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Cost Effective PCB Milling Machine for Rapid Prototyping.

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Abstract: A Low-Cost Open-Source PCB Milling Machine for Rapid Prototyping This paper presents the design and construction of a budget-friendly, open-source PCB milling machine targeted at enabling rapid prototyping for hobbyists and small-scale electronics fabrication. Utilizing readily available materials and open-source electronics, the machine prioritizes affordability and accessibility while maintaining sufficient functionality.

Keywords: PCB milling, low-cost, open-source, fixed gantry, NEMA-17 stepper motors, G-code workflow, rapid prototyping.

I. INTRODUCTION

The machining technique known as "milling" uses spinning cutting tools to mould and shape materials. With regard to PCBs (Printed Circuit Boards), PCB milling is the process of using these instruments to precisely drill holes and carve out copper traces on the board in order to etch the necessary electrical circuits onto its surface. Beyond the constraints of mass production, this approach opens possibilities to bespoke electronics fabrication, small-scale manufacture, and quick prototyping. In the beginning, printed circuit boards (PCBs) were manually designed by drawing a photomask on a transparent mylar sheet, generally twice or four times the actual size. The entire process of creating a PCB involves chemical reactions, which result in waste products from the films that are used to transfer patterns.

II. LITERATURE SURVEY

The expensive cost of commercially available devices is one of the most obvious limitations **[1]**. A sizable group of potential customers who could gain greatly from the learning and prototyping opportunities that PCB fabrication offers are essentially shut out of the market by this price barrier **[2, 3]**. Although there are some reasonably priced options, they frequently require significant compromise. Devices that only offer a small range of pre-defined footprints **[4]** give users a starting point for simple tasks but inhibit their creativity by limiting them to pre-made designs. This lack of flexibility ultimately limits the attractiveness for the more dedicated hobbyist by impeding the investigation of customised electronics and complex circuit configurations.

Greater design freedom is provided by custom-built solutions, but these solutions frequently come with higher complexity and vendor dependence **[5]**. As they explain in their article, using non-standard software and specialised circuits gives customers unmatched control over their computers, but it also makes troubleshooting and upgrading difficult and depends on manufacturers. This strategy prevents wider adoption and reduces the opportunity for learning. Well-liked options like Eagle software further reduce the pool of people who can afford it. Pre-assembled Arduino-based devices with fixed gantry designs **[6]** and pre-loaded GRBL-based software provide some respite, but they limit user control and customization even though they achieve excellent accuracy **[7]**. Similar issues with usability and hardware limitations arise with machines running Mach3Mill software **[8]**.

III. METHODOLOGY

Our low-cost PCB milling machine was developed through an iterative design and construction approach that put practicality and efficiency first. We started with a conceptual framework that focused on rigidity, precision, and cost. Then, we painstakingly picked parts, produced parts, and carried out extensive testing to maximise performance and

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improve our design. Open source software and easily accessible resources were essential to guaranteeing accessibility reproducibility during this procedure.

Limitations of a PCB milling machine: 1. Trace precision: PCB milling machines cannot match the tight tolerances of commercial fabrication. For most hobbyist machines, the minimum trace/space is around 8 mils (0.2mm). 2. Cost: PCB milling has a high initial cost. 3. Boards: Simple mills can only produce two layer boards. 4. Limited size, large and heavy workpieces may not fit on the table or be too heavy to be moved by the machine.

Proposed system:

Conceptual Design: To choose an architecture that was both accessible and reasonably priced, the first stage of the design process placed a high priority on rigidity, accuracy, and ease of construction. The fixed gantry configuration was selected because of its simplicity and built-in stability.

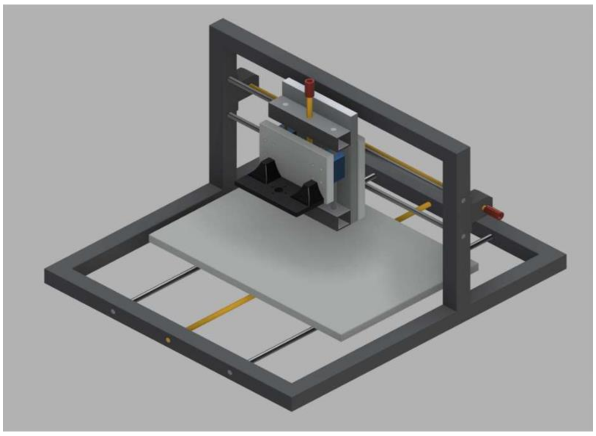

Fig.1:3d model of the machine

The 3D model produced with the CAD application Fusion 360 is shown in Figure.1.It shows the Fixed Gantry technique and the carriage positions for the X, Y, and Z axes.

Software Selection: Well-known open-source programmes like Universal G-Code Sender and FlatCAM were chosen for their user-friendly machine control and design file conversion. We will investigate potential improvements such as direct conversion from Gerber to G-code.

Precise alignment and calibration of stepper motors, lead screws, and axes were crucial for ensuring accuracy. Standard measuring tools and alignment techniques were employed during this process.

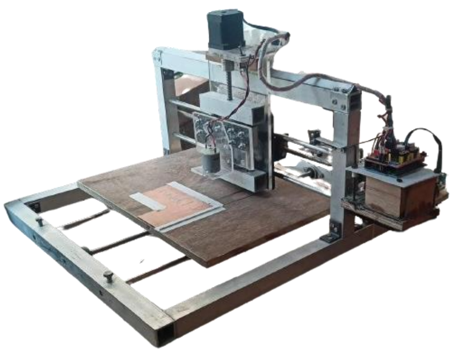

Fig 2: Final model of the machine

The above figure illustrates how we erected the machine using common fasteners and simple equipment, using readily available materials for the structural components, such as acrylic sheets and aluminium square pipes.

IV. RESULTS

In our initial testing phase, the PCB milling machine underwent a series of rigorous trials using test G-code files The results, demonstrated the machine's capacity for precise and controlled production. Notably, the machine achieved an axial accuracy of 0.1mm with a directional change error of only 2%. Furthermore, the repeatability error remained consistent at 5% over ten test runs, highlighting the machine's ability to produce consistent results. These promising initial findings pave the way for further exploration of the machine's capabilities and its potential applications in PCB manufacturing.

V. CONCLUSION

PCB milling machines offer numerous benefits beyond mass production, including quick circuit testing, design iterations, and personalized electronics. However, existing models often lack price, versatility, and user empowerment due to expensive frames, proprietary software, and dependence on manufacturers. This project aims to develop an accessible, open-source, and user modifiable PCB milling machine, paving the way for a future of custom electronics fabrication.

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