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Portable 3D Printer

Shreyash Agalave[1], Ashish Amane[2], Shraddha Pailwan[3], Sammed Nandanikar[4], Dr. Sonali Sankpal[5]
Students, Electronics & Telecommunication[1,2,3,4]
Assistant Professor, Electronics & Telecommunication[5]
Padmabhooshan Vasantraodada Patil Institute of Technology, Sangli, India

Abstract: *This research paper focuses on Portable 3D printing, an innovative blend of Computer Numerical Control (CNC) technology with additive manufacturing techniques. The study begins by defining CNC-based 3D printing and emphasizing its growing significance in the field of precision manufacturing. A brief history of both CNC and 3D printing technologies is presented to provide context. The paper then explores the working process of CNC-integrated 3D printers, including the types of materials used in fabrication. It highlights the advantages of this hybrid approach over traditional manufacturing and standalone 3D printing systems, particularly in terms of accuracy, repeatability, and automation. Real-world applications across various industries are discussed to demonstrate its versatility. Finally, the paper outlines the future scope and potential advancements in CNC-based 3D printing technology.*

Keywords: 3D Printer, CNC Based 3D printer, 3D Models, Printing

I. INTRODUCTION

In recent years, additive manufacturing, commonly known as 3D printing, has revolutionized the way we design and produce objects. This technology builds components layer by layer directly from digital models, offering unprecedented flexibility, customization, and speed. On the other hand, Computer Numerical Control (CNC) systems have long been a cornerstone of subtractive manufacturing, known for their precision, automation, and ability to fabricate parts from a variety of materials through cutting, drilling, and milling processes.

The integration of CNC principles into 3D printing systems brings the best of both worlds, resulting in a hybrid approach that enhances accuracy, control, and reliability. CNC-based 3D printing combines the layered manufacturing technique of 3D printing with the precision motion control of CNC systems. This allows for improved resolution, stable multi-axis movements, and compatibility with complex geometries that may be difficult to achieve with traditional 3D printers alone.

This paper explores the concept, development, and functioning of CNC-based 3D printing technology. It provides a detailed overview of how CNC mechanisms are applied in additive manufacturing, the types of materials involved, and how this fusion improves performance. Moreover, the paper discusses the advantages of this method over conventional manufacturing processes and highlights its current applications across industries such as prototyping, biomedical engineering, and custom part fabrication. The discussion concludes with insights into the future potential and advancements expected in this emerging field.

II. LITERATURE REVIEW

Additive manufacturing (AM), commonly known as 3D printing, has revolutionized modern manufacturing by enabling the creation of complex geometries and customized components with reduced material waste. A comprehensive study by **Chattopadhyay et al. [1]** outlines the recent advancements in additive manufacturing, including material innovations, hybrid techniques, and challenges like process limitations, material compatibility, and post-processing requirements. The review emphasizes the growing importance of integrating automation and precision control to enhance production capabilities.In a critical analysis of AM processes, **Kundu and Mandal [2]** categorize and evaluate various 3D printing techniques such as Fused Deposition Modeling (FDM), Stereolithography (SLA), and Selective Laser Sintering (SLS), highlighting their applications across industries like aerospace, biomedical, and automotive. The

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authors also explore the future potential of AM in decentralized manufacturing and sustainable production, while identifying barriers related to cost, standardization, and mechanical properties of printed parts.

The integration of CNC technology with additive manufacturing is explored in **Kumar's study [3]**, where a 3-axis CNC milling machine is designed and fabricated using AM components. This hybrid system allows both additive and subtractive processes, improving surface finish and dimensional accuracy. The research demonstrates the feasibility and benefits of combining traditional CNC mechanisms with modern AM capabilities.**Wagh et al. [4]** present a practical implementation of a CNC-based 3D printer using Arduino. Their work underlines the role of microcontrollers in controlling stepper motors and heating elements, enabling precise layer-by-layer fabrication. This low-cost setup reflects the growing interest in accessible and customizable 3D printing platforms, especially in educational and prototyping environments. Focusing specifically on Fused Deposition Modeling, **Zhang et al. [5]** provide an in-depth review of materials, techniques, and applications. They note advancements in composite filaments, multi-material printing, and improved extrusion methods. The paper also discusses the environmental impact and recycling potential of FDM materials, contributing to the sustainability discourse in AM Control systems and firmware form the backbone of any 3D printer. **Singh and Singh [6]** analyze various firmware types such as Marlin, Repetier, and Klipper, and their role in motion planning, temperature regulation, and user interface. They also discuss emerging trends in control strategies, including feedback systems and real-time monitoring, which are crucial for enhancing print quality and reliability. Finally, **Lee and Kim [7]** investigate how optimizing stepper motor control can significantly enhance the accuracy of low-cost 3D printers. Through signal processing techniques and improved motor algorithms, the authors demonstrate reductions in vibration and layer misalignment, ultimately leading to higher resolution and precision in prints.

III. WORKING

A CNC-based Portable 3D Printer operates on the fundamental principle of additive manufacturing, where a digital 3D model is transformed into a physical object through a layer-by-layer material deposition process. This innovative technology combines the precision of Computer Numerical Control (CNC) systems with the versatility of 3D printing, allowing for efficient and accurate prototyping and production.

The process begins with designing a 3D model using Computer-Aided Design (CAD) software such as Fusion 360, SolidWorks, or AutoCAD. Once the design is finalized, it is exported in STL (Standard Tessellation Language) format, which is widely used in 3D printing due to its compatibility with slicing software. This STL file is then imported into slicing software like Cura, PrusaSlicer, or Simplify3D, where the model is divided into thousands of thin horizontal layers. During this stage, crucial printing parameters such as layer height, infill density, print speed, support structures, and temperature settings are defined.

The slicing software generates G-code, a standardized language consisting of precise instructions for the printer's movements, temperature control, and extrusion rates. This G-code file is transferred to the printer's control board through an SD card or USB interface, initiating the printing sequence.

The Arduino Mega 2560 microcontroller serves as the central processing unit of the system. It runs the open-source Marlin firmware, which interprets the G-code and issues commands to various printer components via a RAMPS 1.4 (RepRap Arduino Mega Pololu Shield) board. The RAMPS shield acts as an intermediary interface that connects stepper motor drivers, heating elements, endstops, and other peripherals to the Arduino board.

The stepper motors, typically NEMA 17, are controlled by A4988 stepper motor drivers that regulate current flow and allow for microstepping control. These motors move the print head and print bed accurately along the X, Y, and Z axes, guided by the coordinates provided in the G-code. Linear rails, belts, or lead screws are used to achieve smooth and stable motion.

Simultaneously, the extruder mechanism feeds thermoplastic filament (commonly PLA, ABS, or PETG) into a heated nozzle or hotend, where it melts at a precisely maintained temperature—typically between 180°C and 250°C. This molten plastic is then extruded onto the print bed, layer by layer, to build the physical model. The print bed may also be heated, typically to 50–100°C, to enhance first-layer adhesion and minimize warping.

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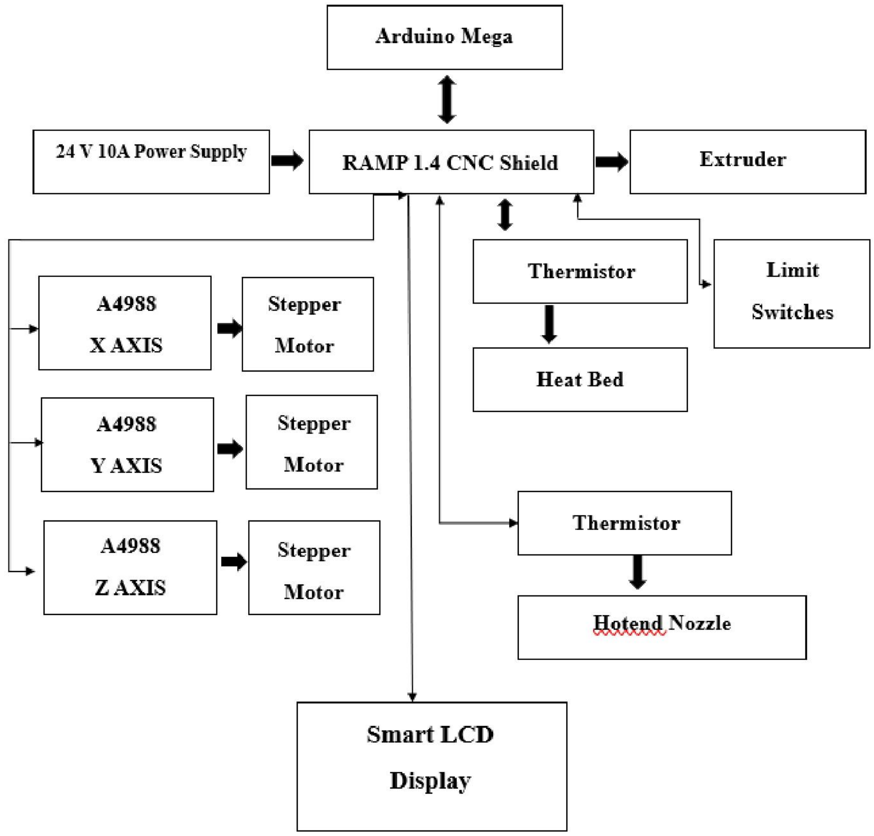

FIG. BLOCK DIAGRAM

The block diagram of a 3D printer illustrates the interaction between the major hardware and control units involved in the printing process. At the center of the system is the Arduino Mega 2560, which acts as the main controller and executes the firmware (typically Marlin) that governs the entire operation. Connected to the Arduino is the RAMPS 1.4 shield, which serves as an interface board, linking the microcontroller with other key components. The stepper motor drivers (such as A4988) are plugged into the RAMPS board and are responsible for controlling the stepper motors that drive the movement of the print head and bed along the X, Y, and Z axes. These motors enable precise positioning based on the G-code instructions.

The system also includes an extruder, which feeds filament into a heated nozzle where the material is melted and deposited layer by layer onto the heated bed to form the object. The hotend and heated bed both contain thermistors that monitor temperature, and this data is used by the controller to regulate heat through PID control. Endstop switches are placed on each axis to provide homing and position feedback, ensuring the printer starts each job from a known reference point. A smart LCD display with an SD card slot allows standalone operation, letting users control prints without a connected computer. Finally, all components are powered by a 24V power supply, which provides the necessary voltage and current to run motors, heaters, and electronics efficiently. This interconnected system works together to perform accurate and automated 3D printing based on digital models.

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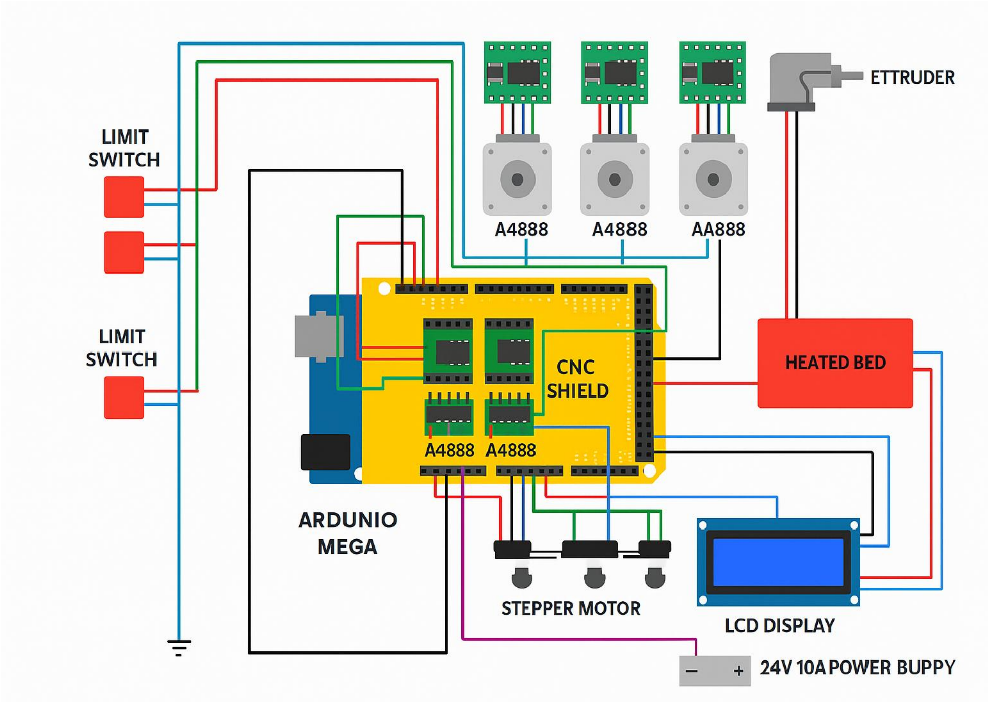

FIG. CIRCUIT DIAGRAM

The circuit diagram of the CNC-based 3D printer illustrates how all the electronic components are connected and powered to function in a coordinated manner. At the core of the circuit is the Arduino Mega 2560, which acts as the brain of the system. Mounted on top of it is the RAMPS 1.4 shield, which serves as a breakout board to connect various modules and components. A4988 stepper motor drivers are inserted into the RAMPS board to control the NEMA 17 stepper motors responsible for the X, Y, Z-axis movements and filament extrusion. The endstop limit switches are connected to the RAMPS inputs to provide position feedback and enable axis homing.

The hotend (nozzle) and heated bed are connected to the RAMPS board through MOSFET outputs, and their temperature is monitored by NTC thermistors, which send readings back to the Arduino. These readings allow the firmware to regulate temperature using PWM control. A 128×64 smart LCD controller with an SD card slot is connected to the RAMPS via the EXP1 and EXP2 headers, allowing the printer to be controlled without a computer. Power is supplied by a 24V 10A SMPS (Switched-Mode Power Supply), which powers the motors, heaters, and the control board. The wiring is organized to minimize interference and ensure safe, efficient operation. This circuit configuration allows the printer to interpret G-code commands, control movement, manage temperatures, and execute print jobs autonomously.

IV. SYSTEM REQUIREMENT

The system requirements for the portable 3D printer include both hardware and software components essential for its operation. On the hardware side, the setup consists of an Arduino Mega 2560, RAMPS 1.4 shield, A4988 stepper motor drivers, NEMA 17 stepper motors, a heated bed, MK8 extruder, endstop switches, a 128×64 smart LCD, and a 24V 10A power supply. The software requirements include the Arduino IDE for uploading firmware, Marlin firmware for controlling printer functions, and Cura slicing software to convert 3D models into G-code instructions.

V. HARDWARE REQUIREMENT

The hardware system of the portable 3D printer is designed using a combination of open-source and modular components that ensure reliability, precision, and ease of assembly. At the core of the system is the Arduino Mega

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2560, a powerful microcontroller that executes firmware instructions and manages all printer operations. It is paired with the RAMPS 1.4 (RepRap Arduino Mega Pololu Shield), which serves as the interface between the Arduino and other electronic modules such as stepper drivers and heaters.

The printer uses A4988 stepper motor drivers, each dedicated to controlling one of the NEMA 17 stepper motors responsible for moving the X, Y, Z axes and the extruder. These motors provide high torque and precise step control necessary for accurate layer deposition. A standard MK8 extruder assembly is used for feeding the filament, connected to a hotend nozzle (typically 0.4 mm) that melts and extrudes the filament onto the print bed. The heated bed, usually made of aluminum, ensures better adhesion of the print during the initial layers and reduces warping.

For motion control feedback and homing, mechanical limit switches are installed on each axis to detect the origin position. To monitor and regulate temperatures, NTC thermistors are connected to both the hotend and the heated bed, allowing real-time temperature management via the firmware.

The user interface is provided through a 128×64 Smart LCD Controller, which allows standalone printing from an SD card and manual control of print operations without needing a constant PC connection. The entire system is powered by a 24V 10A SMPS (Switched-Mode Power Supply), capable of delivering stable power to all motors, heaters, and control electronics. The mechanical frame of the printer is constructed using recycled aluminum profiles, ensuring structural strength, lightweight design, and portability.

TABLE 1

Sr. No	Component name
1.	Arduino Mega
2.	CNC Shield RAMPS 1.4
3.	Stepper Motors
4.	A4988 Motors Drivers
5.	Hotend Nozzle extruder
6.	Limit switches
7	24v 10A power supply
8.	Smart LCD Controller 128×64
9.	Aluminium/steel framework with linear rails and lead screws
10.	Filament Roll
11.	Hotplate
12.	Mechanical Parts: belt, bearings, rod,etc.

SOFTWARE REQUIREMENT

The software system of the portable 3D printer plays a vital role in controlling the hardware, processing 3D models, and executing print commands with precision. The main firmware used in this project is Marlin, an open-source firmware widely adopted in the 3D printing community. Marlin is written in C++ and is specifically designed for microcontrollers like the Arduino Mega 2560. It handles all core functionalities including stepper motor control, temperature regulation, LCD interaction, and interpretation of G-code instructions. Configuration of Marlin is done through two key files: Configuration.h and Configuration_adv.h, where parameters such as printer dimensions, thermistor types, motion settings, and endstop logic are defined and customized to match the hardware setup.

To upload the Marlin firmware to the Arduino board, the Arduino IDE is used. This environment allows users to compile and flash the firmware via USB to the Arduino Mega. It supports multiple libraries and provides a simple interface for debugging and updating the firmware as needed. For slicing 3D models, the project uses Ultimaker Cura, a free and open-source slicing software that converts STL or 3MF 3D model files into G-code. Cura allows customization of print parameters such as layer height, infill density, printing speed, and temperature settings. The generated G-code contains all the movement and extrusion instructions required to build the object layer by layer.

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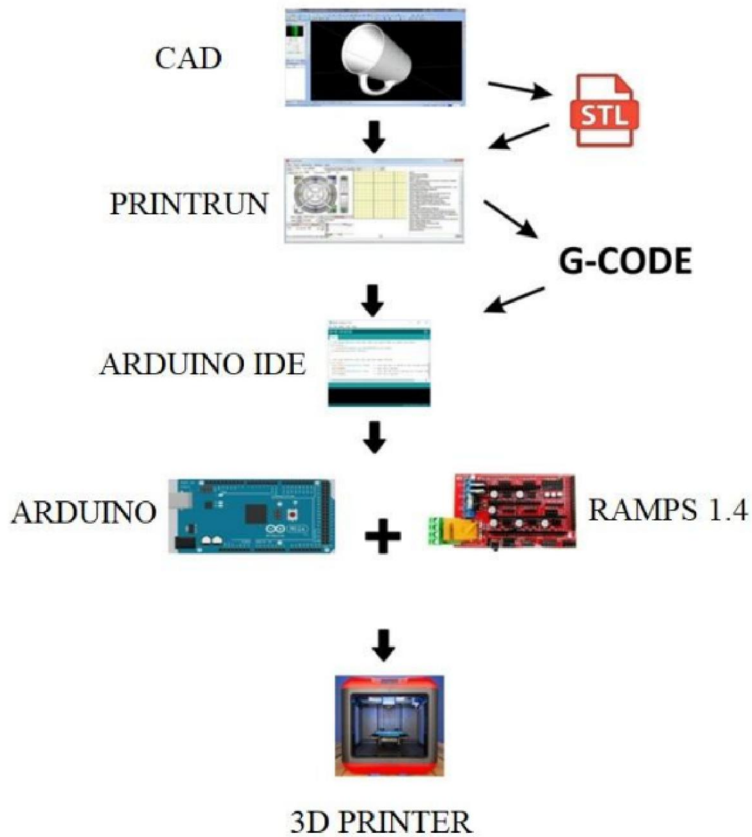

FIG. SOFTWARE FLOWCHART

For real-time printer control and monitoring, optional software tools such as Pronterface or Repetier-Host can be used. These programs connect to the printer via USB and offer functions like manual axis movement, temperature monitoring, G-code preview, and real-time feedback.Together, these software tools ensure smooth operation of the 3D printer from model preparation to print completion, making the system efficient, customizable, and user-friendly.

VI. CONCLUSION

The development of a portable CNC-based 3D printer successfully demonstrates the integration of mechanical, electronic, and software components to create a functional, compact, and cost-effective fabrication system. By utilizing open-source tools such as Arduino Mega, RAMPS 1.4, Marlin firmware, and Cura slicing software, the project achieves reliable and accurate 3D printing capabilities. The use of recycled aluminium for the frame not only reduces cost but also emphasizes sustainability. The system is capable of producing quality prints with good resolution, making it suitable for educational, prototyping, and on-site applications. Overall, the project provides a practical and scalable solution that supports the growing need for portable and customizable digital manufacturing systems.

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