DESIGN AND FABRICATION OF A LOW-COST, COMPACT FUSED DEPOSITION MODELING (FDM) 3D PRINTER

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Abstract

The initial phase of this project established the foundational architecture for a custom Fused Deposition Modeling (FDM) 3D printer. We have centered on the kinematic analysis and structural design of a Core XY-style Cartesian frame, utilizing CAD software to simulate assembly tolerances and motion constraints. A comprehensive Bill of Materials (BOM) was generated, prioritizing standardized off-the-shelf components like the 2020 aluminum extrusion ecosystem and open-source electronics, effectively solving the challenge of high entry costs associated with commercial additive manufacturing systems. The project addresses the physical fabrication, systems integration, and calibration of the prototype. This involves the precision assembly of the mechanical gantry, installation of the linear motion system using 8mm smooth rods and LM8UU bearings, and the complex wiring of the electronic control loop. A critical part of this phase is the configuration of the Marlin Firmware, where parameters such as acceleration limits, thermal runaway protection, and steps-per-mm will be tuned to match the hardware specifications. This project aims to demonstrate the feasibility of constructing a high-precision rapid prototyping machine using open-source hardware. The successful completion of the project will result in a fully functional 3D printer capable of producing dimensionally accurate parts, validating the design choices.

Keywords: FDM 3D Printer, CAD Design, Arduino Mega, Marlin Firmware, Rapid Prototyping, Mechatronics.

INTRODUCTION

Manufacturing is the process of converting raw materials into useful products through various physical, chemical, mechanical, or thermal processes. Traditional manufacturing methods often require expensive tooling, dies, molds, skilled labor, and longer production times. Additive manufacturing, commonly known as 3D printing, represents a transformative approach to rapid prototyping, enabling the physical realization of digital designs with unprecedented accessibility. At its core, this technology translates a computer-aided design (CAD) model into a tangible object through a meticulous, layer-by-layer deposition process.

Fused Deposition Modeling (FDM) is an additive manufacturing process in which a thermoplastic filament is heated until it melts and is deposited through a nozzle onto a build platform. The working principle is based on controlled extrusion of molten thermoplastic material. The motion system moves the nozzle or bed according to instructions generated by slicing software, known as G-code. The motivation for this project stems from the inaccessibility of commercial 3D printers, which often cost between 1,00,000 INR and 2,00,000 INR, limiting their use in educational settings. This project aims to empower users to build their own printer, fostering skills in electronics, mechanics, and programming, while maintaining a compact footprint and strict budget constraints.

METHODOLOGY

The methodology encompasses the complete lifecycle development of a low-cost, compact FDM 3D printer prototype. The primary chassis is constructed using 2040 T-slot aluminum profiles, providing a highly rigid and modular framework. The motion system utilizes hardened 8mm precision-ground steel shafts and LM8UU linear bearings driven by NEMA 17 stepper motors and GT2 timing belts for the X and Y axes, ensuring precise movement with minimal backlash. The Z-axis is driven by a T8 Lead Screw with a brass nut.

Figure 1: Isometric view of 3D printer assembly

The electronic architecture relies on an Arduino Mega 2560 paired with a RAMPS 1.4 shield. A4988 stepper motor drivers facilitate the micro-stepping capabilities necessary for smooth kinematic movements. The thermal extrusion core features an MK8 Metal Extruder feeding Polylactic Acid (PLA) filament into an E3D V6 hot end, which deposits the material onto an aluminum heated build plate. The firmware utilized is the open-source Marlin firmware, customized to match the mechanical specifications, including steps-per-millimeter calibration and thermal runaway protection protocols. Ultimaker Cura was configured as the slicing software to generate the G-code.

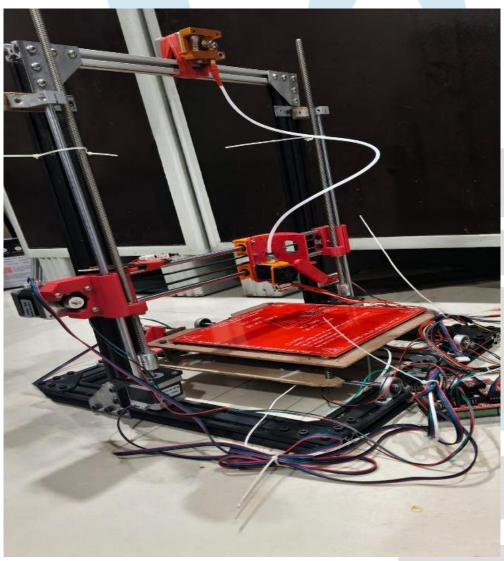

Figure 2: Complete assembly of the FDM 3D printer

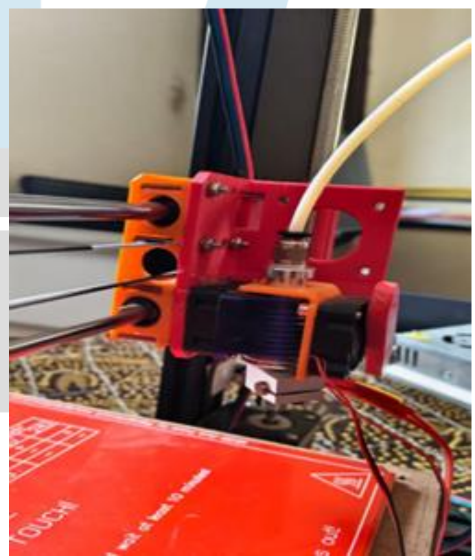

Figure 3: Integrated Extrusion system.

Table 1. Specifications of Printer

Parameter	Specification
Printer Type	FDM
Build Volume	200 × 200 × 200 mm
Filament Diameter	1.75 mm
Nozzle Diameter	0.4 mm
Printing Material	PLA
Control Board	Arduino Mega + RAMPS 1.4

RESULTS AND DISCUSSION

After fabrication and calibration, the printer was rigorously tested by printing sample parts. The results were evaluated based on dimensional accuracy, surface finish, layer bonding, and printing reliability. A 20 mm × 20 mm × 20 mm calibration cube was printed using PLA filament to verify dimensional accuracy along the X, Y, and Z axes. The errors were well within acceptable limits for a low-cost FDM 3D printer, demonstrating the success of the kinematic calibration.

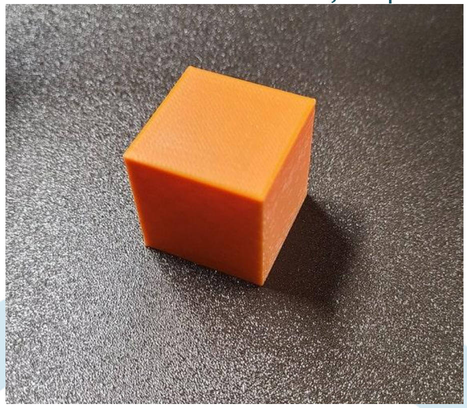

Figure 4: Calibration of Cube

Table 2. Dimensional Accuracy of Calibration Cube

Axis	Designed Value	Measured Value	Error
X-axis	20.00 mm	20.15 mm	+0.15 mm
Y-axis	20.00 mm	19.90 mm	-0.10 mm
Z-axis	20.00 mm	20.20 mm	+0.20 mm

Surface finish quality was found to be highly dependent on layer height, print speed, and part cooling. The inclusion of a customized cooling duct directed airflow efficiently toward the freshly extruded filament, significantly improving layer cooling and overhang performance. Minor dimensional deviations can be further minimized by fine-tuning flow rates and belt tensioning.

CONCLUSION

The project successfully achieved the design and fabrication of a low-cost, compact FDM 3D printer utilizing readily available mechanical and electronic components. A Cartesian configuration was selected due to its simplicity, low cost, and ease of calibration. Calibration was performed for axis movement, extrusion, bed leveling, and temperature control. Test prints confirmed that the fabricated printer is capable of producing PLA components with acceptable dimensional accuracy and surface finish. Ultimately, this project demonstrates that additive manufacturing technology can be democratized, proving that frugal component sourcing and open-source software can yield a highly capable prototyping tool for educational and research environments without prohibitive capital investment.

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