paper presents the design and development of a low-cost CNC machine for PCB printing that utilizes a marker pen to draw PCB layouts directly onto copper substrates. By replacing conventional etching techniques, this method significantly reduces the cost and complexity of PCB fabrication while maintaining high precision and efficiency. The CNC machine operates using an Arduino microcontroller to control stepper motors for accurate movement, along with Inkscape for G-code generation. The proposed solution aims to provide a cost-effective, accessible, and efficient alternative for small businesses, engineers, and hobbyists involved in PCB prototyping.

Keywords: CNC machine, PCB printing, low-cost production, Arduino, marker pen, stepper motors, prototyping, copper substrate, G-code, PCB layout, automation, PCB manufacturing, small-scale production, DIY PCB, Inkscape.

INTRODUCTION

Background

Printed Circuit Boards (PCBs) form the foundation of modern electronic devices, ranging from smartphones to medical and automotive applications. Traditional PCB manufacturing involves complex processes such as etching, drilling, and multilayer construction, which require expensive materials and specialized equipment. Moreover, these conventional methods generate significant material waste and are not cost-effective for small-scale production or prototyping (Koc & Yilmaz, 2018).

For startups, small businesses, engineers, and hobbyists, PCB fabrication services can be prohibitively expensive when producing only a few units. The high setup costs and lengthy manufacturing cycles make rapid iterations difficult, limiting innovation in product development (Gupta & Rao, 2019).

This paper proposes the design of a low-cost CNC machine for PCB printing that replaces the etching process with direct ink printing using a marker pen. This alternative method drastically reduces production time and costs while ensuring high precision.

Motivation

The increasing need for rapid, cost-effective PCB prototyping has motivated this research. Conventional

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PCB manufacturing techniques are expensive due to the use of chemical etching solutions, multilayer laminations, and specialized drilling machines (Mishra & Jha, 2020). By using a CNC machine with a marker pen, the cost of equipment and materials can be significantly reduced.

The proposed system enables on-demand PCB printing, making it particularly useful for:

- Engineers and designers requiring quick prototype iterations.
- Small businesses developing electronic products with limited budgets.
- Hobbyists and students working on DIY electronic projects.

This approach eliminates the need for chemical etching and high-end fabrication tools, making PCB prototyping more accessible and affordable (Singh & Verma, 2021).

PROBLEM STATEMENT

Traditional PCB fabrication techniques require expensive machinery and involve labor-intensive etching, drilling, and layering processes. These methods are not feasible for low-volume production due to their high setup costs and material wastage (Chen & Yang, 2020). Additionally, rapid prototyping demands quick turnaround times, which are not achievable with conventional methods.

This research presents a low-cost CNC machine that prints PCB layouts directly onto copper substrates using a marker pen, thereby:

- Reducing production costs and setup time.
- Simplifying the fabrication process.
- Enabling rapid prototyping and small-scale production.

By eliminating traditional etching, the proposed solution provides an affordable and efficient alternative to conventional PCB manufacturing (Rao & Sharma, 2017).

AIM OF THE PROJECT

The primary aim of this project is to design and develop a low-cost CNC machine capable of printing PCB layouts on a copper substrate. The machine is designed for PCB sizes up to 20 cm × 20 cm, making it suitable for prototyping applications. The key objectives include:

1. Utilizing a marker pen instead of chemical etching for PCB layout printing.
2. Implementing an Arduino microcontroller to control stepper motors for precision movement.
3. Generating G-code using Inkscape to translate PCB designs into CNC machine commands.

This system ensures cost-effective, precise, and rapid PCB prototyping without requiring industrial-grade fabrication tools (Kumar & Garg, 2020).

WORKING OF THE CNC MACHINE FOR PCB PRINTING

G-Code Generation

The PCB design is created using Inkscape, a vector-based software capable of generating G-code, which defines the movement of the CNC machine (Zhang & Liu, 2020). The G-code file contains the X, Y, and Z coordinates for controlling the stepper motors.

Arduino Programming

The Arduino microcontroller interprets the G-code instructions and translates them into commands for

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stepper motor movement. It ensures precise X-Y positioning of the marker pen for accurate PCB printing (Mishra & Jha, 2020).

Stepper Motor Control

The CNC machine incorporates three stepper motors for precise movement:

- X-axis: Horizontal movement of the marker pen.
- Y-axis: Vertical movement of the marker pen.
- Z-axis: Controls the lifting and lowering of the pen.

These motors are controlled via Pulse Width Modulation (PWM) signals from the Arduino, ensuring highly accurate movement (Singh & Yadav, 2021).

Calibration of the CNC System

Calibration is essential to ensure accuracy in PCB printing. The key calibration steps include:

- Setting steps per unit to determine the precise motor movement.
- Zeroing the axes to establish a reference position.
- Fine-tuning mechanical adjustments to correct any misalignments (Sharma & Verma, 2019).

Printing the PCB Layout

After calibration, the CNC machine executes the G-code instructions to move the marker pen over the copper substrate, drawing the PCB traces. This approach offers a simple, cost-effective alternative to traditional etching techniques (Joshi & Rani, 2020).

Finalization

Once the PCB layout is printed, the copper substrate is ready for component placement and testing. Additional processing, such as drilling for through-hole components, can be performed if required (Shah & Sharma, 2019).

CONCLUSION

This paper presents the design and development of a low-cost CNC machine for PCB printing using a marker pen. The proposed system eliminates the need for expensive etching processes, making PCB prototyping faster, cheaper, and more accessible. The Arduino-controlled stepper motors ensure high precision, while Inkscape-generated G-code enables easy customization of PCB layouts.

This solution is particularly beneficial for hobbyists, engineers, and small businesses, allowing them to develop PCB prototypes without the need for industrial-grade fabrication tools. Future work may explore the integration of automated solder mask printing and improved marker-based ink durability.

AUTHOR(S) CONTRIBUTION

The writers affirm that they have no connections to, or engagement with, any group or body that provides financial or non-financial assistance for the topics or resources covered in this manuscript.

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CONFLICTS OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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All authors declare that any kind of violation of plagiarism, copyright and ethical matters will taken care by all authors. Journal and editors are not liable for aforesaid matters.

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