Original Article
ISSN (Online): 2456-8651

International Journal of Engineering Science Technologies
March-April 2025 9(2), 44–61

COMPARATIVE STUDY OF PREDICTIVE MODELS AND REAL-WORLD DATA IN 3D PRINTING TIME ESTIMATION

Sivakumar Karthikeyan [1], Ramu. P [1], Mithunn Balaji. S [2]

[1] Department of Mechanical Engineering, SRM Valliammai Engineering College, SRM Nagar, Chennai 603203, India
[2] Student, Amador Valley High School, Pleasanton, California, USA

Received 15 January 2025
Accepted 17 February 2025
Published 24 March 2025

Corresponding Author
Sivakumar Karthikeyan,
tjksiva2k@gmail.com

DOI 10.29121/IJOEST.v9.i2.2025.678

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

The Additive manufacturing technique plays a significant role in today's industrial environment, helping to meet customer demands. Various processes are available in 3D printing technology, including FDM, SLS, EBM, LOM, and DLP. The main objective of this project is to design and fabricate a portable 3D printer with a build volume of 200 x 200 x 150 mm^3 that can be constructed with economical machining time. We will be using a 4-axis mechanism, where three axes represent the x, y, and z coordinates, and the fourth axis is dedicated to the extruder. The technology we are adopting is FDM, which involves using various materials such as PLA, ABS, and HIPS. In this process, filament material is heated to its melting point and deposited layer by layer. The combination of these layers forms the final 3D model. In this project, we will mathematically estimate the time required to print a simple part using 3D printing. Afterwards, we will compare our estimated time with the time estimated by the machine. In this comparison, we will also calculate the error and the percentage of error.

Keywords: Controller Board, Stepper Motor, 3D Printer, AutoCAD Model

1. INTRODUCTION

A 3D printer is an additive manufacturing technique used to create 3D objects and parts by layering multiple materials. It is often referred to as rapid prototyping. This mechanized method allows for the quick production of 3D objects tailored to specific sizes, with a machine connected to a computer that contains blueprints for the desired objects. Unlike subtractive manufacturing, which involves removing material from a solid block through processes like sculpting or drilling, 3D printing focuses on adding material. The primary advantages of using a 3D printer include a

90% material utilization rate, enhanced product lifespan, and the production of lighter, stronger items. 3D printing is professionally utilized across various fields, including aerospace, automotive, medical, construction, and the manufacturing of numerous household products.

2. LITERATURE SURVEY

The 3D printing is an additive manufacturing technique in which 3D objects are printed with the help of CAD software. Different processes are available in 3D printing technology such as (1) fused deposition method (FDM), (2) selective laser sintering (SLS) (3) EBM electron beam machining (EBM), (4) laminated object manufacturing (LOM), (5) Digital light processing (DLP), etc.

In this article, we have focused on designing and fabricating a portable 3D printer of bed volume (150 x 180 x 200 mm3) which can be constructed carefully. We are using 4-axis mechanisms where 3 axes are x-y-z and the fourth axis is an extruder. The process adopted by us is FDM technology, in which different materials like polylactic acid, acrylonitrile butadiene styrene, high impact polystyrene, etc. By heating any of the filament material to its melting point, it is deposited layer by layer. The combination of many layers of such type will give us a final 3D model of this paper Patil et al. (2015).

3D technology uses a print head to layer raw materials in successive layers to create a three-dimensional object. Testing of printed automotive prototypes will be conducted using various technologies provided by Object 3D printing manufacturers Jayapalan et al. (2024). These case studies include the fabrication of a visionary design for a high-rise product or prototype. The primary contribution of this research lies in the comprehensive survey of practices and emerging trends in the construction and related industries. Additional contributions are made by synthesizing selected practices identified through both the literature review and field surveys to develop innovative design and construction methodologies. These methodologies have been tested through the design of unique architectural projects centered on fabrication using construction 3D printing for this research article Chandrakar and Kachhawaha (2015).

This paper Sivakumar et al. (2012), focuses on designing a 3D printer to reduce costs to an optimal level. 3D printing technology has become a significant topic in today's technological discussions. Companies and individuals worldwide are experimenting by extruding plastics and metal objects for prototyping and various personal needs. To meet these demands, we have developed a machine called the "Additive Manufacturing Machine," which is based on 3D printing technology. With this machine, users can transform any digital file into a physical three-dimensional product. In this paper, we will explore the concept of additive manufacturing. First, we will define the term. Next, we will discuss the methods used in this technology and how we have reduced costs Shedge et al. (2017) . We will also investigate the advantages of this technology compared to conventional manufacturing methods and examine the numerous applications currently utilized. Finally, we will outline the future potential of this technology.

This work presents Sivakumar et al. (2016), a preliminary study evaluating the aesthetic quality of 3D printed parts. A reference part was designed to highlight the limitations of the layer-wise printing process by representing all typical 3D printing defects. Additionally, a benchmarking methodology was developed to quantitatively assess the aesthetic quality of different 3D printers using the proposed reference part. The benchmarking results were summarized using a unique indicator known as the Aesthetic Quality Index (AQI). This methodology was applied to compare three different 3D printers, with the MakerBot Replicator identified as the machine that produced the artifact replica with the highest aesthetic quality. Also, since the reference part encompasses the most common 3D printing defects, it can be used not only to characterize the machine but also to optimize process parameters Galati et al. (2019). Ongoing investigations aim to extend this study to other 3D printers while increasing the number of testers for the benchmarking procedure. In addition to aesthetics, other purely technical indicators will be considered to account for additional quantitative aspects, such as the minimum thickness of infill, which affects the quality of 3D printed parts. Finally, the STL model of the artifact can be downloaded for free from the open-source GrabCAD library, allowing the scientific community to replicate the described methodology and extend this research to a broader range of 3D printers Lan (2015). Design and Fabrication of a Modular Multi-Material 3D Printer. Report..

The printer features a robust and low-cost design utilizing stepper motors for actuation. It employs commercial off-the-shelf components wherever possible, particularly in the framing and linear guide systems. This approach reduces the cost and complexity of the system without compromising performance Arputhabalan et al. (2023). Notably, the printer uses print heads identical to those found in commercial desktop inkjet printers, facilitating high-resolution, multi-material performance in a compact package at a fraction of the cost of industrial inkjet print heads. Additionally, the modular design of the print head mounting allows for independent development and testing of print heads. Recent testing has demonstrated that the printer can produce small, high-resolution, multi-material objects, as illustrated in the results section. The printer is also capable of producing fine details, such as the lettering around the rim of the coin shown in Figure 26. These capabilities enable experimentation and the development of further applications for multi-material printing Arularasan et al. (2022).

This paper Dahle and Rasel (2016), outlines a series of course modules designed as a high-impact and cost-effective learning tool for modeling and simulating the microfabrication processes and design of microelectromechanical systems devices using three-dimensional printing. Microfabrication technology is a well-established method for creating small, high-precision MEMS devices; these processes typically occur in cleanroom environments using expensive high-vacuum equipment. The course modules were developed to provide engineering educators with a more affordable and effective means of teaching MEMS modeling in institutions that do not have cleanroom facilities, which is common in many undergraduate programs Chandrasekharan et al. (2024). Feedback from student evaluations, along with course grades, supports the efficacy of these modules. In these hands-on modules, students learn by designing and constructing MEMS prototypes, experiencing the full process of building a MEMS device from given specifications. The results are also compared to similar assessments conducted in the course before the implementation of these modules to verify their success. The paper provides a detailed description of the modules, the evaluation methodologies employed, and reflections on their implementation Sathish et al. (2024).

Based on the literature, adopting the methodology of a cantilever beam in a 3D printer has presented certain challenges, including vibrations, reduced printing volume, misalignment of the print head, limitations in printer head movement, and deflections. In this paper, we adapt the methodology of simply supported beams for 3D printer fabrication. This approach addresses the challenges outlined in the literature. In a simply supported beam, the use of two fixed supports allows for equal load distribution, which reduces vibrations. There are no movement restrictions for the printer head along any axis, minimizing deflections in the planes and increasing the printing volume (200 x 200 x 150 mm^3).

3. TYPES OF 3D PRINTING TECHNOLOGY

1) Binder Jetting: Binder jetting is an inkjet-based method similar to a 2D inkjet printer. It uses one or more jets to dispense chemical binders' layer by layer into a bed of powdered polymer, stainless steel, bronze, tungsten, or sand for creating molds Kumar et al. (2019)
2) Absorbed Energy Deposition: Laser-Engineered Net Shaping (LENS) and laser cladding. LENS machines utilize deposition heads, similar to inkjet heads, to supply metal powder to the focus of a laser beam, melting the powder into a desired shape. Another technique, Electron Beam Freeform Fabrication, focuses an electron beam onto a metal feedstock in wire form, which is introduced into a vacuum. This process creates a molten pool of metal that solidifies immediately.
3) Fused Deposition Modeling: FDM machines extrude a thermoplastic filament, typically acrylonitrile butadiene styrene or polylactic acid, through a small heated nozzle onto a build platform, constructing the part layer by layer from the platform upwards. A second nozzle may be used to extrude support material, which can be removed after the part is complete. Most consumer-level 3D printers are FDM machines, which are extensively used for prototyping and can also produce finished plastic parts.
4) Aerosol Jet: This process uses a mist generator to create a nonmetal build-to material for printing circuitry or parts on various substrates. The print head nozzle deposits ink, such as silver nanoparticles
5) PolyJet: PolyJet machines, like binder jet machines, are multi-jet, inkjet-like devices that primarily use UV light to cure layers of photopolymer.
6) Laser Melting: Also known as direct metal printing, laser melting machines are powder bed systems that utilize a laser to melt layers of plastic, ceramic, or metal powder.
7) Electron Beam Melting: Similar to laser melting machines, electron beam melting machines build parts from a powder bed in a vacuum.
8) Laminated Object Manufacturing: Laminated object manufacturing machines laminate sheets of paper, plastic, or other materials, which are then cut into desired shapes using lasers or knives.
9) Ultrasonic Lamination: This method employs a process called ultrasonic additive manufacturing, where sound waves fuse layers of metal foil.
10) Digital Light Processing: In this technology, mirrors project an image of each object layer onto the surface of a photopolymer; the light source cures the image, building the product layer by layer.
11) Stereolithography: Stereolithography (SLA) is one of the earliest 3D printing technologies. It uses a UV light source to cure a vat of liquid photopolymer resin layer by layer and is widely employed for prototyping.

4. METHODOLOGY

1) Modelling

To begin 3D printing, the object or model must first be designed using a CAD (computer-aided design) tool, such as SolidWorks. Alternatively, a 3D scanner or a digital camera can be used along with specialized photogrammetry software. The models created through CAD help reduce errors that can be identified and corrected before the printing process begins. The manual modeling of geometric data for 3D computer graphics is similar to traditional plastic arts, such as sculpting, allowing for the creation of scanned objects. Once the modeling is complete in the CAD tool, the 3D model is usually saved in formats like. skp, .dae, or .3ds. It must then be converted to either.STL or.OBJ format, which is necessary for the printing software to process and read the file correctly Patil et al. (2017).

2) Printing

Later, a model has been converted to an STL file, it must first be examined for errors in a process known as "fixup." Most CAD applications can produce STL files with errors such as self-intersections, improper holes, and incorrect face normals that need to be corrected. Once the file is properly transformed to STL, it must be processed by a software program called a “slicer.” The slicer converts the model into a series of layers and generates a G-code file containing instructions for a specific type of 3D printer. This G-code file can be printed using 3D client software, which loads the G-code and guides the 3D printer during the printing process. Various slicer programs and client software exist, including Cura, Slic3r, Repetier Host, PrinterFace, and Skein forge, in addition to closed-source programs like Simplify3D and KISSlicer3D.

3D printer follows the G-code commands to lay down successive layers of materials such as liquid, powder, plastic, sand, or metal through a print nozzle. These layers correspond to the virtual cross-sections from the CAD model and are fused to create the final shape Al-Maliki and Al-Maliki (2015). The printing process can take anywhere from a few minutes to several hours, depending on the size of the model, the method used, printing speed, and model complexity. Printer resolution is defined by layer thickness and X-Y resolution, measured in dots per inch (dpi) or micrometers (μm). Standard layer thickness can be around 100 μm, although some advanced machines, like the Object Connex series and the 3D Systems Project series, can print in layers as thin as 16 μm. The X-Y particle sizes range from 50 to 500 μm (510 to 250 dpi) in diameter. The time required to construct models can vary widely, from several hours to several days, depending on the model's size, the printing method used, and its complexity. Naturally, the printing time can be reduced to just a few hours, depending on the type of machine and the size of the model. 3D printers allow designers to create conceptual models using desktop-sized machines.

3) Finishing

The resolution produced by printers is generally sufficient for many applications. However, the printed objects may come out slightly oversized compared to the desired dimensions. Achieving standard resolution and then removing excess material can lead to greater precision. Some printable polymers can achieve a smoother surface finish, especially when enhanced through chemical vapor processes. Certain additive manufacturing techniques are capable of utilizing multiple materials during the construction of parts. These methods can print in various colors and color combinations simultaneously. Some printing techniques require the creation of internal supports to support overhanging features during the build process. These supports must be either mechanically removed or dissolved after the printing is complete Jandyal et al. (2022). Commercial metal 3D printers often involve trimming the metal component of the substrate after deposition. A new process for Gas Metal Arc Welding 3D printing allows for substrate surface modifications, enabling the manual removal of many aluminum components using a hammer.

5. APPLICATION

1) Education

New learning materials are often desired, but budget constraints can make them unaffordable. Fortunately, 3D printing offers a cost-effective solution, allowing educational resources to be created in-house, which saves money for your department. Not only are 3D-printed materials generally cheaper, but they are also quicker to produce. While traditional teaching methods often rely on books and theory, kinaesthetic learners benefit greatly from hands-on aids and materials. 3D printing enables educators to bring subject matter to life with physical aids, effectively engaging students over long periods Sathish et al. (2024). This interactive approach enhances their learning and improves their problem-solving and critical thinking.

2) Apparel

3D printing has also made its mark in the fashion industry, with designers experimenting with 3D-printed bikinis, shoes, and dresses. In terms of commercial production, Nike uses 3D printing to prototype and manufacture football shoes for American football players, while New Balance creates custom-fit shoes for athletes through 3D manufacturing. Additionally, companies are now able to produce consumer-grade eyewear using 3D printing, offering on-demand customization for fit and style, although the lenses themselves cannot be printed. Rapid prototyping allows for this level of personalized eyewear.

3) Medical

The medical applications of 3D printing are rapidly expanding and are expected to revolutionize healthcare. These applications can be broadly categorized into several areas, including:

- Tissue and Organ Fabrication: The development of artificial tissues and organs.
- Modified Prosthetics and Implants: Creating tailor-made prosthetics, implants, and anatomical models.
- Pharmaceutical Research: Investigating drug dosage forms, delivery mechanisms, and discovery processes.

The use of 3D printing in medicine offers numerous benefits, such as: - Customization and personalization of medical products, drugs, and equipment- Cost-effectiveness- Increased productivity- Democratization of design and manufacturing- Enhanced collaboration among healthcare professionals. However, despite these significant and exciting advances, challenges remain in terms of scientific and regulatory aspects. Many of the most transformative applications are still in development and may not yet be practical. Additionally, 3D printing has found applications beyond medicine. For instance, it has been used to create working clocks, gears for home woodworking machines, and ornamental objects.

Websites related to home 3D printing offer a variety of products, including coat hooks, doorknobs, and more.

6. WORKING PRINCIPLE

The working principle of a 3D printer, Figure 1, is based on the Fused Deposition Modeling (FDM) method. This process involves melting filament and extruding it through a nozzle according to a programmed design. The printer operates using three coordinates: the x-axis, y-axis, and z-axis. Cartesian 3D printers are named after this coordinate system, which determines how the printer moves in three dimensions. In these printers, the heated print bed typically moves only along the z-axis, while the extruder moves in the x and y axes, allowing for movement in four directions on a gantry system. This setup is exemplified in models from manufacturers like Ultimaker and MakerBot. In this approach, instead of moving the print head solely in the x-y plane, one of the axes is altered by moving the print bed itself. This design is straightforward to maintain, although it may come at the expense of printing speed Kamble et al. (2018).

Figure 1

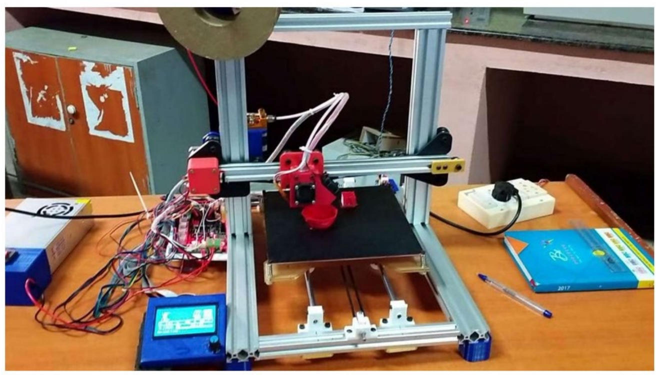

Figure 1 Designed and Experimental 3D Printer Setup

7. MATERIALS USED IN FDM 3D PRINTING

1) Polylactic acid

PLA (Polylactic Acid) is one of the two most commonly used materials for desktop 3D printing, the other being ABS. It is often the recommended default material for many desktop 3D printers, and for good reason. PLA is versatile and suitable for a wide range of printing applications. It is odourless, low in warp, and does not require a heated bed during printing. Additionally, PLA is one of the eco-friendlier 3D printing materials available. It is made from annually renewable resources, such as corn starch, and requires less energy to process compared to traditional petroleum-based plastics.

2) ABS

ABS (Acrylonitrile Butadiene Styrene) is a popular material used in 3D printing. It is ideal for creating durable parts that need to endure higher temperatures. Compared to PLA, ABS is less brittle, making it a better choice for certain applications. Additionally, ABS can be post-processed with acetone to achieve a glossy finish.

3) Work Order

The following flowchart illustrates Figure 2, the methodology we used in constructing a 3D printer. Next, we choose an appropriate mechanism for the X, Y, and Z axis movements. This decision is based on various factors such as fabrication cost, design simplicity, synchronization, and accuracy. Once the mechanism is selected, the next step is to integrate the electronics and software, followed by the design and fabrication of the machine Ma et al. (2024).

Figure 2

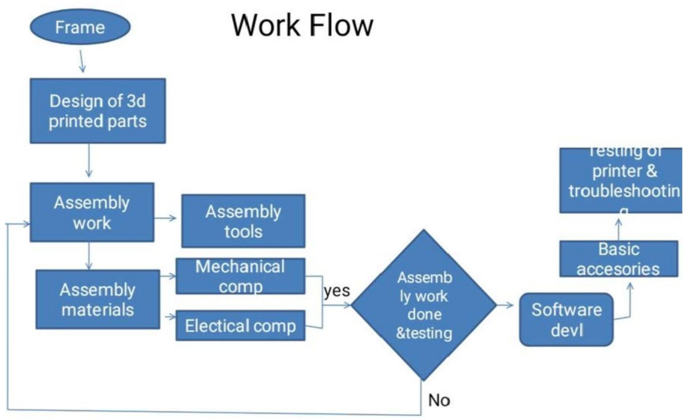

Figure 2 Flow Chart for my 3D Printer Methodology Ma et al. (2024)

The final step involves synchronizing the mechanical, electrical, and software components of the machine, which can work with various materials to achieve different objectives. The model or part is created by extruding thermoplastic material into the desired shape layer by layer, as the material solidifies immediately after being expelled from the nozzle. A plastic filament or metal wire is unwound from a spool and fed into an extrusion nozzle, which can control the flow. Typically, a worm drive pushes the filament into the nozzle at a controlled rate. The nozzle is heated to soften the material, with thermoplastics warmed beyond their glass transition temperature before being deposited by an extrusion head. The nozzle can move in both horizontal and vertical directions using a numerically controlled mechanism. Its movement follows a tool path dictated by a computer-aided manufacturing (CAM) software package, and the part is built up layer by layer. Stepper motors or servo motors are commonly used to move the extrusion head. While the conventional drive system is often an X-Y-Z rectilinear framework, other mechanical designs have also been employed. Although Fused Deposition Modeling (FDM) is a highly adaptable printing technology, it can effectively manage fine details by utilizing thinner layers.

Currently, mechanisms such as SCARA, Cartesian, Polar, and Delta are used in the development of Fused Deposition Modeling (FDM) 3D printers. We have chosen a Cartesian arrangement for our design, where the build platform (or bed) moves vertically along the Z-axis, while the extruder nozzle moves horizontally along both the X and Y axes. The Z-axis movement in this type of 3D printer is highly precise and requires low acceleration speeds. However, it is essential for the bed to be lightweight to maintain this precision, which complicates the integration of a fully automated bed-leveling controlling a linear Cartesian system like this is mechanically straightforward and relatively simple from a software perspective Karthikeyan and Sivakumar (2024). This is why most 3D printers on the market today utilize this design. The Cartesian coordinate system has a long history of being employed in devices such as plotters, CNC milling machines, and 2D printers.

4) Electronics

The controller serves as the "brain" of our 3D printer. Almost all 3D printer controllers are based on Arduino microcontrollers, although many variations exist. These controllers are interchangeable, and fundamentally, they serve the same purpose. Sometimes, the controller is a standalone circuit board filled with chips, while other times it consists of an Arduino Mega paired with an additional board known as a "shield."

8. DESIGN CALCULATIONS

1) BEARINGS

Bearings are devices used to support and guide a rotating, Oscillating, sliding shaft, pivot, or wheel. At whatever point a pole pivots, it needs a heading for smooth, powerful activity.

A heading is planned to:

- Reduce friction
- Support a load
- Guide moving part – wheel, shaft, pivots

There are two major types of bearings we use in this project, they are:

- Linear ball Bearing
- Ball bearings

Linear Ball Bearings: These are used in linear motion systems, allowing smooth movement along a shaft, often found in CNC machines, 3D printers, and automation equipment in the Figure 3.

Ball Bearings: These are rotary bearings that reduce friction between moving parts, commonly used in motors, wheels, and machinery.

Figure 3

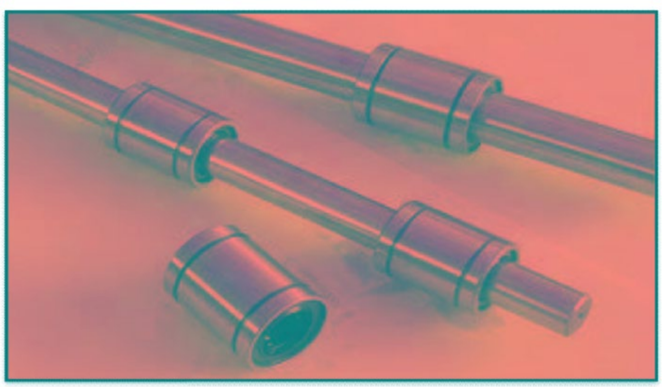

Figure 3 Linear 8 mm Bearing Chandrakar and Kachhawaha (2015).

Here we are recommended	: L8MUU
Bearing number: LM08UU Size (mm)	: 8x15x24 Brand: CX
Bore Diameter (mm): 8 Outer Diameter (mm)	: 15 Width (mm): 24

Bearing dimensions and specifications in the brand catalogue:

d - 8 mm D - 15 mm B - 24 mm

B1 - 17,5 mm D1 - 14,3 mm W - 1,1 mm

Weight - 0,011 Kg

Basic dynamic load rating (C) - 0,365 kN Basic static load rating (C0) - 0,24 kN

2) TIMING BELT

A Timing belt, timing chain, or cam belt is part of an internal combustion engine that synchronizes the rotation of the crankshaft and the camshaft(s) so that the engine's valves open and close at the correct circumstances during each cylinder's intake and exhaust strokes.

Design of timing belt for X and Y axis D = d = Diameter of pulley = 2cm C = Center distance between two pulleys = L = 700 mm.

Length of the timing L = $\pi(D+d) + (\sqrt{4c^2 + D^2 + d^2}$ (5)2

Length L = 1.46319 m

The ultimate strength of polyurethane = 20.77MPa Considering FOS = 4 Force = 40N (From Motor)

σ = F(6) A

Area = 7.703 mm2 Width=5.925mm Standard width = 6mm

Conclusion for timing belt selection: The width of the belt is found to be 5.925mm and standardized to 6mm. MXL pitch of 2.032mm is selected for smooth movement.

Design of timing belt for Z axis:

Where:

D = d = Diameter of pulleys = 15mm

C = Center distance between two pulleys = 0.736

L = Length of the timing

T=Thickness of the belt = 1.3mm

$L = \pi(D + d) + \sqrt{4c^2 + D^2 + d^2} / 2$

L = 1.540 m

The ultimate strength of polyurethane = 20.77MPa Considering FOS = 2 Force = 250/2=125 (From Torque of NEMA 23 – 150Ncm)

σ = F A

Area = 12.03mm2 Width=9.25 mm Standard width=10 mm

3) PULLEY

A pulley is a wheel with a grooved rim that a rope passes over, allowing it to change the direction of force to lift the weight.

- Fixed pulley
- Movable pulley
- Compound pulley

A pulley is designed to assist in developing and changing the path of a rope or belt along its outline. Pulleys are used in various applications for lifting loads, applying forces, and transmitting power. In nautical contexts, the assembly of the wheel, pivot, and supporting casing is referred to as a "block." A pulley may also be known as a sheave or drum and can have a hub between two flanges around its perimeter. The driving mechanism of a pulley system can be a rope, cable, belt, or chain that runs over the pulley inside the casing Kulkarni et al. (2024).

4) ELECTRONICS BOARD

The electronics board plays a crucial role in controlling the printing process, making it an essential component. The design is user-friendly, catering to beginners, developers, and manufacturers alike. With multiple quick connectors, users can easily connect the power cables in parallel. The electronic board consists of:

- Controller Board
- Ramps
- Stepper Motor
- Stepper Drive
- LCD Controller
- End Stops
- Extruder
- Power Supply
- Heated Bed
- Firmware and software
- Software used for design purpose

1) Controller Board

Controller boards are the brains of your 3D printer, and their management of power directly affects the quality and precision of your finished prints. The development of printer controller boards is advancing rapidly, with new models featuring enhanced functionalities that allow for simplified resolution through micro stepping. Additionally, these boards are being equipped with more powerful processors to handle complex calculations, and some even operate their operating systems. This evolution in technology ensures that you have access to more capable processors for intricate tasks and systems tailored for optimized performance Shahrubudin et al (2019).

Here are some types of controller boards:

a. Arduino Due; b. Beagle Bone Printer Board; c. Azteeg X5; d. Smoothie board

2) Ramps

Arduino and its compatible boards use printed circuit extension boards known as "shields," which connect to the standard Arduino pin headers. Shields can facilitate various functions such as motor control, GPS, Ethernet, LCD, or breadboarding (prototyping). RAMPS (RepRap Arduino Mega Pololu Shield) is the most popular shield for the Arduino Mega 2560 and has become the most widely used hardware for 3D printers since 2012. It shares hardware components such as stepper drivers, thermistors, and MOSFETs with many other devices. Additionally, both the RAMPS board and the Arduino Mega 2560, along with the Pololu drivers, are relatively inexpensive compared to other shields and controllers Shahrubudin et al. (2019).

3) Stepper Motors

A stepper motor, often referred to as a step motor, is a type of brushless DC electric motor that divides a full rotation into a specific number of equal steps. This allows for precise control of the motor's position, enabling it to move and hold at one of these steps without the need for a feedback sensor, as long as the motor is appropriately matched to the application. Every time the motor receives a pulse of energy—supplied by a stepper driver—it moves a known distance, which is known as a "step." Because each movement corresponds to a predetermined distance, stepper motors are ideal for applications that require repeatable positioning. In our project, we will be using a NEMA 17 stepper motor to move the bed carriage and other components along the X, Y, and Z axes. The NEMA 17 stepper motor is a widely used motor with a faceplate measuring 1.7 x 1.7 inches. In comparison, the NEMA 14 is larger and generally heavier than other motors like the NEMA 17. However, this increased size allows it to produce higher torque. It's important to understand that size does not always correlate with power. This 4-wire bipolar stepper motor has a step angle of 1.8 degrees per step, which facilitates smooth movement and offers good holding torque. The motor operates with a maximum current of 350mA, making it compatible with the Adafruit motor shield for Arduino, as well as with wall adapters or lead-acid batteries.

4) Stepper Drive

A stepper drive, also known as a stepper motor driver or stepper controller, is an electronic device that controls the operation of a stepper motor. It translates signals from a control system (such as a microcontroller, PLC, or computer) into precise electrical pulses that drive the stepper motor. These pulses determine the motor's movement, including its speed, direction, and position.

5) LCD Controller

An LCD controller is an essential component in LCD-based systems that manages the display of images, text, and graphics on the screen. It acts as an intermediary between the display panel and the host system (e.g., a microcontroller, computer, or embedded system), converting digital signals into the appropriate format for the LCD.

6) End Stops

Cartesian axes require a reference point, or datum, to guide their movements. At the beginning of each build, each axis must be calibrated until it reaches this datum point. The switches also play a crucial role in protecting the machine by preventing it from moving beyond its intended range and causing damage.

7) Extruder

An extruder is a critical component in many manufacturing and fabrication processes, particularly in 3D printing, plastic extrusion, and food processing. It is a device that pushes or draws material through a shaped die to create objects of a fixed cross-sectional profile. The material used can be plastic, metal, clay, food, or other substances, depending on the application.

8) Power Supply

The motor, along with a single hot end, typically requires up to 5A. The heated bed usually consumes between 5A and 15A. For a standard setup that includes a heated bed, you can expect a total current draw of around 18A to 30A, which translates to approximately 220W to 360W at 12V. Some setups may be able to operate with lower power requirements. Switch mode power supplies feature relatively complex circuits designed to convert mains AC electricity into the DC voltages required by the stepper motors and electronic circuits. The primary advantage of a switch mode power supply is its high efficiency in energy conversion.

9) Heated Bed

A heated build platform (HBP) improves the printing quality of 3D models by helping to prevent warping. As extruded plastic cools, it shrinks slightly, but this shrinkage doesn't occur evenly throughout the printed part. This uneven shrinkage often results in warping, commonly seen as corners lifting off the build platform.

Using a heated bed keeps the printed parts warm during the printing process, allowing for more even cooling and shrinking of the plastic as it drops below the melting point. Consequently, a heated bed can lead to higher quality finished builds, particularly when using materials like ABS and PLA.

10) Firmware And Software

Firmware refers to the permanent software stored in read-only memory (ROM) in the form of nonvolatile memory, enabling control of hardware devices. It can range from providing a basic operating environment for devices to more complex software that allows hardware to function with an operating system (OS), enabling various monitoring and manipulation tasks. Firmware is used in a variety of applications, including consumer appliances and computer peripherals. In 3D printers, electronic devices are typically controlled by a CPU, such as an Intel processor, and are often based on an Arduino microcontroller. These processors run essential software that allows the 3D printer to operate. The firmware is crucial for making the 3D printer functional, and working with firmware is often referred to as cross-compiling.

11) Software Used for Design Purpose

Computer software is an integral part of a computer system, encompassing both data and instructions. It includes all the information processed by computer systems, as well as programs and data. In the context of a 3D printer, software plays a crucial role in transmitting information from one location to another. Without software, it would be impossible to create and print virtual objects, as they need to be sliced and printed. The programming platforms used typically involve embedded C and C++ languages, with C++ playing a significant role in the functionality of the 3D printer. The specifications required for movement and other parameters are directly calibrated and loaded onto the controller. Software also serves as the environment in which users can create any 3D model using various 3D.

9. ESTIMATION OF MACHINE TIME VARIOUS OBJECTS

1) Cube

Extrusion diameter = 0.4 mm

Layer Height= 0.12 mm

Print Speed = 60 mm/s

Flow rate = Extrusion *layer height*printing speed

= 0.4*0.1*60

= 2.4 mm/s

Time = (W/S) *(D/S) *(H/S)

= (20/2.4) *(20/1.75) *(20/1.75)

Time = 18.10 min

2) Cuboid

Extrusion diameter = 0.4 mm Layer

Height = 0.33 mm

Print Speed = 60 mm/s

Flow rate = Extrusion *layer height* printing speed

= 0.4*0.33*60

= 7.92 mm/s

Time = (W/S) *(D/S) *(H/S)
= (20/7.92) *(20/1.75) *(30/1.75)
= 4.86*11.42*17.4
= 13.24 min

3) Cylinder

Extrusion dia. = 0.4 mm Layer
Height = 0.22 mm
Print Speed = 80 mm/s
Flow rate = Extrusion *layer height *printing speed
= 0.4*0.33*80
= 7.04 mm/s
Time = (W/S) *(D/S) *(H/S)
= (30/7.04) *(50/1.75) *(50/1.75)
= 4.26 *28.57 *28.57
= 57.95 m

4) P100

Extrusion dia = 0.4 mm
Layer Height= 0.42 mm
Print Speed = 60 mm/s
Flow rate = Extrusion *layer height *printing speed
= 0.4 *0.42 *60 = 10.08 mm/s
Time = (W/S) *(D/S) *(H/S)
= (40/10.08) *(80/1.75)*(80/1.75)
= 3.96 *45.71 *45.71
= 138 min

Table 1

Table 1 Machine Time Calculation Table

S.NO	Parts	Estimated time (min)	Actual time (min)	Difference (min)	Error (%)
1	Cube	18.10	19.50	1.40	7.7
2	Cuboid	13.24	16.54	2.30	17.3
3	Cylinder	57.95	59.95	2.00	3.4
4	P100	138	148	10.00	7.2

10. CONCLUSION

In this study, we conducted a comprehensive analysis of the priority time and characteristics of the 3D printing process. Our primary focus was on mathematically calculating the printing time of an object and comparing it with the actual time required by the 3D printer to complete the printing task. Through this comparison, we identified a noticeable difference between the manually calculated time and the machine's actual printing time.

Based on this discrepancy, we further calculated the error percentage to quantify the deviation between the theoretical and practical printing times. The results highlight the inherent limitations and variations in the printing process, which may arise due to factors such as machine calibration, material properties, environmental conditions, and operational inefficiencies. Moving forward, we aim to optimize the error percentage by refining our mathematical model and incorporating additional variables that influence the printing process. Potential areas for improvement include accounting for machine-specific parameters, material behavior during printing, and real-time adjustments during the printing process. By addressing these factors, we hope to achieve a more accurate prediction of printing time, thereby enhancing the efficiency and reliability of 3D printing operations.

This study not only provides valuable insights into the time dynamics of 3D printing but also lays the groundwork for future research aimed at minimizing errors and optimizing the overall printing process. Our findings contribute to the growing body of knowledge in additive manufacturing and underscore the importance of bridging the gap between theoretical models and practical applications in 3D printing technology.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

We would like to express our sincere thanks to the principal and management of SRM Valliammai Engineering College, as well as to our thermal laboratory technician, Mr. Venkatesan. His expertise and meticulous attention to detail significantly enhanced the quality and clarity of our work from the lathe and other machinery. We are truly grateful for his dedicated time and unwavering commitment to helping us improve this research

DECLARATION

Declaration	Suggestions
Funding/ Grants/ Financial Support	**If not applicable:** No, I did not receive it.
Conflicts of Interest / Competing Interests	**If not applicable:** No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	**If not applicable:** No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material / Data Access Statement	**If not applicable:** Not relevant.
Authors Contributions	**If applicable and having more than two authors:** **study conception and design: Sivakumar Karthikeyan** **data collection and experiments, analysis and interpretation of results: Ramu. P** **draft manuscript preparation: Mithunn Balaji.S.**

REFERENCES

Arputhabalan, J. J., Sangamaeswaran, R., Rajeshwaran, M., Asaithambi, T., Sivakumar, K., & Devi, M. (2023). Tribology Behavior of Aluminum Alloy Joints by Friction Stir Processing. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2023.05.584

Arularasan, A. N., Mathew, M., Sudhakar, M., Sivakumar, K., Perumal, S. B., Madhu, P., Dhanalakshmi, C. S., & Lalvani, J. I. J. R. (2022). A Holistic Framework for

Environment-Conscious Material Selection and Experimental Assessment using Digraph-Based Expert System. Scientific Programming. https://doi.org/10.1155/2022/2112683

Chandrakar, A. K., & Kachhawaha, A. (2015). Application of Additive Manufacturing on Three-Dimensional Printing. International Journal of Science and Research, 4(6), 2012-2016.

Chandrasekharan, T., Balasubramanian, G., Karthikeyan, S., Jayapalan, S., Muthuswamy, P., & Babu, S. (2024). Investigation on the Mechanical Properties of Stir Casted AA5128 Reinforced with Carbon Nanotubes/E-Glass Hybrid Composites. AIP Conference Proceedings, 3042(1), 020019. https://doi.org/10.1063/5.0194213

Dahle, R., & Rasel, R. (2016). 3D Printing as an Effective Educational Tool for MEMS Design and Fabrication. IEEE Transactions on Education, 59(3), 210-215.

Galati, M., Minetola, P., Marchiandi, G., Atzeni, E., Calignano, F., Salmi, A., & Iuliano, L. (2019). A Methodology for Evaluating the aesthetic quality of 3D Printed Parts. Procedia CIRP, 79, 95-100. https://doi.org/10.1016/j.procir.2019.02.018

Jandyal, A., Chaturvedi, I., Wazir, I., Raina, A., & Ul Haq, M. I. (2022). 3D printing – A review of Processes, Materials and Applications in Industry 4.0. Sustainable Operations and Computers, 3, 33-42. https://doi.org/10.1016/j.susoc.2021.09.004

Jayapalan, S., Kumar, R., Karthikeyan, S., Chandrasekharan, T., Muthuswamy, P., & Babu, S. (2024). Investigation on the Mechanical and Corrosive Behavior of FSW AA2218/B4C Metal Matrix Composites. AIP Conference Proceedings, 3042(1), 020009. https://doi.org/10.1063/5.0194216

Kamble, P. S., Khoje, S. A., & Lele, J. A. (2018). Recent Developments in 3D Printing Technologies: Review. Second International Conference on Intelligent Computing and Control Systems (ICICCS), 468-473. https://doi.org/10.1109/ICCONS.2018.8662981

Karthikeyan, S., & Sivakumar, M. (2024). An Innovative Hydrogen Dual Fuel Engine with Integrated Aqua Silencer. IJSAT, 15(4). https://doi10.71097/IJSAT.v15.i4.1153

Kulkarni, V. R., Saha, T., Giri, B. R., Lu, A., Das, S. C., & Maniruzzaman, M. (2024). Recent Advancements in Pharmaceutical 3D Printing Industry. Journal of Drug Delivery Science and Technology, 100, 106072. https://doi.org/10.1016/j.jddst.2024.106072

Kumar, T. S., Jebaraj, A. V., Sivakumar, K., & Mathivanan, P. (2019). Machinability Studies of TiAlN-/AlCrN-Coated and Uncoated Tungsten Carbide Tools on Turning EN25 Alloy Steel. In Chandrasekhar, U., Yang, L. J., & Gowthaman, S. (Eds.), Innovative Design, Analysis, and Development Practices in Aerospace and Automotive Engineering (I-DAD 2018). Springer. https://doi.org/10.1007/978-981-13-2697-4_24

Lan, J. (2015). Design and Fabrication of a Modular Multi-Material 3D Printer. Report.

Ma, T., Zhang, Y., & Ruan, K. (2024). Advances in 3D Printing for Polymer Composites: A Review. InfoMat, 6(6), e12568. https://doi.org/10.1002/inf2.12568

Patil, R., Ahmed, I., Shariff, M. S., Zeeshan, S. I., & Prashanth, S. (2015). Design and Fabrication of Portable 3D Printer. International Journal of Mechanical Engineering and Technology, 8(11), 129-135.

Patil, R., D., Gowda, S. D., Kashyap, K. C. S., Murtaza, M., N., Prashanth, S., Harsha, N., & V. G., Bharath. (2017). Economical 3D Printer by Adopting FDM Technique.

International Journal of Mechanical Engineering and Technology, 8(4), 442-447.

Qasim Al-Maliki, J., & Qasim Al-Maliki, A. (2015). The Processes and Technologies of 3D printing. International Journal of Advances in Computer Science and Technology, 161-165.

Sathish, T., Karthikeyan, S., Sathyamurthy, R., Kumar, A., Rajaram, K., Kumar, S. S., Al-Kahtani, A. A., Pandit, B., Gupta, M., Senthilkumar, N., Malik, N., & Ubaidullah, M. (2024). Waste Coconut Oil Meal to Hydrogen Production Through Combined Steam/Water Gasification with Varying Operating Parameters and NaCl Additions. International Journal of Hydrogen Energy. https://doi.org/10.1016/j.ijhydene.2024.01.323

Sathish, T., Karthikeyan, S., Sathyamurthy, R., Rajaram, K., Kumar, S. S., Kumar, P. S., Giri, J., & Amesho, K. T. T. (2024). Synergistic Effects of Nano-Enhanced Waste Transformer oil and Hydrogen Premixing on CI Engine Performance and Emissions. International Journal of Hydrogen Energy, 56, 484-497. https://doi.org/10.1016/j.ijhydene.2023.12.176

Shahrubudin, N., Lee, T. C., & Ramlan, R. (2019). An Overview on 3D Printing Technology: Technological, Materials, and Applications. Procedia Manufacturing, 35, 1286-1296. https://doi.org/10.1016/j.promfg.2019.06.089

Shedge, P. R., More, A. D., Chachar, S. N., Kamble, A. K., Kirve, D. D., Huddedar, S. M., & Narkar, R. R. (2017). Design and Fabrication of Low-Cost Additive Manufacturing Machine. International Journal of Advance Research, Ideas and Innovations in Technology, 3(2), 487-493.

Sivakumar, K., Natarajan, E., & Kulasekharan, N. (2012). Comparative Study Between Experimental Work and CFD Analysis in a Square Convergent Ribbed Duct. In Sathiyamoorthy, S., Caroline, B., & Jayanthi, J. (Eds.), Emerging Trends in Science, Engineering, and Technology. Springer. https://doi.org/10.1007/978-81-322-1007-8_41

Sivakumar, K., Natarajan, E., & Kulasekharan, N. (2016). Numerical Simulation on Rectangular Divergent Ribbed Channels. ARPN Journal of Engineering and Applied Sciences, 11(18), 11023-11030.

ABBREVIATIONS

FDM	Fused Deposition Modeling
SLS	Selective Laser Sintering
EMB	Electron Beam Melting
LOM	Laminated Object Manufacturing
DLP	Digital Light Processing
3D	Three Dimension
PLA	Polylactic Acid
ABS	Acrylonitrile Butadiene Styrene
HPS	High Impact Polystyrene
AQI	Aesthetic Quality Index
MEMS	microelectromechanical systems
LENS	Laser-Engineered Net Shaping
SLV	Stereolithography

UVL	Ultraviolet Light
GMAW	Gas Metal Arc Welding
CAM	Computer-Aided Manufacturing
CNC	Computerized Numerical Controller
NEMA	National Electrical Manufacturers Association
DC	Direct Current
ROM	read-only memory
HBP	heated build platform
AC	Alternative Current
OS	Operating System
CPU	Central Processing Unit