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ORIGINAL STUDY

Design and Implementation of a 3D Laser Printer for Scientific Purposes

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ABSTRACT

In recent years, the demand for efficient and cost-effective 3D printing technology has surged, opening up a plethora of potential applications across various industries. One promising solution is the design and implementation of a 3D printer utilizing PLA (Polylactic Acid) filament, an eco-friendly and biodegradable material. This approach not only promotes sustainability but also offers a reliable printing system for creating accurate 3D models. By harnessing the power of this innovative technology, users can effectively capture complex geometries and intricate details, ultimately revolutionizing the way we perceive and interact with the physical world around us. In this work, the design process takes a practical method in complying with simulations. Several software were used for simulation including fritzing for electronic circuit design, AutoCAD for overall mechanical layout design and Cura 3D for 3D model simulation and 3D printing fine operation, The aim of the work is to design and implement a 3D printer for the use in scientific purposes. This work focuses on the design and implementation of a 3D laser printer that can effectively function with PLA filament, the principles and benefits of this technology, and potential applications across various fields.

Keywords: 3D Printer, Electronics design, Cura 3D, Fritzing, AutoCAD

1. Introduction

In recent years, the demand for efficient and cost-effective 3D printing technology has surged, opening up a plethora of potential applications across various industries. One promising solution is the design and implementation of a 3D printer utilizing PLA (Polylactic Acid) filament, an eco-friendly and biodegradable material. This approach not only promotes sustainability but also offers a reliable printing system for creating accurate 3D models. By harnessing the power of this innovative technology, users can effectively capture complex geometries and intricate details, ultimately revolutionizing the way we perceive and interact with the physical world around us.

The design and implementation of a 3D printer using PLA filament offers a promising solution to the challenges faced in digitizing physical objects. By harnessing the potential of this versatile and eco-friendly material, the scanning process can be optimized in terms of accuracy, efficiency, and cost. This innovative approach paves the way for a multitude of applications, from industrial design to heritage preservation. Additionally, the integration of cutting-edge software and hardware components further enhances the capabilities and robustness of the 3D printing process [1, 2].

3D printing technology has gained significant traction in various industries, offering numerous benefits and innovative applications. The design and implementation of a 3D printer utilizing PLA filament brings about a cost-effective and environmentally friendly solution to various sectors such as manufacturing, engineering, and the medical field. By leveraging the capabilities of PLA filament, the 3D printer can produce highly accurate and detailed scans while minimizing waste and ecological impact. This work focuses on the development of such a cutting-edge 3D printer that can effectively function with PLA filament, the principles and benefits of this

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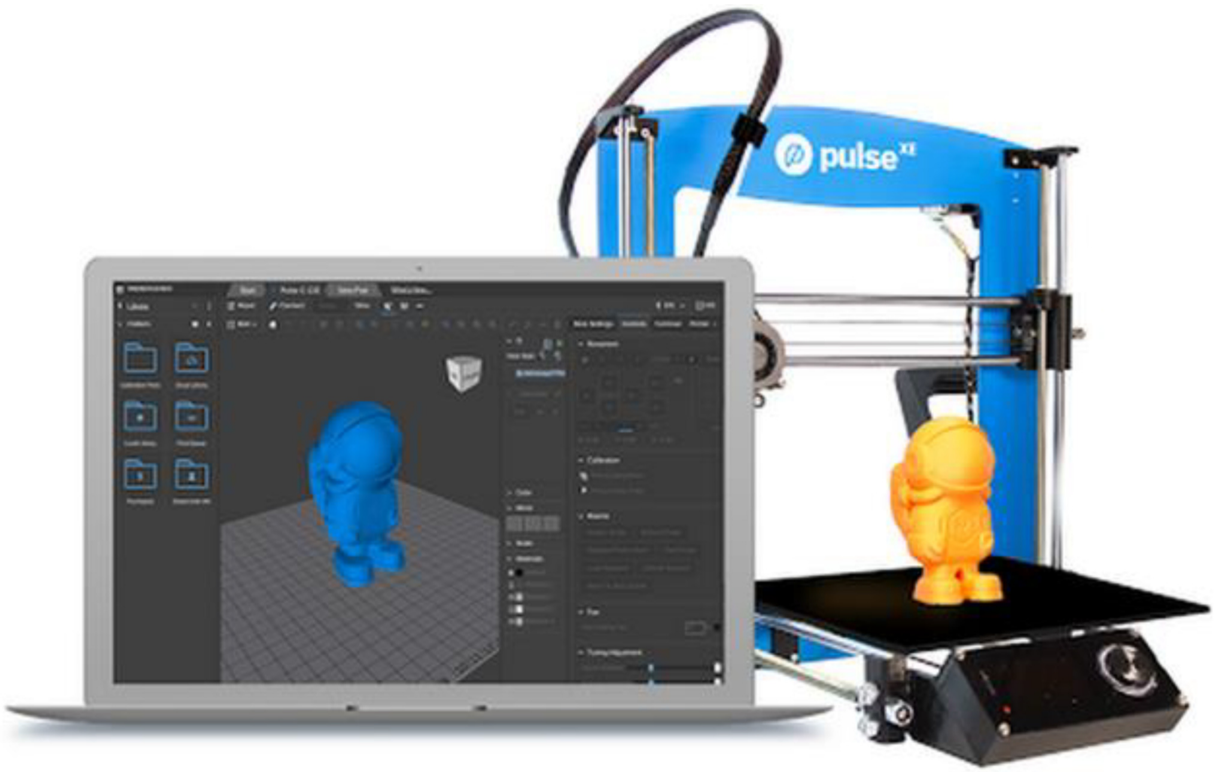
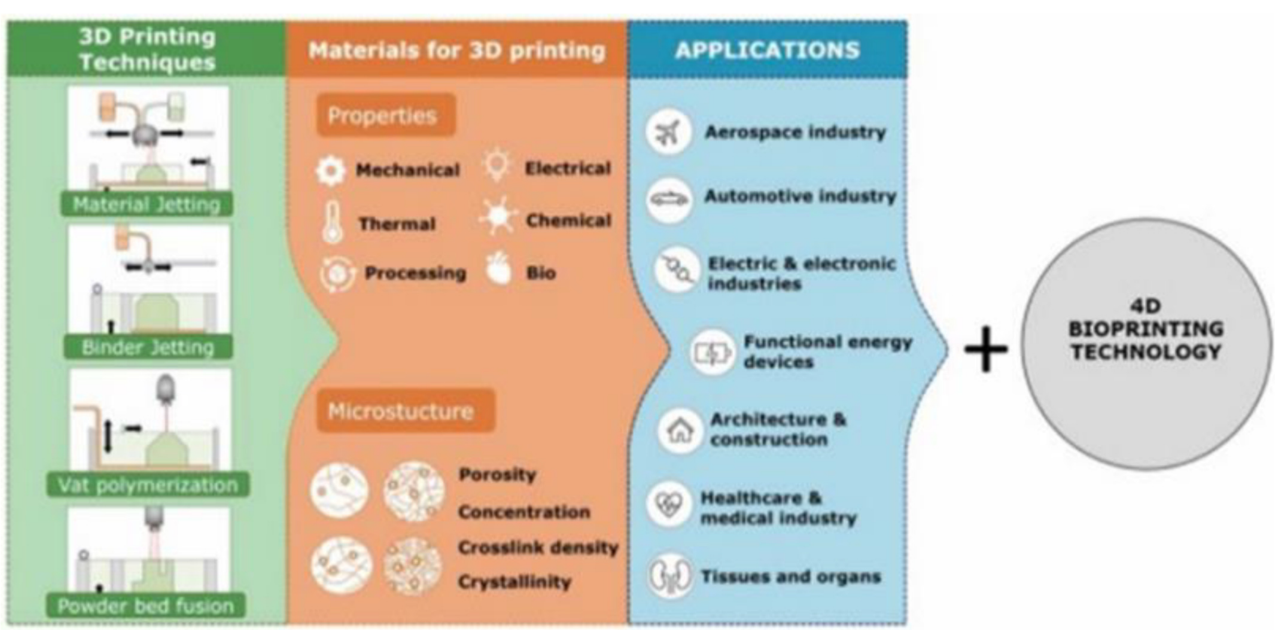


(a)



(b)

Fig. 1. (a) 3D printer scheme (b) The most recent 3D printing procedures, application and customized properties of the final products [1].

technology, and potential applications across various fields [3, 4].

In recent years as shown in Fig. 1, 3D printing has developed significantly and can now perform circular roles in many applications, with the most common applications being manufacturing, medicine, architecture custom art and design and can vary from fully functional to purely aesthetic applications. Here are some of these applications: [5, 6] Medical a. Customized Implants: An example of this is using laser-based 3D printing to create a customized skull implant for a patient with a severe cranial deformity, allowing surgeons to perfectly fit the implant and achieve better healing. Prosthetics An example is using laser-based 3D printing to manufacture personalized prosthetic limbs tailored to the anatomy and needs of individual patients, enabling them to regain comfortable and efficient movement [7, 8]. Industry a. Tooling and Prototyping: An example is using laser-based 3D printing to create customized molding tools for producing plastic parts in manufacturing industries. Metal Additive Manufacturing An example is using laser-based 3D printing to produce intricate metal parts, such as internal components for aircraft engines. Architecture: a. Scale Models: An example is using laser-based 3D printing to create accurate models of historical buildings, allowing architectural engineers to study architectural details before commencing renovations. Architectural Design: An example is using laser-based 3D printing to create complex architectural models, such as unique buildings that rely on intricate architectural engineering and fine details [9, 10].

Various types of lasers are used in 3D printing, each suited for different printing processes and materials. Here are some common types of lasers used in 3D printing: [12, 13] CO2 Lasers Carbon dioxide (CO2) lasers are commonly used in laser-based 3D printing processes such as Selective Laser Sintering (SLS) and Direct Metal Laser Sintering (DMLS). These lasers emit infrared light at a wavelength of around 10.6 micrometers, suitable for heating and melting powdered materials like polymers or metal alloys. Fiber Lasers Fiber lasers have become increasingly popular in metal 3D printing processes such as Selective Laser Melting (SLM) and Laser Metal Deposition (LMD). They emit laser light through a fiber-optic cable, offering high power, precision, and efficiency, making them well-suited for metal processing. Diode Lasers Diode lasers are used in some lower-power applications of laser-based 3D printing, such as Stereolithography (SLA) and Digital Light Processing (DLP). They emit light directly from semiconductor diodes and are often employed for curing photopolymer resins layer by layer to create solid objects [14, 15]. Nd:YAG Lasers Neodymium-doped yttrium aluminum garnet (Nd:YAG) lasers have been used in certain laser-based 3D printing processes as shown in Fig. 3, particularly in research settings. They emit light at various wavelengths depending on the doping level and are known for their high power and pulsed operation. The choice of laser

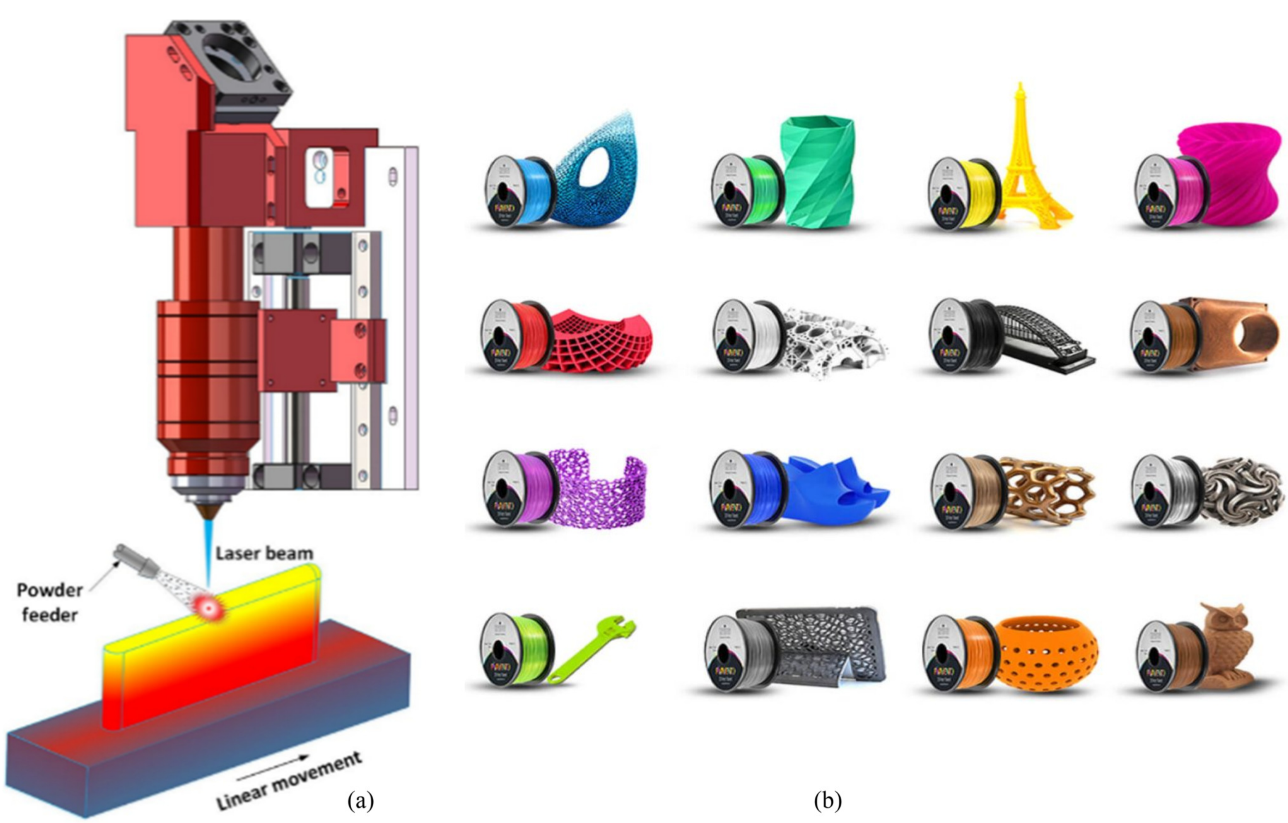


Fig. 2. (a) Laser 3D printing procedure [4], (b) Materials for 3D printing [11].

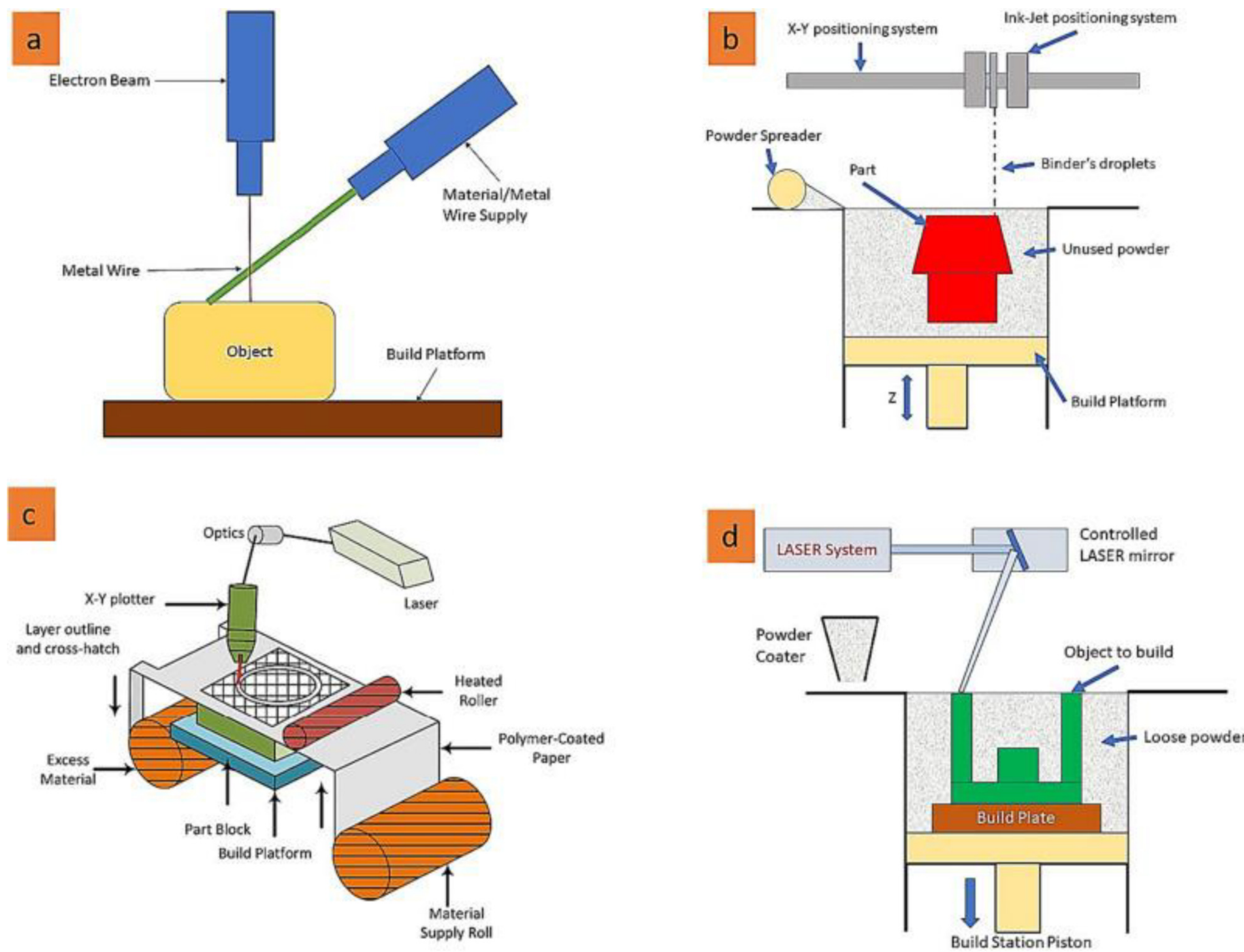


Fig. 3. Schematic diagram of (a) Directed energy deposition, (b) binder jetting system (c) sheet lamination process and (d) powder bed fusion technique [19].

type depends on factors such as the material being processed, desired printing resolution, power requirements, and budget constraints. Each type of laser offers distinct advantages and limitations, influencing its suitability for specific 3D printing applications [16–18]. Generally, different types of materials are employed in the implementation of the 3D printing model, these materials include: Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), Thermoplastic Polyurethane (TPU), Wood, High Impact Polystyrene (HIPS), Nylon, Polyvinyl Alcohol (PVA), and Polyethylene Terephthalate Glycol (PETG), as shown in Fig. 2(b).

2. Materials and methods

Additive manufacturing, commonly known as 3D printing, has emerged as a transformative technology with significant implications across various industries. Traditional 3D printing methods have primarily relied on layer-by-layer deposition of materials to create objects. However, the advent of laser-based 3D printing has introduced novel capabilities and advancements, paving the way for faster, more precise, and versatile manufacturing processes. This chapter aims to provide an overview of laser 3D printing technology, its types, applications, and fundamental equations governing its operation. One starts with a bath of liquid or powder, having a smooth surface. A laser beam is then moved over the top surface, irradiating some parts of it, causing the solidification, while not hitting other parts. Often, the laser beam is moved just along lines in arbitrary directions (vector method). In other cases, the whole area is systematically scanned, and the laser beam is turned on only for those parts to be processed (raster method). One may also combine those methods, for example vector scanning for the contours followed by raster scanning for the inner parts.

The created flat structure is then somewhat lowered in the bath, so that its surface is again covered with a thin layer of liquid or powder. (Swiping over the surface with a solid object may help to get a smooth surface of the bath.) One can then use the laser to create another layer of solid material. This process is repeated until the full height of the wanted solid workpiece is created. Afterwards, the created piece is taken out of the bath, remaining liquid or powder is removed, and possibly some additional processes such as polishing are applied to improve the surface quality (post-processing). The remaining unprocessed powder or liquid can be used for the next part to be fabricated. Another possibility is that the irradiation occurs from the bottom, e.g. through a glass sheet below the bath.

The made workpiece is then step-by-step pulled upwards to allow fresh powder or liquid to get to its bottom. There are other methods where the source material is continuously supplied during the process with some kind of feed mechanism. Such processes are generally automated to a large extent, carried out by some kind of 3D laser printer device. Still, one often requires some amount of manual work, e.g. for filling the bath, removing and cleaning the workpiece, etc.

3D printing is becoming the future of the manufacturing era. Due to the fact that there are many different processes which are suitable for different types of materials. A few of them are mentioned below. SLS printing begins with a thin layer of powdered material spread evenly across the build platform. The thickness of each layer typically ranges from tens to hundreds of micrometers, depending on the specific printer and material being used. A high-powered laser, controlled by computer-aided design (CAD) software, selectively scans the surface of the powdered bed according to the cross-sectional shape of the desired object. Wherever the laser beam strikes, it heats the powdered material to just below its melting point, causing particles to fuse together and form a solid layer.

Selective laser melting (SLM) as shown in Fig. 4 is a comparatively newer 3D-printing technology and developed in 1995 by German scientists. UV laser is used, a high-powered laser beam is used in SLM to form 3D parts. During the printing process, the laser beam melts and fuses various metallic powders together. As the laser beam hits a thin layer of the material, it selectively joins or welds the particles together. After one complete print cycle, the printer adds a new layer of powered material to the previous one. The object is then lowered by the precise amount of the thickness of a single layer The main difference between SLM and SLS is that SLM completely melts the powder, whereas in SLS, only partly melted or sintered powdered is used. In general, SLM end products tend to be stronger as they have fewer or no voids. A common use for SLM printing is with 3D parts that have complex structures, geometries and thin walls.

Stereolithography, also known as vat photopolymerization or resin 3D printing, SLA printers generally print objects upside down. The liquid resin tank has a transparent base through which the laser beam is guided from below. Once the CAD file is ready for printing, the SLA printer goes through the following process guided from below. Once the CAD file is ready for printing, the SLA printer goes through the following process

1. The laser/mirror combination directs the beam according to the path needed for the first cross-section layer of the object you are printing. The resin solidifies wherever the laser beam hits it.
2. The build platform, which is upside down toward the top of the resin tank, raises in preparation for the second and subsequent layers
3. The object builds layer by layer. When the print is complete, the platform raises the object entirely out of the resin so that excess resin can drain away. Any resin that isn't solidified by the laser remains in the tank and can be used again.
4. Post-processing can include washing the object to remove excess resin and removing any support pieces. The object is then put into a UV oven for curing.

Digital light processing (DLP) 3D printing is a resin 3D printing process that uses a light projector rather than a laser to cure liquid resin one layer at a time. DLP printers' light source is projected using a series of micro mirror devices laid out in a matrix on a semiconductor chip. These micro mirror devices each represent a single voxel (or 3D pixel) of the part. The number of micro mirror devices and size of the build area determines the resolution of the part. The specific process of DLP 3D printing causes DLP printed parts to have specific, distinguishable qualities. Like all resin 3D printing technologies, UV light from the DLP printer's light source cannot penetrate more than 100 microns (0.1 mm) into the resin tank. This means that layer heights on DLP 3D printers typically fall between 25 and 100 microns. This means that even a centimeter-tall print can have up to 400 layers. Direct Metal Laser Sintering (DMLS) is a laser-based technology of metal 3D printing that uses a high-powered laser to melt powdered layer by layer to build up your design. The process is comparable to welding with a very fine and precise laser. Parts are then printed in an enclosed build chamber infused with argon gas. A Yb-fiber laser focused via dynamic mirrors

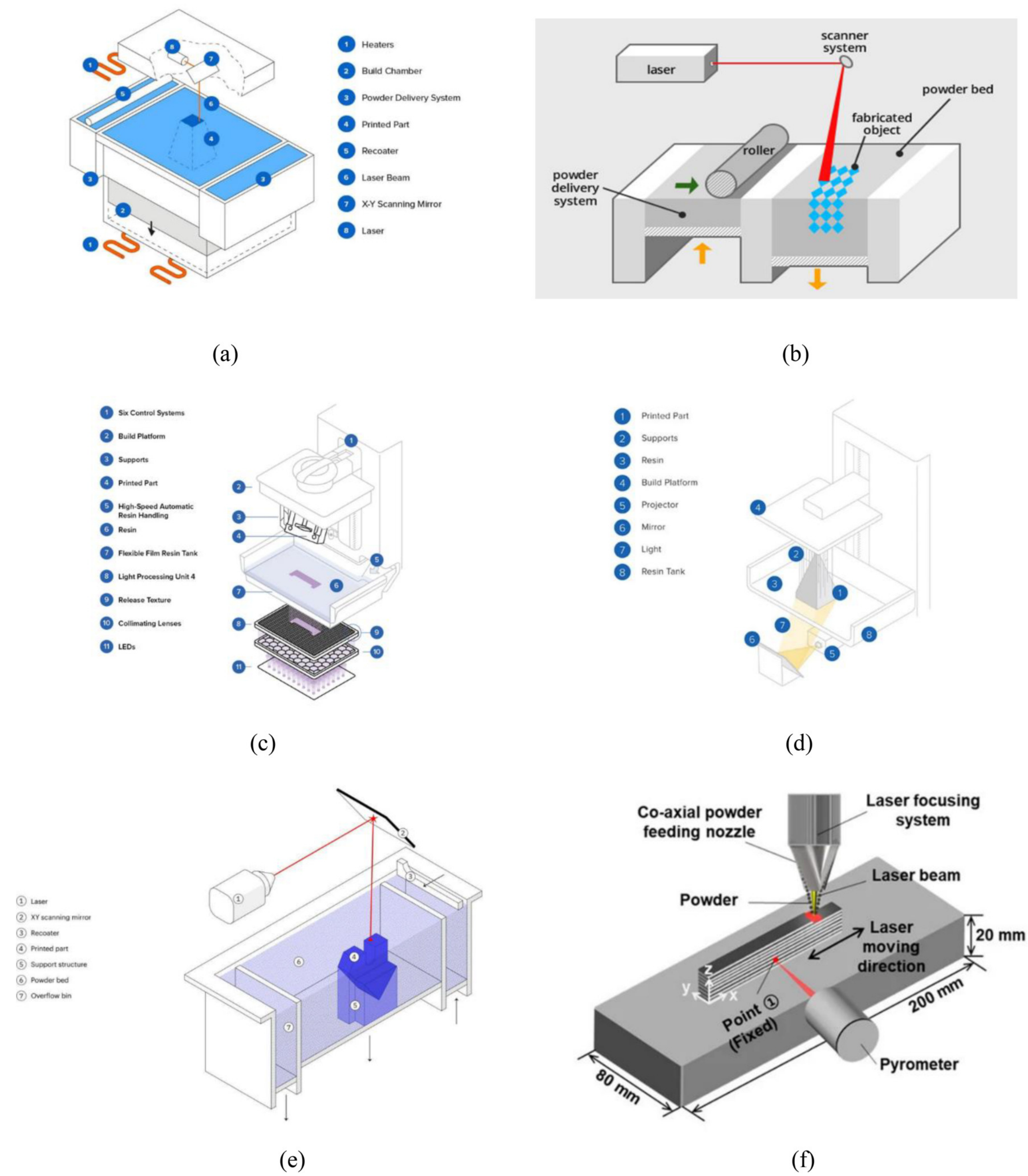


Fig. 4. (a) Selective laser sintering process 3D printing uses a high-power laser to sinter small particles of polymer powder into a solid structure based on a 3D model (b) Selective laser melting (SLM) printing process (c) SLA 3D Printing Process (d) Digital light processing 3D printing (e) Direct metal laser sintering 3D printing process (f) LMD 3D printing process.

selectively melts the design's cross section through computer-determined scan path. Printed parts with DMLS technology are durable, lightweight and precisely detailed.

- Print complex geometries with strong and durable components
- Rapid prototyping with high quality and high accuracy- ideal for functional testing
- Create complex shapes, intricate details and delicate features
- Reduce cost & development time by consolidating parts, no tooling required
- Build parts in a matter of hours

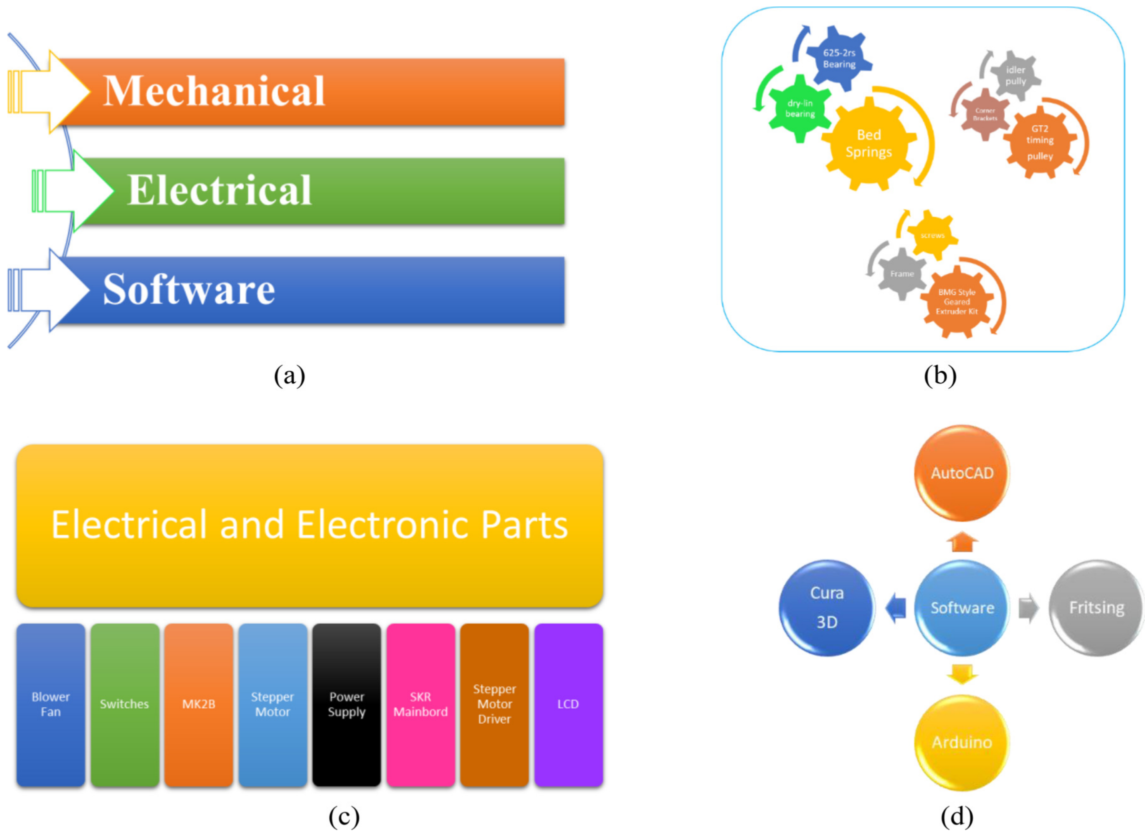


Fig. 5. (a) 3D Printer Design Categories (b) Mechanical parts of 3D Printer (c) Electrical and electronic parts of 3D Printer (d) Software used in the design and implementation of the 3D printer.

LMD is a laser-based DED technique that selectively adds metal material onto a base workpiece in a layer-by-layer process. In powder-based LMD (p-LMD), a nozzle aggregates metal powder onto a workpiece, where a Fiber laser (parallel to the nozzle) melts both the powder and the Workpiece into a melt pool. This nozzle moves across the build plane, depositing powdered material and fusing it to the workpiece into the desired shape. There is also so-called wire laser metal deposition (w-LMD), which works the same except it uses metal wire in place of powdered metal. LMD offers a low heat, high strength method of laser additive manufacturing, minimizing dilution, heat effect zones, and stress distortions. It can produce fully customized, functionally-graded parts for demanding applications, or restore existing parts to their original strength.

3. Results and discussion

3D printing tools encompass a range of essential components and software vital for the additive manufacturing process. From slicing software that translates digital designs into printable layers to specialized nozzles and filament spools, these tools form the backbone of the 3D printing ecosystem. Based on this, 3D printer design can be divided into three main categories according to their functions and roles in the printing and manufacturing process, as shown in Fig. 5(a).

Mechanical tools are integral components of 3D printers, essential for precise and efficient printing. From the robust frame providing stability to the motion system ensuring accurate movement, these tools work together to bring digital designs to life in the physical world.

The electric and electronic parts are the cornerstone of the 3D printing process. They convey the essential operation of filament fusion, code translation, 3D printer movement in the 3D space, control and power supply, as shown in Fig. 5(c). The software tools enable the integration of the design, development, and successful implementation of the 3D laser printer. From the frame design to the electrical circuit design to the software integration with the personal computer and the coding operation of the 3D laser printer, there are four software that we used in the work including: Fritzing (for circuit design), Arduino (for coding and 3D laser printer operation), AutoCAD

Table 1. Component usage in the design of 3D laser printer.

Tool/Part Name	Type	Number	Uses
Frame	Mechanical	1	Provides structural support and stability to the printer
Build platform	Mechanical	1	Serves as the foundation for printing and ensures adhesion of printed objects.
Motion system	Mechanical	Multiple	control movement of the print head and build platform along X,Y and Z axes with precision
Extruder Assembly	Mechanical	1	deposits filament material layer by layer to shape the final printer object
Bearings	Mechanical	Multiple	reduce friction and enable smooth movement of various parts within the printer, such as in the motion system
Nozzle	Mechanical	1	melt and deposits filament materials onto the build platform during printing
Filament spool	Mechanical	1	holds the filament material and feeds it into the extruder
Electronics	Electrical	1	Integrate the design with essential software
Cooling fans	Electrical	1	Control the heat and remove it
LCD display	Electrical	1	For on-screen operation command

(for frame design), Cura 3D (for 3D model design and simulation and model conversion to .STL format that integrate with the 3D laser printer, as shown in Fig. 5(d).

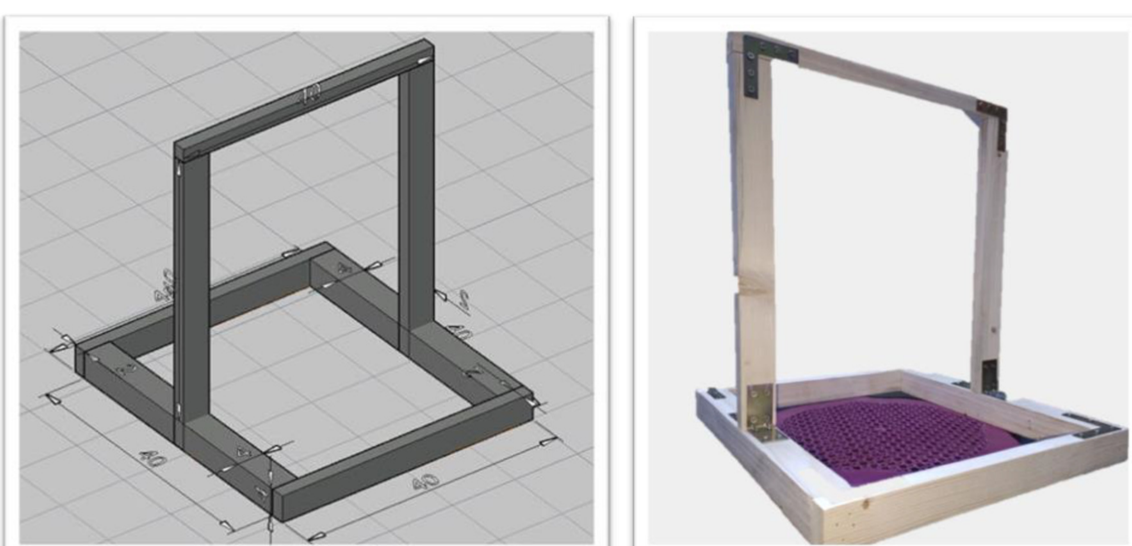
The tools, parts and materials used in the work can be summarized in the Table 1. The frame of the 3D printer was designed in the AutoCAD software and then implemented to make the backbone of the 3D printer, as shown in Fig. 6

The 3D model design and simulation were done using Cura 3D software, where time duration, filament wight and length can be estimated from the software, as shown in Fig. 7

Using Fritzing software, the core electrical circuits was designed as shown in Fig. 8. The circuit controls the movement of the 3D printer in X, Y, and Z directions with the employment of the DC servo motors, also the extruder motor used to control the flow of the filament.

The 3D printer final shape can be shown in Fig. 9 below

The 3D laser printer implemented is as a 3D object printing device for multiple scientific, industrial and research purposes. The printing volume is around 20 cm x 20 cm x 20 cm which limits the 3D objects to these specifications. As the 3D laser printer is turned on, the heating process for the heater is automatically turned on. When the temperature reaches 210 °C the heater will be ready to extrude the installed filament and shape it according to the .STL file uploaded to the main board using USB cable. The file format will change from .STL file to a .gcode file enabling



(a) (b)

Fig. 6. (a) AutoCAD Design of the 3D printer frame (b) The 3D printer frame after implementation.

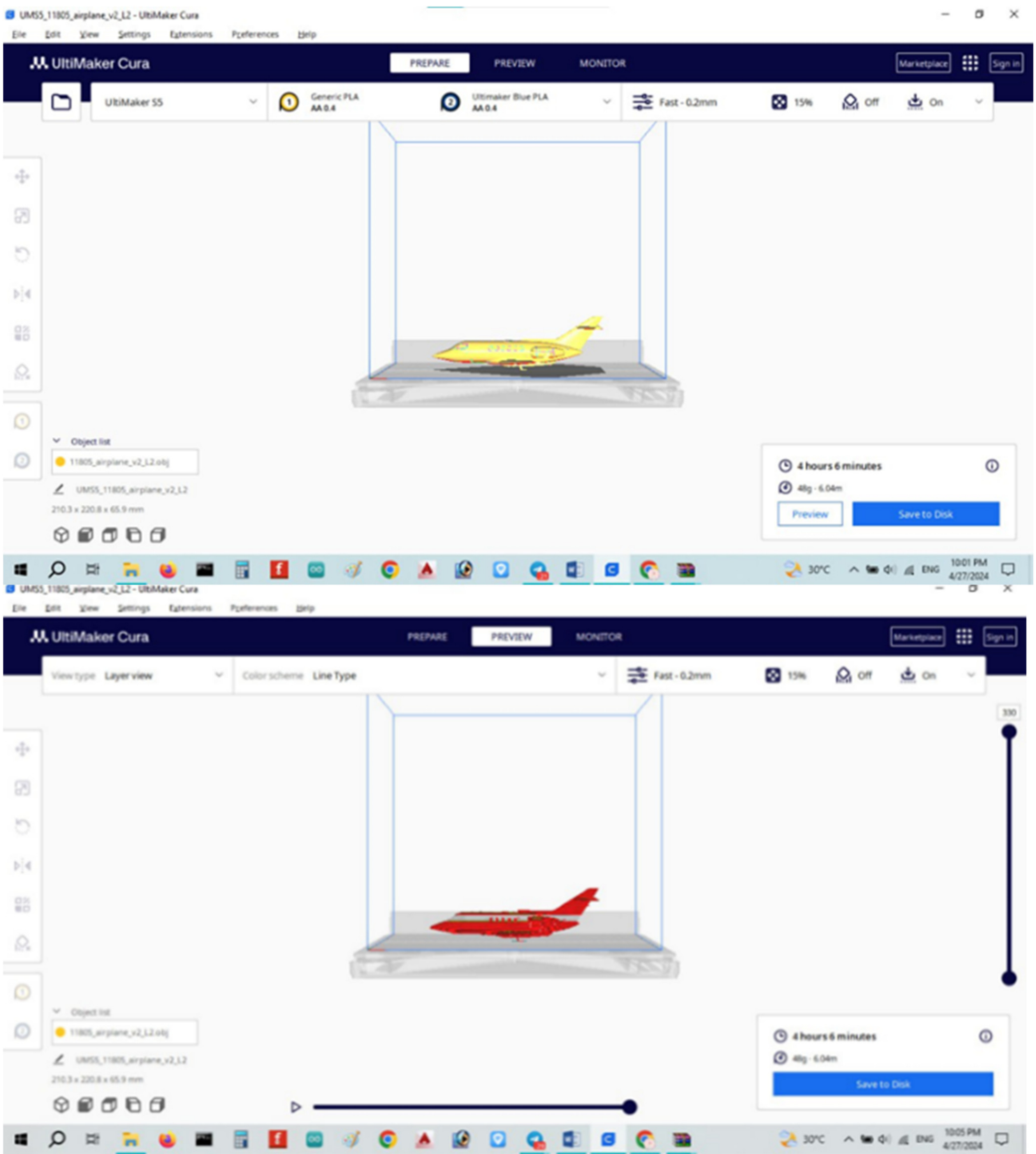


Fig. 7. Cura 3D model simulation.

the reading process for the spatial coordinates of the printing volume .Once the code of the 3D object is uploaded a manual user push button will be turned on to start the printing process. When the process is finished, the printing and thus the filament extrusion will end and the heater will be cooled to reach room temperature.

4. Conclusion

3D printing has a bright future, not just in rapid prototyping but also in medicine arts, and engineering.3D Printing can be used to initiate prototypes of several components used in engineering and manufacturing 3D printers capable of extracting colorful

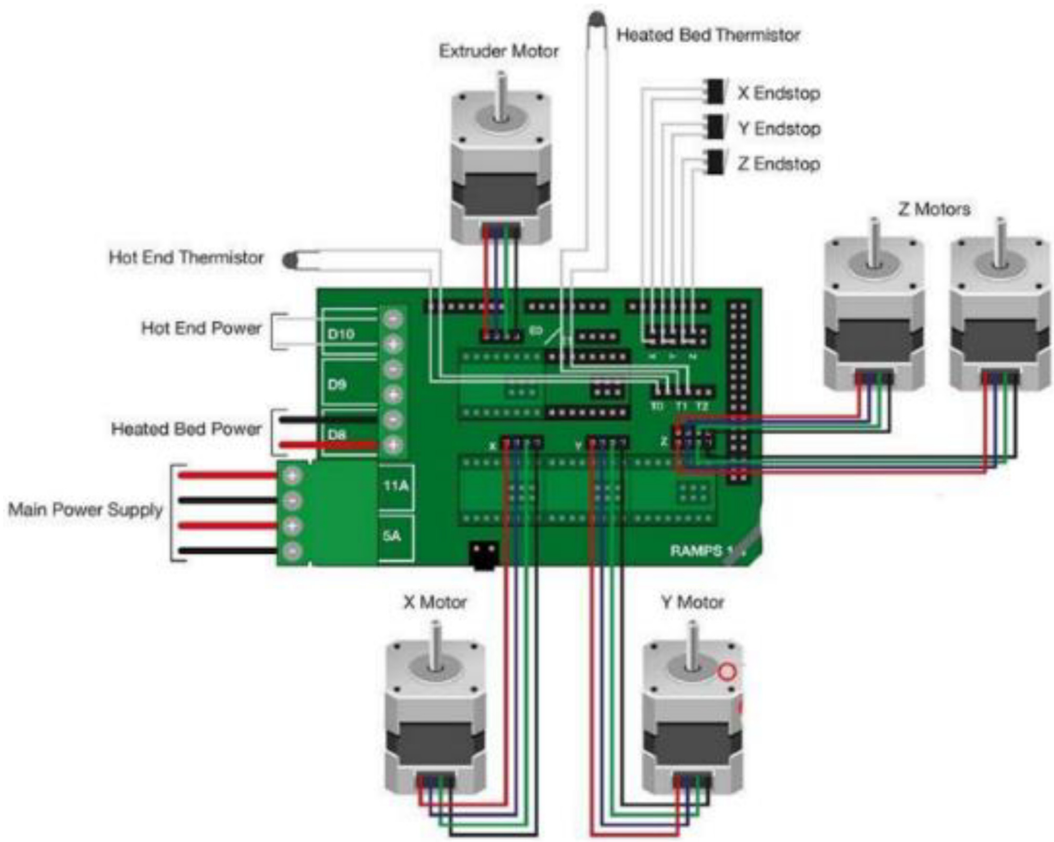


Fig. 8. Core electrical circuit design.

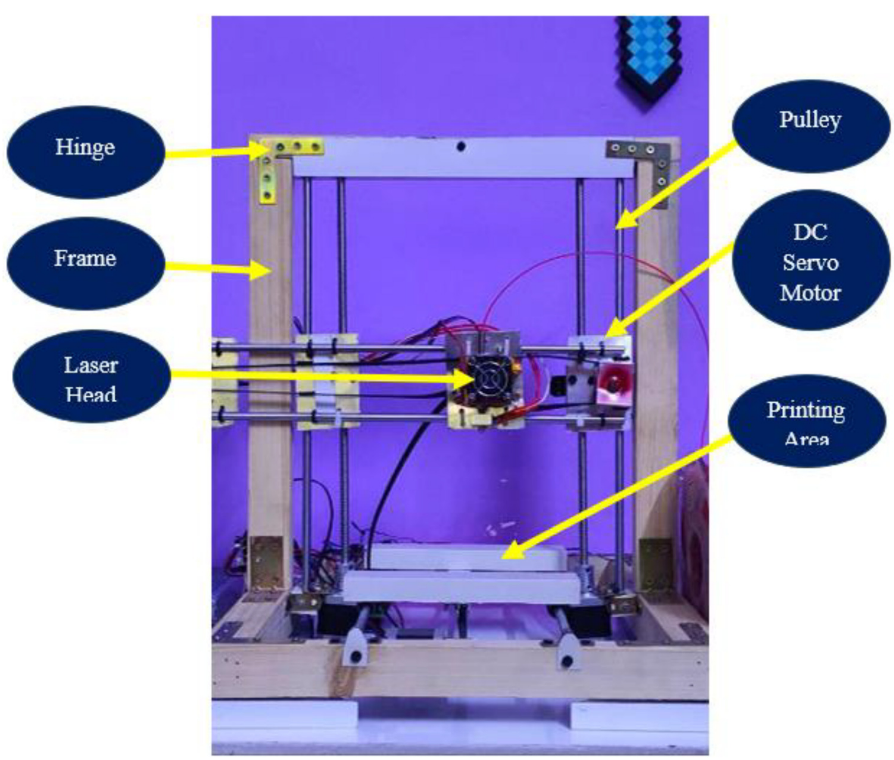


Fig. 9. Implementation of 3D printer.

objects with multiple materials to play crucial role in demonstrating, repair, safety, and so more To demonstrate the design and implementation criteria here we provided a detailed description of the design process showing the feasibility of design and implementation which enables the use for scientific purposes.

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