Manufacturing of a cost-effective 3D Printer for prototyping and educational purpose.

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Abstract - *Additive manufacturing (AM), especially Fused Deposition Modelling (FDM), has become increasingly popular due to its affordability and flexibility. This project aims to design and assemble a custom FDM 3D printer, allowing us to gain practical experience in additive manufacturing while providing a functional printing solution for our institution. The printer is constructed using an Arduino Mega 2560, RAMPS 1.4, NEMA 17 stepper motors, and a Creality Ender 3 V2 hotend. During our initial test prints, we encountered problems like layer misalignment and unstable vertical movement. To find solutions, we researched and found a reference video that demonstrated the addition of structural supports—L-supports and R- supports—to stabilize the lead screw and minimize vibrations. Motivated by this, we decided to implement similar modifications by 3D printing custom supports on an Ender 5 Pro. We anticipate that these changes will enhance print accuracy, improve dimensional stability, and decrease mechanical inconsistencies. This paper outlines the design, assembly, challenges, and modifications made to our 3D printer. We will conduct final print tests to confirm the improvements, making this project a valuable resource for students and researchers interested in the development of 3D printer*

Key Words: Fused Deposition Modelling, Additive Manufacturing, 3D Printer Development, Lead Screw Stability, RAMPS 14, Arduino Mega 2560, Print Quality Optimization

1.INTRODUCTION

Additive Manufacturing (AM), commonly known as 3D printing, has revolutionized the way objects are designed and fabricated. The concept of AM dates back to the 1980s, with the development of stereolithography (SLA) by Charles Hull in 1986, which laid the foundation for modern 3D printing. Over the years, various AM techniques such as Selective Laser Sintering (SLS), Fused Deposition Modelling (FDM), and Digital Light Processing (DLP) have been developed, each catering to different industrial and consumer needs. Among these, FDM technology, introduced in the late 1980s and patented by Stratasys in 1992, has become the most widely used due to its affordability, ease of operation, and material versatility.

This project focuses on the design and fabrication of a cost-effective FDM 3D printer to gain hands-on experience in additive manufacturing and provide a functional printing solution for our institution. The motivation behind this project stems from the lack of a working 3D printer in our college, which limits students' ability to explore and experiment with 3D printing technology. To bridge this gap, we aimed to build a 3D printer from scratch, understanding its mechanical structure, electronic control systems, and software configurations. Through this, we sought to develop a deeper knowledge of stepper motor control, firmware tuning, calibration, and material extrusion processes.

The 3D printer was developed using Arduino Mega 2560 with RAMPS 1.4, NEMA 17 stepper motors, A4988 motor drivers, a V6 J-head hot end, and a MK2B heated bed, ensuring a balance between affordability and functionality. During initial tests, print quality issues such as layer misalignment and unstable vertical movement were observed. After researching potential solutions, we found that lead screw vibrations contributed to these errors. Inspired by a reference study, we integrated L-support and R-support structural modifications to stabilize the lead screws and improve print accuracy. These supports were 3D-printed using an Ender 5 Pro and are currently being integrated into our system.

This paper documents the design, fabrication, assembly, and testing of our custom 3D printer, highlighting the challenges faced, modifications made, and expected improvements.

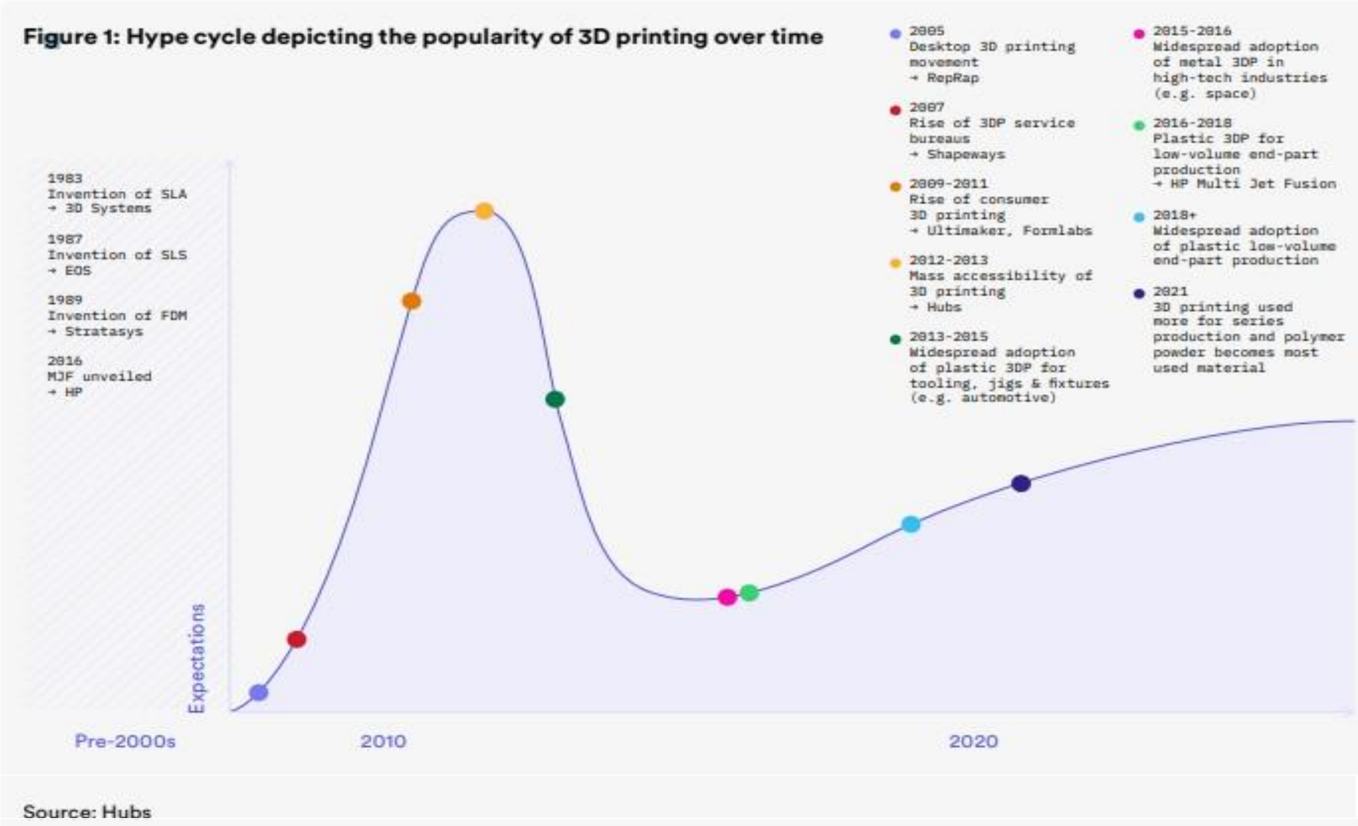

Figure 1. Hype cycle depicting the popularity of 3D printing over time (Source: Hubs).

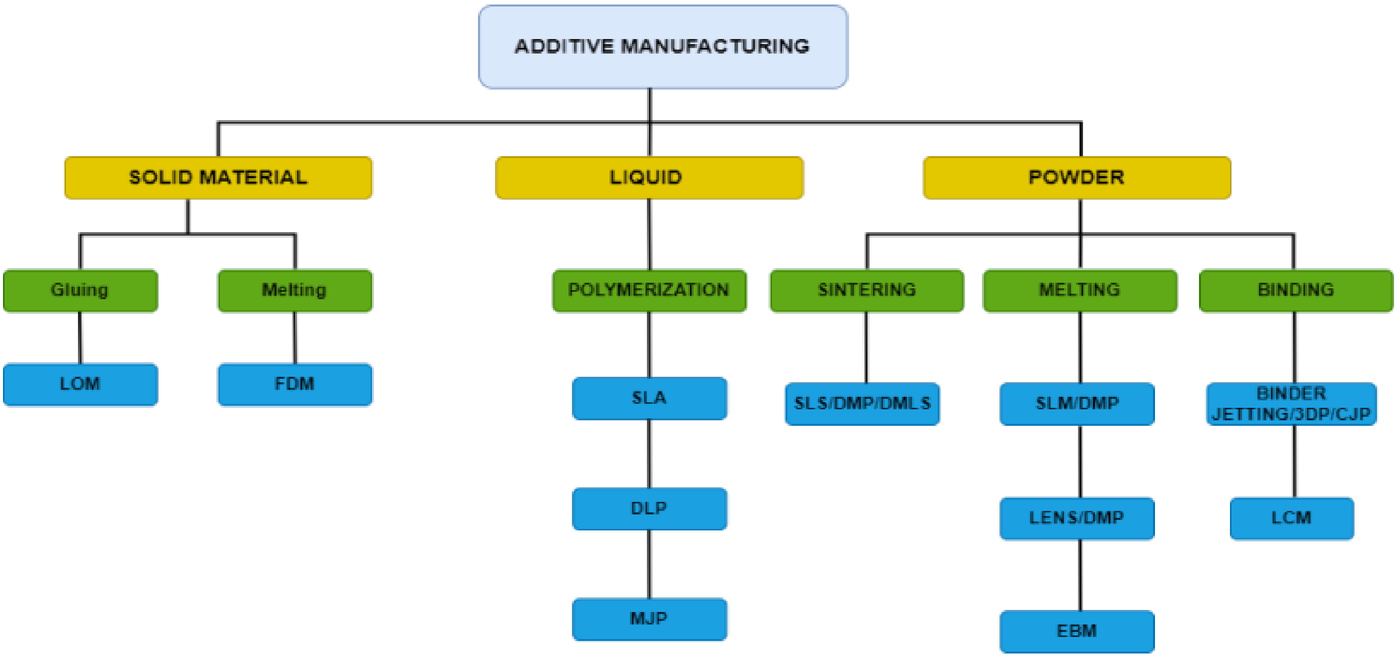

Figure 2. Types of additive manufacturing processes (made with draw.io)

1.1. ADDITIVE MANUFACTURING

According to the paper by Tomasz Grzegorz Gaweł, titled "Review of Additive Manufacturing Methods," additive manufacturing (AM) has progressed significantly from rapid proto- typing to large-scale production. It now provides a variety of techniques for creating parts from polymers, metals, ceramics, and composites.

The Additive Manufacturing processes can be separated according to input material and type of process carried out. Input materials can be solid, liquid, powder [1].

Additive Manufacturing (AM), or 3D printing, is a layer-by-layer creation of objects from a digital 3D model. It begins in Computer-Aided Design (CAD) software, where the object is designed and then converted into a stereolithography (STL) file or another usable format. The file is processed using slicing software, which divides the model into thin layers and creates instructions (G-code) for the 3D printer. Once the file is prepared, the printing process begins, using either a bottom-to-top or top-to-bottom layer-depositing method, depending on the AM technology employed.

In Selective Laser Sintering (SLS) and Fused Deposition Modelling (FDM), material is deposited or melted layer by layer from the bottom up. A hot nozzle deposits thermoplastics in FDM, while in SLS, a laser melts powder particles. Stereolithography (SLA) and Digital Light Processing (DLP) work in the opposite direction, from the top down, using a UV laser or light to cure liquid resin as the object builds upwards. Binder Jetting and Material Jetting deposit material or binding agents layer by layer on a surface, typically from the bottom up. This precise layer-by-layer building enables complex forms, minimal material waste, and highly customized designs, making Additive Manufacturing a significant technology in modern manufacturing.

1.2. PROBLEM STATEMENT

Access to affordable 3D printers in educational institutions is limited, restricting hands-on learning in additive manufac- turing. To address this, we aimed to build a cost-effective 3D printer for our college lab while gaining practical knowledge of 3D printing technology. This project enhances learning opportunities and provides an affordable prototyping solution for students.

1.3. OBJECTIVES

- Develop and produce a low-cost 3D printing device that can be utilized for prototyping and educational purposes.
- Gain hands-on experience in additive manufacturing by understanding the operational processes, hardware integration, and firmware setup involved with a 3D printer.
- To design a modular FDM 3D printer with open-source components and firmware to enable future customization.
- To increase knowledge on modelling and different parameters of firmware configurations (for e.g., JERK, Steps per mm and etc.)

1.4. SCOPE

- The project is all about designing, developing, and fine- tuning a budget-friendly FDM 3D printer with a build volume of 200mm x 200mm x 200mm.The main aim here is to create an affordable and accessible prototyping solution for educational institutions, especially for students and re- searchers diving into engineering and manufacturing. Unlike those pricey commercial 3D printers, this initiative focuses on using cost-effective components while still ensuring that the printer is reliable and produces accurate prints.
- By tackling these key areas, the project hopes to achieve the following:
  Cost-Effective Design – Create a low-cost 3D printer using open-source firmware (Marlin) and commonly available parts (like RAMPS 1.4 and Arduino Mega 2560).
- Educational Utility – Give students hands-on experience with additive manufacturing, helping them grasp 3D printing technology, firmware setup, and machine calibration.
- Print Quality Optimization – Make structural enhancements such as lead screw supports and optimized stepper motor calibration to boost print accuracy and consistency.
- Customization and Upgradability – Design the printer to be modular, so it can be easily upgraded in the future with features like automatic bed levelling, advanced stepper drivers (like TMC2208), and multi-material extrusion.
- Practical Implementation – Build a fully functional prototype that can be used in the college lab, allowing students and faculty to explore rapid prototyping, research projects, and hands-on manufacturing exercises.

1.5. METHODOLOGY

A. IDEATION PHASE

i. Project Topic Discussion and Finalization: Discussed with group members and faculty guides to finalize a final- year project having practical use and innovation possibilities. Finalization of the idea to build a low-cost 3D printer was finalized keeping in view educational utility and existing market needs.

ii. Early-stage Research: Carried out initial research across different types of 3D printers, such as FDM (Fused Deposition Modelling) technology, trending open-source hardware platforms (e.g., Arduino Mega 2560 with RAMPS 1.4), and standard components appropriate for low-cost manufacture.

B. FINALIZATION STAGE

i. Problem Statement Development: Composed a brief problem statement highlighting the lack of affordable 3D printers in schools and the need for a DIY approach.
ii. In-Depth Research: Conducted thorough analysis of open-source designs, firmware (specifically Marlin), and slicing software (such as Ultimaker-Cura and Repetier- Host), and determined settings appropriate for our own customized printer configuration.

C. LITERATURE SURVEY

i. Component Selection and Functionality Analysis: Study technical documents and online forums to understand the working principles of key components like NEMA 17 motors, A4988 stepper drivers, MK2B heated beds, and V6 hot ends.
ii. Benchmarking and Feasibility Analysis: Compared similar low-cost printer designs to establish a baseline for print volume, resolution, and overall performance.

D. DESIGN AND ASSEMBLY PHASE

i. CAD Modelling and Frame Design: Designed a 3D printer model using Catia. Developed frame with aluminium profiles and mild steel components for cost and structural integrity.
ii. Electronics and Wiring Layout: Planned and implemented the wiring diagram for the RAMPS 1.4 board, Arduino Mega 2560, end stops, thermistors, and power supply.
iii. Firmware Configuration: Printer-specific Marlin firmware based on printer parameters like steps/mm, thermistor model, bed size, and ends top logic.

E. CALIBRATION AND TESTING

i. Axis Calibration: X, Y, and Z axes calibrated to precise steps/mm using threaded rods and pulleys.
ii. First Print Trials: Conducted first test prints using PLA+ to test adhesion, layer uniformity, and extrusion.
iii. Troubleshooting: Solved problems like X-axis drift, extrusion gaps, and motor calibration by updating firmware and hardware changes.

F. EVALUATION AND MODIFICATIONS

i. Print Quality Test: Sample prints tested for precision of dimensions, overhangs, and surface finish.
ii. Thermal Management and Safety Check: Checked hot end and bed heat profiles for safe temperatures and electrical safety.
iii. Iteration and Upgrades: Improved tensioners, improved cable management, and researched further upgrades (like silent stepper drivers or improved bed levelling) for extended use.

2. LITERATURE REVIEW

A. Tomasz Grzegorz Gaweł [1] The manuscript reviews the additive manufacturing technology. The principle of operation of the most popular and new AM methods was discussed. the manuscript presents the possibility of skewing different materials for individual technologies. Additive manufacturing technologies have been described that can manufacture parts from polymers, metals, ceramics and composites.

B. 3D Printing Failures (2020 Edition) by Sean Aranda [2] was referred to for troubleshooting and setting printing parameters. Based on the book’s recommendations, a hot end temperature of 200°C and a bed temperature of 60°C were used for PLA, improving first-layer adhesion and overall print quality.

C. The project report “3D Printer Using Fused Deposition Modelling” [3] by D. Supriya, K. Jayanth, K.H.V.S Sai Madhu, and Ch. Sai Krishna details the development of an affordable FDM 3D printer using Arduino Mega 2560 and PLA material. It covers programming with Arduino IDE, slicer software for G-code generation and successful prototype printing.

D. The guide "Wiring 3D Printer RAMPS 1.4: 12 Steps by Core3D)" [4] discusses the complete wiring process of a RAMPS 1.4-based 3D printer, covering connections for mo- tors, endstops, heaters, thermistors, and power supply. We referred to this guide to correctly wire all the electronic components of our 3D printer, ensuring safe and functional operation.

E. The Document “Configuring Marlin-Marlin 3D printer firmware” [5] discusses the customization of Marlin firmware settings for different 3D printer hardware. We referred to it for configuring firmware parameters such as thermistors, steps per mm and basic setup for our 3D printer.

3. PROPOSED WORK

A. Initial Planning, Frame Design & Procurement

i. Project Motivation and Background

Seeing that the current 3D printer in our college laboratory was not operating as it should lead us to decide to work on a do-it-yourself model. This disparity motivated us to investigate our last year engineering project—building a reasonably priced, dependable printer—by means of possibilities. The concept of building a machine that could not only meet our own academic requirements but also help the college's prototyping capacity for next generations of students drives us.

We started the project by looking at a number of research papers, tutorials, and videos about do-it-yourself 3D printers. We observed a trend during this phase: most successful homemade 3D printers used either aluminium channels or extrusions for the frame. After looking at the local pricing and availability, we discovered aluminium extrusions were out of our means. We thus chose 2"×1" aluminium channels, which were more affordable yet still gave reasonable structural rigidity.

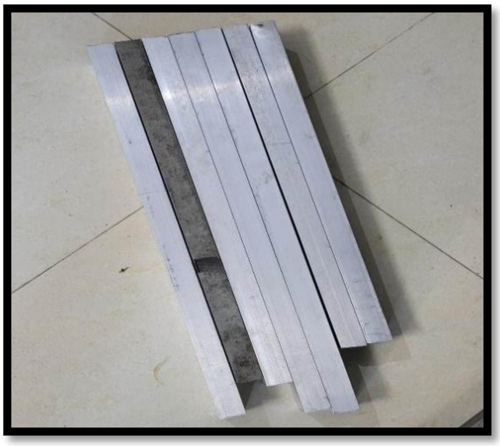

Figure 3: 2"×1" aluminium channels used for fabrication of 3D printer

We also finalized for our design after noticing from our research that most manufacturers used a standard build volume of 200mm x 200mm x 200mm.

ii. Concept Sketching and CAD Modelling

We began with a rough 2D hand sketch to obtain a sense of the spatial relationship of the components. We then developed a precise 3D CAD model using CATIA V5. In the CAD model:

The frame was dimensioned and assembled using the alu- minimum channel sections. Standard components such as stepper motors, lead screws, hotend, bed, and extruder were downloaded and positioned within the assembly.

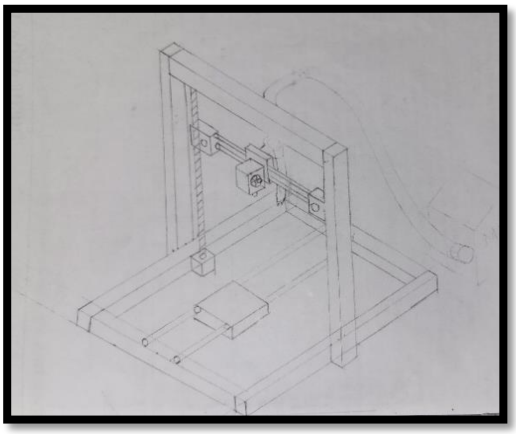

Figure 4: Basic 2D hand sketch showing assembly of aluminium channels

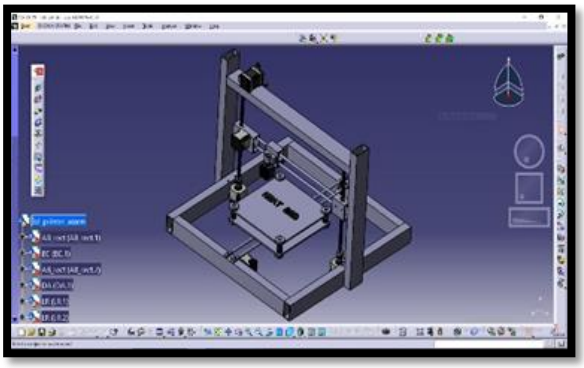

Figure 5: CAD model showing assembly of aluminium channels

iii. Frame Machining and Assembly

Once the CAD model was completed, the machining of the aluminium channels was initiated in the college workshop.

- The channels were cut to precise size according to the CAD drawing using a manual hacksaw prior to being smoothed further using a file and bench grinder.
- Drilling: There were special holes marked and drilled for:

1. Installation of the X-axis stepper motor.
2. Permitting lead screws to travel along the Z-axis supports.
3. Attaching L-brackets to connect frame sections in right angles.

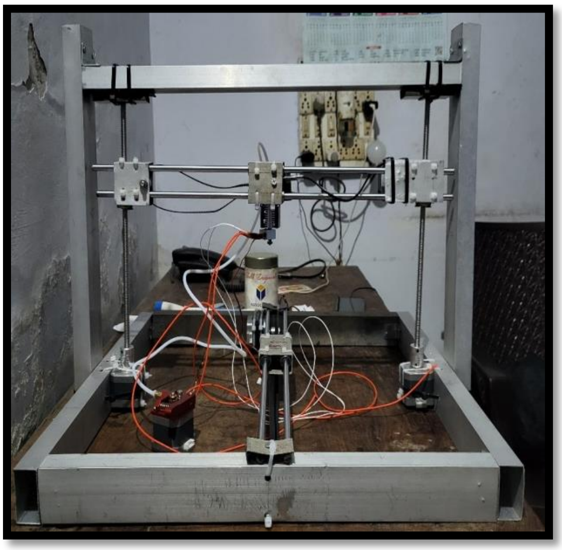

Figure 6: Actual prepared Model

Table 1: Components used in the project

Sr. No	Components	Quantity
1.	Arduino Mega 2560	1
2.	12V 30A 360W SMPS	1
3.	LM8UU Linear Bearing	10
4.	8mm Smooth Rod	6
5.	Mechanical Endstops	3
6.	Creality Ender 3 V2 Hotend	1
7.	12V Heater Cartridge	1
8.	MK2B HeatBed	1
9.	Bed levelling screws and springs	4
10.	Nema 17 4kg-cm stepper motor	5
11.	Flexible Coupling	2
12.	8mm Trapezoidal lead screw	2
13.	GT2 Pulley 16 teeth 5mm bore	4
14.	100K NTC 3950 Thermistor	1
15.	Ramps 1.4	1
16.	2 x 1" Aluminium channel, 11 feet	1
17.	Ball Bearings	2
18.	A4988 stepper motor drivers	4
19.	Extruder right hand all metal	1
20.	GT2 Open Loop 6mm Timing Belt 2m	1
21.	Numakers Black Filament – 1kg	1
22.	LCD128x64 Display	1
23.	Wiring and jumper cables	

Firmware & Calibration:

b. Key Firmware Settings:

The following parameters were updated in the Marlin firmware's [5] Configuration.h file:

c. Motherboard Selection:

MOTHERBOARD BOARD_RAMPS_14_EFB

This sets the controller board configuration suitable for our RAMPS 1.4 setup (EFB: Extruder, Fan, Bed.

d. Baud Rate:

BAUDRATE 115200

A high baud rate ensures faster serial communication between the printer and host software.

e. Thermistor Configuration:

TEMP_SENSOR_0 1 (Hotend)
TEMP_SENSOR_BED 1 (Heatbed)

f. Temperature Limits:

HEATER_0_MAXTEMP 275 (Hotend)
BED_MAXTEMP 90 (Heatbed)

g. Axis Inversion and Homing Direction:

INVERT_X_DIR false
INVERT_Y_DIR false
INVERT_Z_DIR false
X_HOME_DIR -1
Y_HOME_DIR -1
Z_HOME_DIR-1

h. Endstop Logic:

X_MIN_ENDSTOP_INVERTING true
Y_MIN_ENDSTOP_INVERTING true
Z_MIN_ENDSTOP_INVERTING true

i. Micro stepping (via hardware jumper):

- All axes configured with 1/16 micro stepping using A4988 drivers.

B. Steps per mm Calibration:

Precise movement is critical for dimensional accuracy. We used an iterative method to calibrate the **steps/mm** for X, Y, Z axes and the extruder.

- **Formula to calibrate steps per mm:**

$$\text{New Steps/mm} = \text{Current Steps/mm} \times \left(\frac{\text{Expected Movement}}{\text{Actual Movement}}\right)$$

- **X-Axis (Belt Driven):**
  - Initial value: 100
  - Commanded move: 60mm
  - Actual Movement (Measured): 150mm
  - New value:

$$\text{New Steps/mm} = 100 \times \left(\frac{60}{150}\right)$$

New Steps/mm for X-Axis = 40mm

- **Y-Axis (Belt Driven):**
  - Initial value: 80mm
  - Commanded move: 50mm
  - Actual Movement (Measured): 125mm
  - New value:

$$\text{New Steps/mm} = 100 \times \left(\frac{50}{125}\right)$$

New Steps/mm for X-Axis = 40mm

- **Z-Axis (Lead Screw Driven):**
  - With 8mm pitch, 1.8° NEMA17 motor, and 1/16 micro stepping[3].

$$\text{Steps per mm} = \frac{\text{Motor Steps per Rev} \times \text{Microstepping}}{\text{Lead}}$$

$$= \frac{200 \times 16}{8}$$

Steps/mm for Z-Axis = 400mm

- **Extruder (E-Axis):**
  - Loaded filament 80 mm using G1 E80 F100
  - Measured extrusion: 95.4 mm
  - New steps/mm:

$$\text{New Steps/mm} = 100 \times \left(\frac{60}{150}\right)$$

Steps/mm for E-Axis= 80mm

Table 2: Alterations for steps per mm of axes

Axis	Steps/mm	
	Before Calibration	**After Calibration**
X	100	40
Y	80	40
Z	400	400
Extruder	80	80

- **Calibration was repeated at least 2–3 times to eliminate backlash and measurement inconsistencies.**

C. Cura Profile

Table 3: Table representing Cura slicer profile of our 3D printer

Parameter	Value	Description
Layer Height	0.1 mm	Fine quality print for better detail
Wall Line Count	3	Strong outer walls and better surface finish
Infill Density	20%	Balanced strength and print time
Infill Pattern	Grid / Cube	Suitable for uniform internal strength
Printing Temperature	200°C	Ideal for PLA+ filament
Build Plate Temperature	60°C	Improves bed adhesion and reduces warping
Print Speed	48 mm/s	Optimized for quality and reliability
Retraction Distance	6.5 mm	Prevents stringing in Bowden-style setups
Retraction Speed	25 mm/s	Moderate speed to avoid filament grinding
Initial Layer Height	0.3 mm	Improves first layer adhesion and tolerance
Cooling Fan Speed	100%	Enhances print quality by cooling PLA+ effectively

4. RESULT & DISCUSSION

A. Successful Prints

Throughout the project, various models were printed to evaluate and validate the performance of the assembled 3D printer. Among the successful prints: **Low-Poly Ganesha Model**: Printed using PLA+ filament with a layer height of 0.1 mm and a print time of approximately 2 hours and 30 minutes. The model was successfully printed with support, showing clean details and minimal stringing.

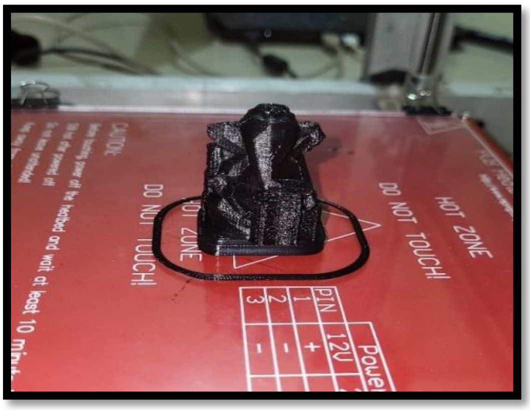

Figure 2: Low poly Lord Ganesha model printed with supports

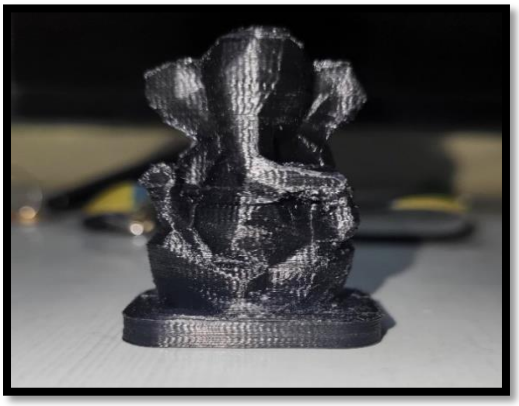

Figure 3: Low poly Lord Ganeha 3D model with removed supports

Figure 4: 20 × 20 mm Calibration Cube

20 × 20 mm Calibration Cube: Accurately printed, measured exactly 20 mm on all axes, confirming proper dimensional calibration.

Figure 5: Calibration cube measured with digital vernier caliper

B. Initial Successful Print: Initial Successful Print:
Before we modified our Cura profile, we achieved our first successful print — a symbol-printed badge with a cross-patterned raised design.
This 3D print affirmed that:

- The motion system and firmware were functioning well.
- Filament feeding and extrusion were consistent.
- Bed adhesion and first-layer print quality were good.

Even though the detailing and surface finish were minimal, it was where the printer transitioned from mechanical configuration to functional product. This led to additional optimization and slicing parameters.

Figure 6: First successful 3D print

Figure 7: Minimal detailing on first successful 3D print

C. Print Quality Evaluation

The first test prints showed uneven layer alignment and dimensional errors, particularly in the calibration cube. Subsequent to prolonged tuning, cura profile updates, and firmware upgrades, print quality dramatically improved. The main observations are:

- **Layer Adhesion:** Robust and consistent across best printing temperature (200°C for PLA+) and bed temperature (60°C) [2].
- **Surface Finish:** Smooth surface obtained with a 0.1 mm layer height and 3 wall lines.
- **Support Structures:** There was testing both with and without support for more complex models, and both solutions were found acceptable with excellent overhang management.

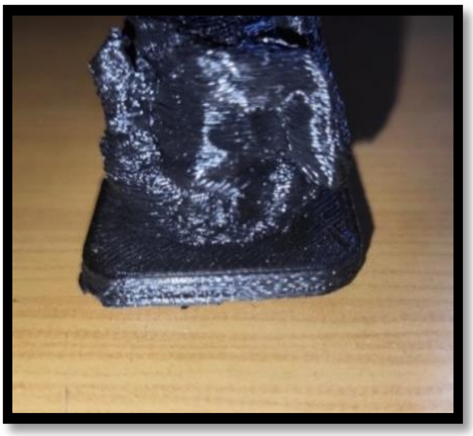

Figure 8: Visible layer lines on incomplete Lord Ganesha 3D model due to absence of supports

Figure 9: Better surface finish due to presence of supports on Lord Ganesha 3D model

5. CONCLUDING REMARKS AND SCOPE FOR FUTURE WORK

A. CONCLUSION

The development and optimization of a low-cost FDM 3D printer for prototyping and educational purposes have demonstrated great potential in demystifying additive manufacturing technology. By utilizing open-source components such as the Arduino Mega 2560, RAMPS 1.4, and NEMA 17 stepper motors, the project effectively demonstrates how low-cost systems can deliver reliable performance and print quality. The research confirms that with proper mechanical alignment, firmware configuration, and slicing profile adjustments, low-cost printers can deliver results comparable to commercial systems.

The initial test phase revealed some hardware and software-level issues like extruder step skipping and infill irregularities. These issues were resolved with systematic debugging via firmware adjustment, Bowden tube adjustment, and retraction setting adjustment, particularly in Ultimaker Cura. Following these adjustment measures, prints like the calibration cube and the low-poly Ganesha model print were successfully printed, which demonstrated the system to be stable and accurate. The follow-up successful print ensured the validity of the custom print profile, proper bed leveling, and extrusion calibration, again emphasizing the importance of iterative testing.

Additionally, the hands-on experience significantly developed the group's working understanding of stepper driver control, G-code interpretation, and firmware features like Z-babystepping, which are critical for adjusting the first layer in real-time. These activities developed not just technical skills but also valuable team and problem-solving skills required for roles in industrial or research-focused design and production.

In general, the effective deployment of the custom FDM 3D printer confirms the viability of open-source technology in realistic engineering simulation and prototyping settings. With continued improvement, these systems have the potential to offer scalable solutions to rapid manufacturing, design verification, and experimentation education, all within the contexts of affordability and accessibility.

B. SCOPE FOR THE FUTURE WORK

Building on this project, a number of directions for the 3D printer system's expansion and practical improvement can be investigated:

1) **Auto bed leveling integration:** By doing away with the need for manual leveling, an automatic bed leveling sensor, like BLTouch or a capacitive probe, would improve print consistency and cut down on setup time.
2) **Power Loss Recovery and Filament Run-out Detection:** Reliability would be increased and the printer would be more production-ready if the firmware were improved to support functions like filament run-out detection and power-loss recovery.
3) **AI-Based First Layer Monitoring System:** An AI-enabled camera system that can identify first layer flaws in real time and notify users or halt the print could be a future addition to the first layer monitoring system. This would increase first-layer dependability and cut down on material waste.

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