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DESIGN AND FABRICATION OF DUAL-HEAD 3D PRINTER

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ABSTRACT

This study presents the design and fabrication of a dual extruder 3D printer aimed at enhancing multi material and multi color additive manufacturing capabilities. Unlike conventional single head 3D printers, the proposed system integrates two independent extruders, enabling simultaneous deposition of different filaments for increased design flexibility and productivity. The mechanical structure is developed with an aluminum frame, ensuring rigidity and precision. Key subsystems including the X, Y, and Z axes are driven by belt and screw mechanisms, with dynamic analysis conducted to determine operating forces and ensure motion accuracy. Finite Element Method (FEM) simulations verify the structural integrity of the frame under expected loads, showing stress and deformation well within safe limits. The prototype features a working volume of 200×200×250 mm, a maximum printing speed of 55 mm/s, and achieves high dimensional accuracy, demonstrated by a machine bed parallelism deviation of only 0.01 mm. Experimental results validate the effectiveness of the dual head configuration in producing high quality, dual color printed parts, highlighting the printer's potential in rapid prototyping and customized manufacturing applications.

1. INTRODUCTION

In the landscape of modern manufacturing, few innovations have garnered as much attention and excitement as 3D printing. Often hailed as the technology of the future, 3D printing has swiftly transformed from a niche process to a mainstream manufacturing technique with far reaching implications across industries [1-5]. This transformative technology, also known as additive manufacturing, enables the creation of three-dimensional objects layer by layer from digital models. Its applications span from rapid prototyping and custom part fabrication to medical implants and even construction materials.

While traditional manufacturing methods have long been the cornerstone of production processes, 3D printing offers a range of distinct advantages that set it apart from its conventional counterparts. One of the primary advantages of 3D printing lies in its ability to expedite the manufacturing process. Unlike traditional methods, which often involve complex tooling and lengthy setup times, 3D printing enables rapid prototyping and production through layer-by-layer deposition of materials. This layer-by-layer approach eliminates the need for specialized tooling, reducing lead times and enabling faster iterations of product designs. Traditional manufacturing often involves high setup costs and economies of scale, meaning that small-batch or custom production runs can be prohibitively expensive. In contrast, 3D printing excels in producing low-volume, highly customized parts at competitive prices, making it particularly attractive for niche markets and personalized products. One of the most compelling advantages of 3D printing is its unparalleled design flexibility. Unlike traditional methods, which are often constrained by the limitations of subtractive or formative processes, 3D printing enables the creation of complex geometries and intricate structures with ease [6-15]. This freedom of design allows engineers and designers to explore innovative concepts and push the boundaries of what is possible, leading to the development of lighter, stronger, and more efficient products.

Across the globe, the field of 3D printing has witnessed remarkable advancements, leading to a diverse array of printers tailored to various industries and applications. The world of 3D printing is characterized by a diverse range of printers, each catering to specific needs and applications across various industries [16-19]. From affordable FDM printers for rapid prototyping to high end SLA, DLP, SLS, and binder jetting printers for precision engineering and production grade applications, the global 3D printing market continues to expand and innovate, driven by technological advancements and growing demand for additive manufacturing solutions.

Traditional 3D printers typically feature a single extruder, limiting users to printing objects in a single color or material at a time. While post processing techniques such as painting or assembly can be used to add color or incorporate different materials into printed objects, these methods are often time consuming and labor intensive. By integrating dual extruders into the printing process, this

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research aims to streamline the production of multi colored and multi material objects, offering users greater flexibility and creativity in their 3D printing projects. The objective of this research is to propose a constructional solution for a 3D printing device equipped with dual extruders, enabling the simultaneous printing of objects using two different colors or materials. This innovative solution seeks to enhance the capabilities of traditional 3D printers by allowing users to create multi colored or multi material objects with greater ease and efficiency.

2. METHODOLOGY

Overall of structure

The preliminary structure of a 2-head 3D printer typically consists of several key components designed to facilitate the simultaneous printing of objects using two different colors or materials. While the specific design may vary depending on the manufacturer and model, the following components are commonly found in such printers:

Frame: The frame provides the structural support for the printer and houses the various components. It is usually made of durable materials such as aluminum or steel to ensure stability and rigidity during the printing process.

Extruders: The printer is equipped with two extruders, each containing a heated nozzle and filament feeding mechanism. These extruders are responsible for melting and depositing the printing material onto the build platform layer by layer. They may be mounted on a gantry or carriage that moves along the X and Y axes to cover the entire print area. The developed printer employs a dual-head FFF system, where each hotend has an independent heater and PID controller. This configuration supports both multi-color and multi-material printing. For dissimilar polymers (e.g., PLA with PVA supports, or PLA with PETG), differences in melting temperature and shrinkage are addressed by applying materialspecific nozzle temperatures, independent retraction/prime settings, and idle-nozzle standby modes to reduce oozing

Print Bed: The print bed is the surface on which the object is built. It may be heated to improve adhesion and minimize warping of the printed layers. Some printers feature a removable or flexible print surface to facilitate object removal and maintenance.

Control Electronics: The printer includes a control board and associated electronics responsible for coordinating the movements of the extruders and other components. These electronics may be housed in an enclosure located near the base of the printer.

User Interface: A user interface, such as a touchscreen display or LCD panel, allows users to interact with the printer, select printing parameters, and monitor the printing process. It provides feedback on the printer's status and allows users to troubleshoot issues as they arise.

Table 1 *Expected design parameters of 3D printer*

Machine frame size	*545x490x770mm*
Working area	*200x200x250mm*
Maximum movement speed	*0.08m/s*
Maximum printing speed	*0.055m/s*

When designing a 3D printer, several key parameters need to be considered to ensure optimal performance, reliability, and user satisfaction. While specific design parameters may vary depending on factors such as the intended application, budget, and target market, the following are some of the expected design parameters commonly addressed in the development of 3D printers, as shown in the Table 1. The overall dimensions of the machine are 545x490x770mm (WidthxDepthxHeight), The working area of 200x200x250mm (X, Y, Z). The maximum movement speed of 80mm/s dictates the speed at which the print head and build platform can move during non-printing operations, such as homing, calibration, and travel between printing locations. The maximum printing speed of 55mm/s determines the rate at which filament is extruded and deposited to create each layer of the printed object.

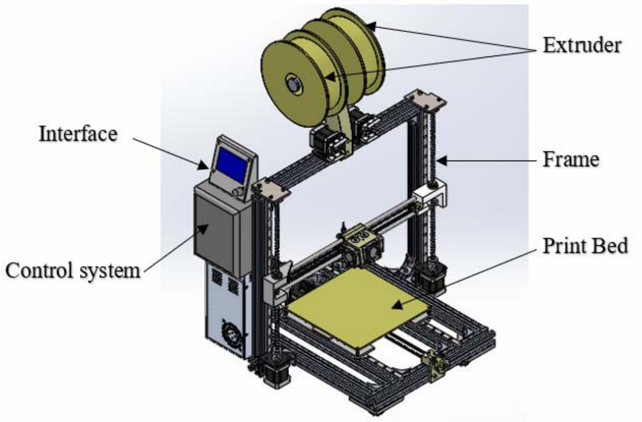

Fig. 1. Overall Structure

X-axis design

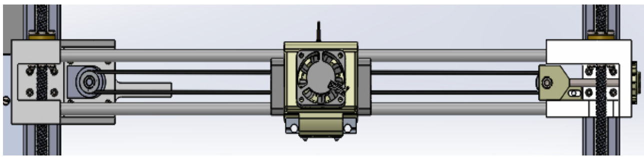

Fig. 2. Structure of the X axis

The X-axis movement is achieved using a toothed belt drive system guided by a slider, as shown in the Figure 2. This mechanism allows the plastic nozzle to move horizontally across the machine, thereby determining the width of the printed object. The belt is attached to the stepper motor, which drives the movement of the X-axis by rotating the pulleys. By implementing a toothed belt drive system guided by a slider for the X-axis movement, the 3D printer can achieve precise and consistent lateral movement of the plastic nozzle, enabling accurate control over the width of the printed objects.

Specifications: Reach a velocity increase from 0 m/s to 0.08 m/s across a distance of 1mm, acceleration is calculated using the formula:

$$a_x = \frac{v_x^2 - v_0^2}{2 \times s} = \frac{0.08^2 - 0}{2 \times 0.001} = 3.2\, m/s^2 \quad (1)$$

Maximum force acting on the system:

$$F_{x\,max} = F_{1x} = \mu \times m_x \times g + m_x \times a_x = 2.19\, N \quad (2)$$

In which $m_x = 0.5\, kg$, $\mu = 0.12$, $\eta = 0.9$ [26].

The power transmission by belt drives:

$$P_x = F_{x\,max} V_x / 1000\eta = 0.195 W \quad (3)$$

Y axis design

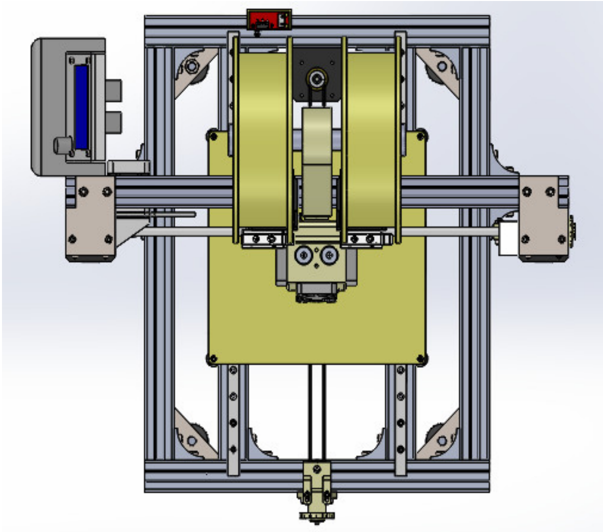

Fig. 3. Structure of the Y axis

Y-axis movement is the longitudinal reciprocating movement of the machine by toothed belt drive guided by the machine frame and drive roller.

Specifications: Reach a velocity increase from 0 m/s to 0.08 m/s across a distance of 1mm, acceleration is calculated using the formula:

$$a_y = \frac{v_y^2 - v_0^2}{2 \times s} = \frac{0.08^2 - 0}{2 \times 0.001} = 3.2\, m/s^2 ,\ m_y = 2\,kg \quad (4)$$

Maximum force acting on the system:

$$F_{y\,max} = F_{1y} = \mu \times m_y \times g + m_y \times a_y = 8.75\,N \quad (5)$$

The power transmission by belt drives:

$$P_y = F_{y\,max} V_y / 1000\eta = 0.97\,W \quad (6)$$

Z axis design

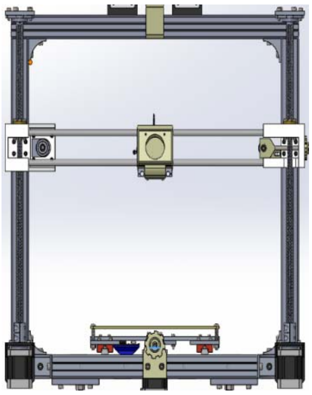

Fig. 4. Structure of the Z axis

The axial force acting on the screw drive is the total mass of the nozzle shaft assembly, radiator fan, pulley, bearing, belt, motor and guide shaft

Specifications: Reach a velocity increase from 0 m/s to 0.01 m/s across a distance of 1mm, acceleration is calculated using the formula

$$a_z = \frac{v_y^2 - v_0^2}{2 \times s} = \frac{0.01^2 - 0}{2 \times 0.001} = 0.05\, m/s^2 \quad (7)$$

Maximum force acting on the system:

$$F_{z\,max} = m_z g + \mu \times m_z \times g + m_z a_z$$

$$F_a = F_{2z} = 0.1 \times 3 \times 9.81 + 3 \times 0.05 + 3 \times 9.8 = 32.5\,N \quad (8)$$

Design of machine frame system

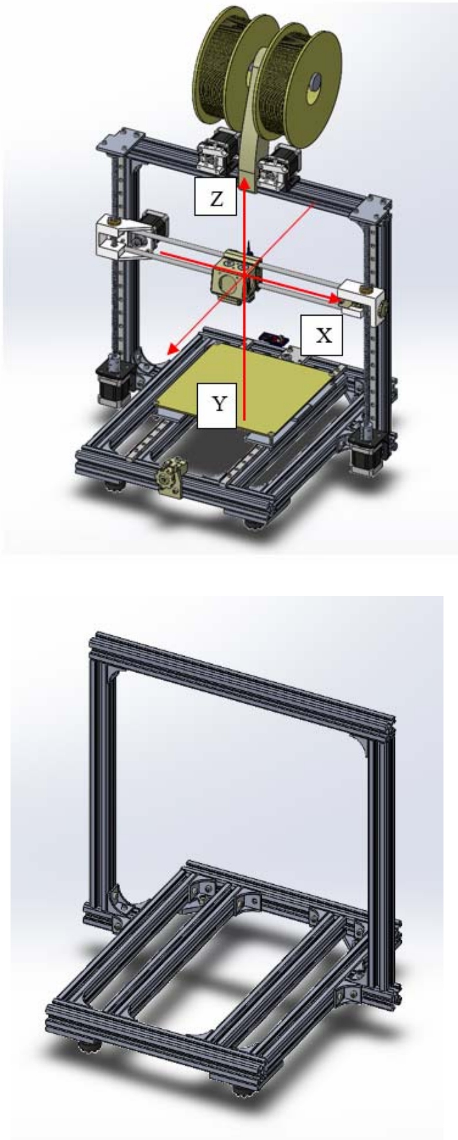

Fig. 4. Machine frame structure

Use FEM software to simulate the stress and deformation of the machine frame system when the load applied to the machine frame is m=4.5 kg including 2 extrude plastic extrusion assemblies, two plastic rolls, plastic roll jig and shifting assembly X,Y,Z axis, as shown in the Figure 4. The structural design of the dual-jet 3D printer, showcases a Cartesian coordinate configuration with three orthogonal axes X, Y, and Z responsible for the spatial positioning of the extruder assembly. The left image presents the complete system, where the dual extruder module is mounted on the X-axis carriage, enabling lateral movement. This X axis assembly is supported by linear bearings and is driven by a toothed belt mechanism to ensure precise and consistent motion. The Y axis corresponds to the movement of the build platform in the front to back direction, while the Z axis governs the vertical displacement of the entire X axis gantry, allowing layer by layer deposition of material. Notably, the filament spools are mounted above the frame, providing gravity assisted feeding to the extruders. The right image details the foundational frame of the printer, which is constructed from aluminum extrusion profiles to guarantee rigidity, stability, and modularity. This base supports the linear rails and mechanical components of the Y axis. The structural layout emphasizes a rigid, lightweight design optimized for dimensional accuracy and vibration resistance during high speed printing operations. Together, the dual-extruder mechanism and robust frame architecture offer enhanced functionality for multi material or multi color printing while maintaining mechanical integrity and ease of maintenance. The structural frame is assembled from 6063-T5 aluminum extrusions (E = 69 GPa, ν = 0.33, yield strength ≈ 150 MPa, density = 2700 kg/m³).Angle connections are secured using steel L-brackets and M5 bolts. In the finite element model these joints were represented as bonded contacts to approximate the stiffness of tightened connections; a sensitivity check with reduced connector stiffness showed no significant change in maximum displacement

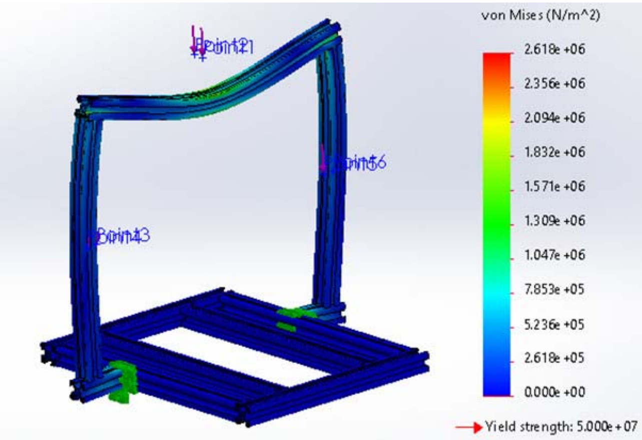

Fig. 5. Stress diagram of the machine frame

According to the stress diagram from Figure 5, the maximum stress value on the machine frame is $\sigma_{max}=2.618\times10^6$ (N/m^2), which is lower than the limit stress of the aluminum material, which is 5×10^7 (N/m^2). Therefore, the machine frame is in a strength condition.

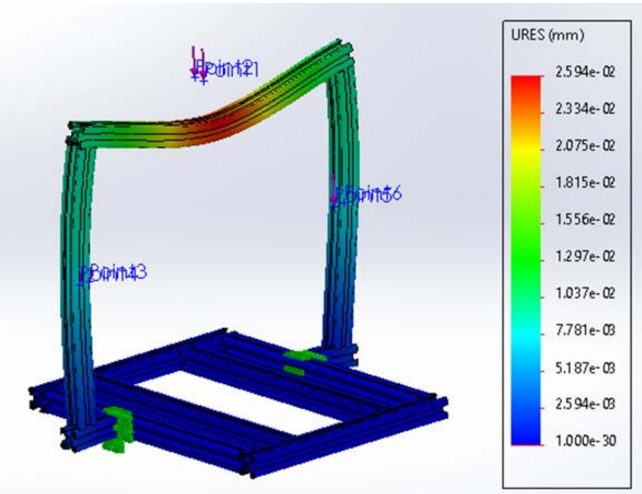

Fig. 6. Displacement diagram of the machine frame

Based on the Displacement diagram from Figure 6, the point with the largest displacement on the frame is: 0.026 mm, this is a very small, acceptable deformation of the frame system. The machine frame system meets practical working requirements. The frame is supported on four elastomer-damped feet, which were modeled as fixed boundary conditions at the contact pads. This support scheme induces small bending of the lowest horizontal profiles, but the predicted deformation remains below 0.03 mm, well within the tolerance for first-layer accuracy. Including the material properties and realistic boundary conditions ensures that the simulation results reliably reflect the actual structural performance of the fabricated machine.

3. RESULTS AND DISCUSSION

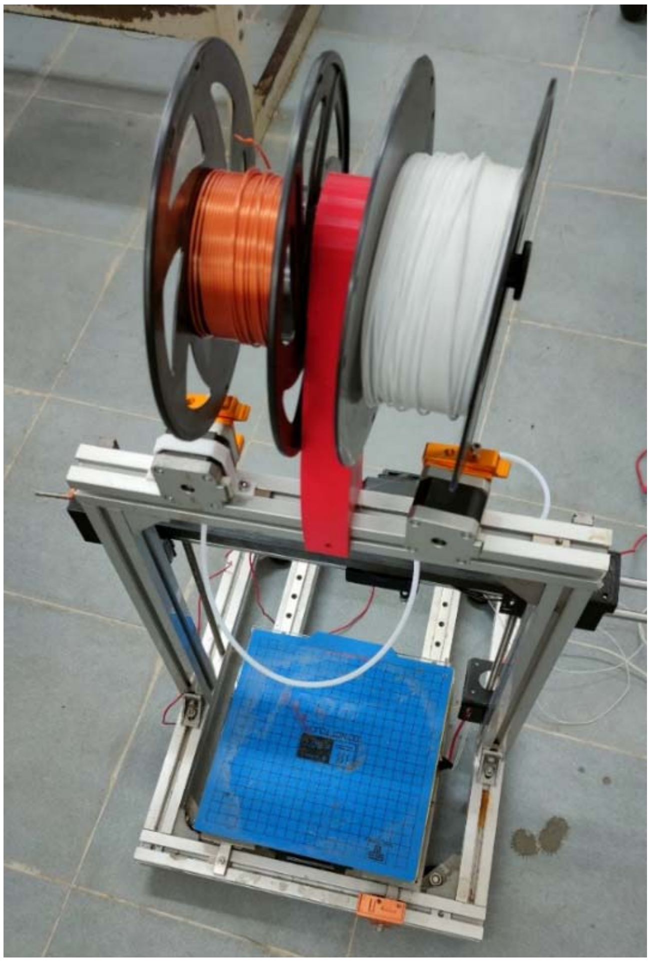

Fig. 7. Dual-head 3D printer prototype

The 3D printer measures 545 mm in length, 490 mm in width, and 770 mm in height. The machine is capable of producing objects with maximum dimensions of 200 mm in length, 200 mm in width, and 250 mm in height with the maximum printing speed of the print head, which is 0.08 m/s. The print head, responsible for extruding printing material, features a diameter range of 0.4 mm to 0.6 mm. This variation allows for flexibility in adjusting the thickness of material deposition, enabling users to customize print settings based on specific requirements such as resolution, speed, and material usage. These technical specifications of the 3D printer provide a comprehensive framework for understanding its capabilities and limitations. By analyzing factors such as machine dimensions, printable object size, print head diameter, and maximum printing speed, users can make informed decisions regarding its usage, optimization, and integration into various workflows and applications.

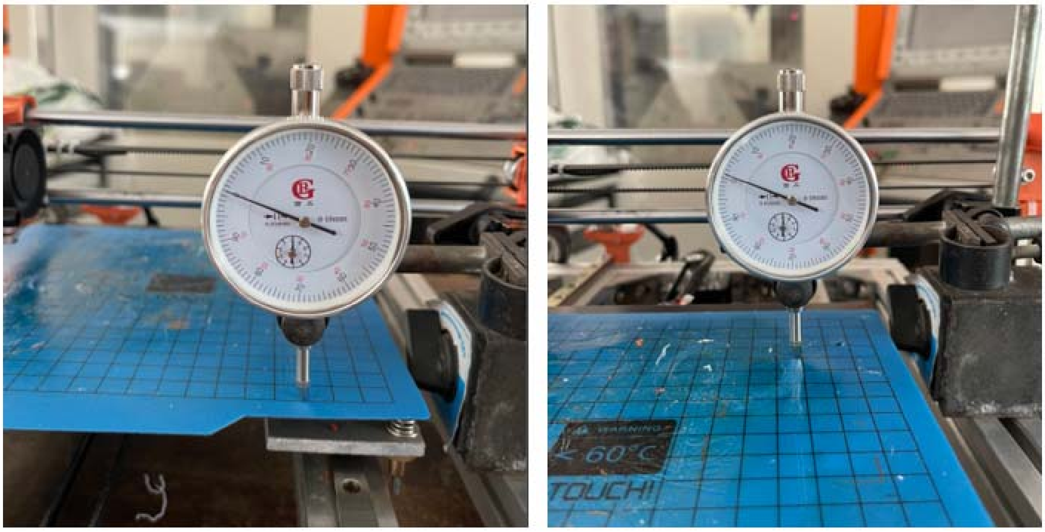

Fig. 8. Check the parallelism of the machine table frame

The measurement results depicted in Figure 8 demonstrate the meticulous precision achieved by the printer, with the non-parallelism of the machine table frame compared to the print bed measuring at a mere 0.01mm. This infinitesimal margin of error underscores the exceptional accuracy of the printer, meeting and surpassing stringent requirements for precision in actual printing operations.

In the realm of additive manufacturing, where even slight deviations can result in defects or imperfections in the final product, achieving such remarkable accuracy is paramount. By minimizing non-parallelism between the machine table frame and the print bed to a mere 0.01mm, the printer ensures that each layer of material is deposited with utmost precision, resulting in superior print quality and dimensional accuracy.

Furthermore, the ability of the printer to consistently maintain this level of accuracy throughout the printing process is a testament to its robust design and meticulous calibration.

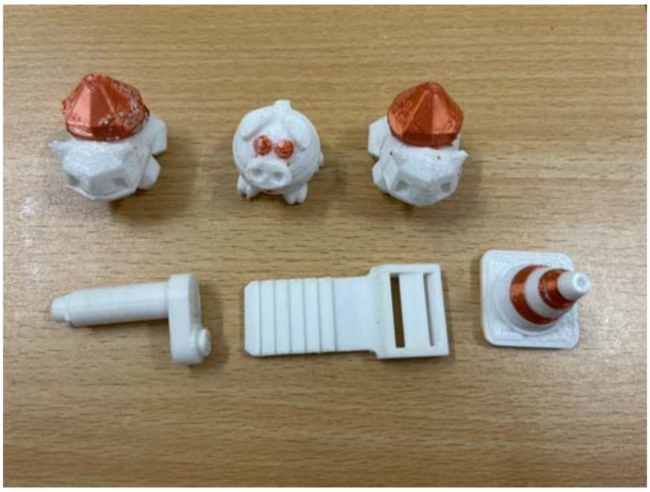

Fig. 9. Products that are made with 3D printing

Figure 9 showcases a selection of 3D printed products that highlight the printer's capability to seamlessly integrate two colors into the manufacturing process, unlocking a new dimension of creativity and customization. These products exemplify the versatility and aesthetic potential afforded by dual-color 3D printing technology, enabling the fabrication of visually striking and intricately detailed objects.

Each showcased product demonstrates the seamless transition between two colors, resulting in vibrant and eye-catching designs that captivate the imagination. From intricate patterns and gradients to bold contrasts and harmonious blends, the incorporation of dual-color printing enhances the visual appeal and artistic expression of the objects, elevating them beyond mere functional items to captivating works of art.

Moreover, the diverse range of products featured in Figure 9 underscores the versatility of dual-color 3D printing across various applications and industries. Whether it's decorative ornaments, functional prototypes, or personalized accessories, the ability to combine two colors opens up a myriad of possibilities for customization and innovation. From consumer products and fashion accessories to architectural models and educational tools, dual-color 3D printing offers limitless opportunities for creative expression and design exploration.

Furthermore, the introduction of dual-color printing capabilities expands the utility of 3D printing technology beyond prototyping and small-scale production to encompass more complex and visually engaging projects.

4. CONCLUSION

The design and fabrication of the dual-head 3D printer presented in this study demonstrate a significant advancement in enhancing the flexibility and functionality of desktop additive manufacturing systems. By integrating two independent extruders, the printer enables simultaneous multi-material and multi-color printing, addressing key limitations of conventional single-head configurations. The mechanical design, including a rigid aluminum frame and precisely engineered motion systems for the X, Y, and Z axes, ensures high structural integrity and printing accuracy. FEM simulations confirm that the frame deformation and stress remain within acceptable limits under operational loads, validating the mechanical reliability of the system. Experimental results further confirm the printer’s capability to produce complex, visually rich, and dimensionally accurate parts. With a parallelism deviation of only 0.01 mm and successful demonstration of dual-color prints, the developed system meets both functional and aesthetic demands of modern 3D printing applications. This dual-head printer serves as a versatile platform for rapid prototyping, educational use, and customized production, and lays the foundation for future work focused on process optimization, intelligent control, and expanded material compatibility. Further development of the dual-head printer will focus on increasing automation and material compatibility. Planned improvements include automatic calibration of nozzle offsets, adaptive purge and waste-reduction strategies, and the application of input-shaping algorithms to enable higher printing speeds without sacrificing surface quality. Future research will also extend to systematic studies of multi-material combinations (e.g., PLA–PETG, PLA–TPU, PLA–PVA) with quantitative evaluation of dimensional accuracy, bonding strength, and inter-nozzle registration. In the longer term, the integration of modular toolheads, active thermal management, and real-time process monitoring is envisioned to expand the applicability of dual-head FFF technology in rapid prototyping, education, and customized small-batch manufacturing.

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