

DESIGN AND FABRICATION OF A 3D PRINTER USING FILAMENT PRODUCED FROM RECYCLED THERMOPLASTIC WASTE

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Abstract: The increasing accumulation of thermoplastic waste poses a significant environmental challenge, necessitating sustainable recycling and manufacturing solutions. This project presents the design and fabrication of a low-cost fused deposition modeling (FDM) 3D printer that operates using filament produced from recycled thermoplastic waste. Discarded plastics such as PET bottles and packaging materials are collected, cleaned, shredded, and processed through a filament extrusion system to produce usable 3D printing filament. The fabricated printer consists of a rigid frame, precision motion system driven by stepper motors, an Arduino-based control unit, a heated bed, and a temperature-controlled extruder assembly. The recycled filament is melted and deposited layer by layer to manufacture three-dimensional objects from digital CAD models. Experimental results demonstrate that the recycled filament provides adequate dimensional accuracy and mechanical strength for prototyping and functional part fabrication. The proposed system significantly reduces material costs, minimizes plastic waste, and promotes environmentally responsible manufacturing. This work highlights the feasibility of integrating plastic recycling with additive manufacturing and offers a sustainable, cost-effective solution for educational, industrial, and small-scale production applications.

Keywords - 3D Printing, Recycled Thermoplastic, Fused Deposition Modeling (FDM), Plastic Waste Recycling, Filament Extrusion, Sustainable Manufacturing, Low-Cost 3D Printer, Additive Manufacturing.

1. INTRODUCTION

The widespread use of plastic materials has resulted in a continuous rise in thermoplastic waste, posing a serious threat to environmental sustainability. Traditional waste disposal practices such as dumping and incineration are no longer sufficient, as they contribute to land degradation, air pollution, and the loss of valuable resources. Since many thermoplastics can be repeatedly melted and reshaped, recycling these materials into functional products presents a viable approach to reducing environmental impact.

Additive manufacturing has gained significant attention as an efficient method for producing complex components with minimal material wastage. Among the available techniques, Fused Deposition Modeling (FDM) is the most commonly used due to its straightforward operation, low initial cost, and wide range of applications. Despite these advantages, the dependence on commercially manufactured filaments, often produced from virgin plastics, increases production costs and limits the environmental benefits of the technology. The use of recycled thermoplastic filament offers a sustainable alternative while maintaining compatibility with existing FDM systems.

This research addresses the development of a cost-effective FDM 3D printer capable of operating with filament derived from recycled thermoplastic waste. Discarded plastic materials are processed through cleaning, shredding, and controlled extrusion to obtain printable filament. The fabricated printer employs a microcontroller-based control system, precision stepper motors, and a thermally regulated extrusion mechanism to achieve accurate and reliable printing. The system is designed to convert digital three-dimensional models into physical objects through a layer-by-layer deposition process.

The aim of this work is to demonstrate the practical integration of plastic waste recycling and additive manufacturing within a single, low-cost platform. By reusing thermoplastic waste for filament production and 3D printing, the proposed approach reduces material costs, minimizes plastic pollution, and supports sustainable manufacturing practices. The developed system is well suited for educational use, research applications, and small-scale production, contributing to the advancement of circular economy principles in modern manufacturing.

2. LITERATURE REVIEW

In recent years, increasing attention has been directed toward the reuse of plastic waste due to growing environmental concerns and the depletion of natural resources. Several studies have emphasized the importance of recycling thermoplastics, particularly polyethylene terephthalate (PET), owing to their widespread availability and favorable melting characteristics. Researchers have demonstrated that recycled PET can be effectively processed into filament for additive manufacturing when appropriate cleaning, drying, and extrusion parameters are maintained.

Previous investigations into filament production from waste plastics have focused on optimizing extrusion temperature, nozzle diameter, and cooling methods to achieve consistent filament diameter and improved mechanical properties. It has been reported that variations in filament thickness significantly affect print quality and dimensional accuracy in FDM-based 3D printers. Consequently, several authors have proposed closed-loop control systems and improved cooling mechanisms to enhance filament uniformity during the extrusion process.

The application of recycled filaments in Fused Deposition Modeling has been explored by multiple researchers, who evaluated the mechanical strength, surface finish, and print reliability of printed components. Experimental results from earlier works indicate that recycled thermoplastic filaments can produce parts with acceptable tensile strength and structural integrity for non-critical applications. However, challenges such as material degradation due to repeated heating cycles and contamination of waste plastics have been identified as key limitations.

In parallel, studies on low-cost and open-source 3D printer development have contributed to increasing accessibility of additive manufacturing technologies. Researchers have designed printers using microcontroller-based control systems, stepper motors, and modular mechanical structures to reduce overall system cost. The integration of recycled filament into such low-cost printers has been recognized as a promising approach to enhance sustainability while maintaining functional performance.

Although previous research has addressed filament recycling and printer fabrication independently, limited studies have focused on the complete integration of waste plastic recycling with a custom-built 3D printing system. The present work addresses this research gap by combining recycled filament production with the design and fabrication of a low-cost FDM 3D printer. This integrated approach provides a practical solution for sustainable manufacturing and demonstrates the feasibility of converting plastic waste into functional 3D printed products.

3. METHODOLOGY



The methodology of this work consists of two major phases: recycled filament production and the design and fabrication of the FDM-based 3D printer. Each phase was systematically developed to ensure material consistency, printing accuracy, and overall system reliability.

3.1. Collection and Preparation of Waste Plastic

Thermoplastic waste materials, primarily polyethylene terephthalate (PET), were collected from post-consumer sources such as used bottles and packaging materials. The collected plastics were thoroughly cleaned to remove labels, adhesives, and contaminants, followed by drying to eliminate moisture content. The cleaned materials were then mechanically shredded into small flakes of uniform size to facilitate consistent melting during the extrusion process.

3.2. Filament Extrusion Process

The shredded plastic flakes were fed into a filament extrusion unit equipped with a temperature-controlled heating chamber. The extrusion temperature was maintained within the optimal melting range of the selected thermoplastic to prevent thermal degradation. The molten plastic was forced through a calibrated nozzle to produce continuous filament of standard diameter (1.75 mm). A cooling mechanism was employed immediately after extrusion to solidify the filament, which was then spooled for subsequent use in the 3D printer. Filament diameter consistency was monitored to ensure reliable printing performance.

3.3. Design and Fabrication of the 3D Printer

A low-cost FDM 3D printer was designed using a rigid structural frame to provide mechanical stability during operation. The motion system was configured with stepper motors controlling the X, Y, and Z axes through belt-pulley and lead screw

mechanisms. An extruder assembly with a heated nozzle was integrated to melt and deposit the recycled filament. A heated print bed was incorporated to improve first-layer adhesion and minimize warping.

3.4. Control System and Software Integration

An Arduino-based microcontroller with a compatible motor driver shield was used to control axis movements, extrusion rate, and temperature regulation. Open-source firmware was configured to interpret G-code generated from digital CAD models using slicing software. The firmware parameters were optimized to accommodate the thermal and flow characteristics of the recycled filament.

3.5. Printing and Performance Evaluation

Test specimens were printed using the fabricated system to evaluate print quality, dimensional accuracy, and layer adhesion. Printing parameters such as extrusion temperature, print speed, and cooling rate were adjusted to obtain optimal results. The printed components were visually inspected and measured to assess the feasibility of using recycled thermoplastic filament for functional prototyping applications.

4. MATERIALS

The materials used in this project were selected to ensure low cost, availability, and compatibility with recycled filament-based 3D printing. The materials can be broadly categorized into mechanical components, electronic components, extrusion materials, and software tools.

4.1. Thermoplastic Material

Post-consumer thermoplastic waste, primarily polyethylene terephthalate (PET), was used as the raw material for filament production. Waste PET bottles and packaging materials were collected, cleaned, dried, and shredded prior to extrusion. PET was selected due to its recyclability, adequate mechanical strength, and suitability for FDM-based additive manufacturing.



FIG 1: Waste PET bottles

4.2. Heater and Nozzle for PET Filament Production

Polyethylene terephthalate (PET) is widely used for filament production due to its recyclability and suitable thermal properties. The filament extrusion unit melts shredded PET flakes and forms continuous filament through a controlled heating and extrusion process.



FIG 2: Heater and Nozzle

Heater Specifications for PET:

Type: Band heater or cartridge heater

Power rating: 400–500 W

Operating voltage: 220–240 V AC

Temperature range: 250–280 °C (optimal for PET melting)

Control: PID-based temperature controller with K-type thermocouple feedback

Maintaining a stable temperature is critical for PET, as overheating can lead to thermal degradation and discoloration, while under heating may cause inconsistent flow and diameter variations.

Nozzle Specifications for PET:

Material: Brass or stainless steel

Filament diameter: 1.75 mm or 3.0 mm

Nozzle orifice tolerance: ± 0.05 mm

Maximum operating temperature: 300 °C

The nozzle ensures precise shaping of molten PET into uniform filament suitable for FDM 3D printing. Combined with controlled heating, this setup enables consistent production of high-quality PET filament from recycled plastic waste.

4.3. Filament Re-rolling

After extrusion and cooling, the newly produced filament is guided through a spooling or re-rolling system to form uniform coils for storage and subsequent 3D printing. Proper re-rolling is critical to maintain filament diameter consistency, prevent tangling, and ensure smooth feeding into the 3D printer.

Filament Making

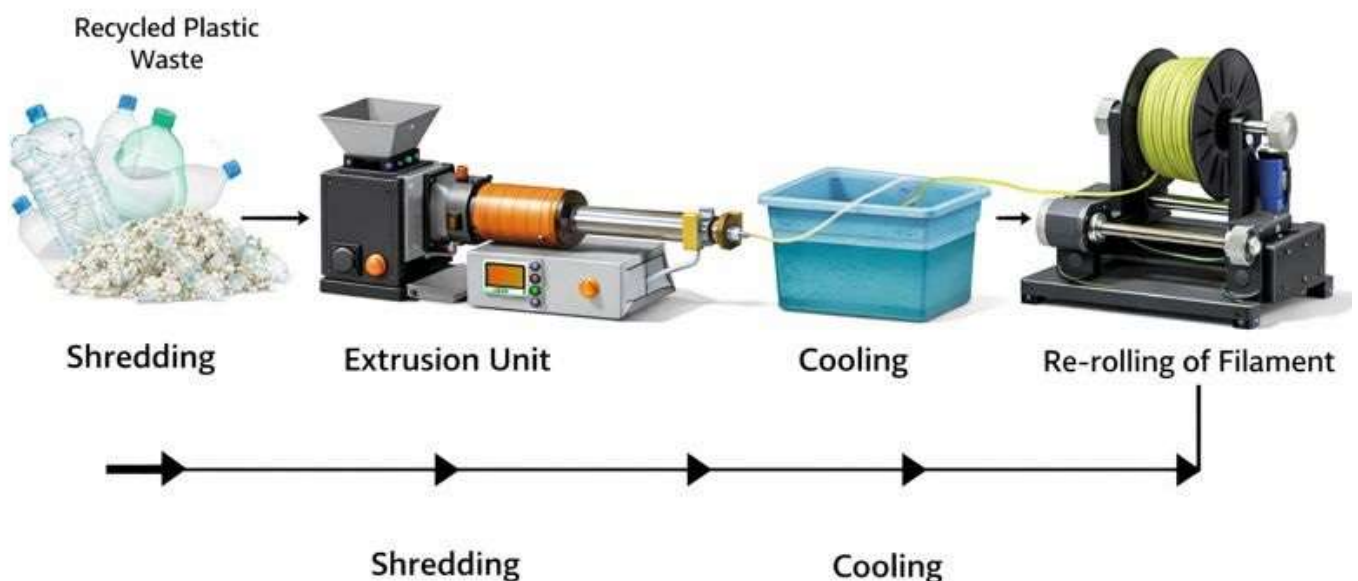


FIG 3: Filament Re-rolling

Re-rolling Process:

Filament Guidance: The extruded filament passes through a series of guide rollers to maintain tension and alignment.

Diameter Monitoring: An optical or mechanical sensor can be used to monitor the filament diameter in real-time, ensuring it remains within the standard tolerance (± 0.05 mm for 1.75 mm or 3 mm filament).

Spooling Mechanism: A motor-driven spool rotates at a controlled speed, winding the filament uniformly to avoid overlaps or loops. The spool may include tension adjustment to maintain consistent winding force.

Cooling Confirmation: Before re-rolling, the filament must be fully cooled to prevent deformation or sticking. Fans or a cooling bath are typically used after extrusion to solidify the filament.

Specifications for Re-rolling:

Spool diameter: 100–200 mm (adjustable)

Spool width: 50–100 mm

Rotational speed: 5–15 rpm (controlled to match extrusion rate)

Filament diameter tolerance: ± 0.05 mm

Proper re-rolling ensures the filament is ready for storage or immediate use in FDM 3D printing, providing consistent feeding and reducing printing errors caused by uneven filament tension or diameter variations.

4.4. Mechanical Components

The structural frame of the 3D printer was fabricated using aluminum profiles or mild steel to provide rigidity and vibration resistance. Linear motion components such as guide rods, linear bearings, lead screws, and belt-pulley mechanisms were employed to enable smooth and precise movement along the X, Y, and Z axes. A heated build platform made of aluminum was used to ensure proper adhesion of printed parts.

4.5. Extruder and Heating Elements

A standard FDM extruder assembly consisting of a stepper motor, drive gear, hot end, and nozzle was utilized to feed and melt the recycled filament. Heating cartridges and thermistors were incorporated to regulate the extrusion temperature. Cooling fans were used for rapid solidification of deposited layers and to prevent overheating of the extruder assembly.

4.6. Electronic Components

The control system was built around an Arduino-based microcontroller with a compatible motor driver shield. Stepper motor drivers were used to control the motion of the axes and the extruder. Additional electronic components included limit switches for axis homing, a power supply unit, wiring harnesses, and connectors.

4.7. Software Tools

Open-source firmware was used to control the printer's hardware and interpret G-code instructions. Computer-aided design (CAD) software was employed to create three-dimensional models, while slicing software was used to convert the models into printable G-code files. These software tools enabled precise control over printing parameters such as layer height, print speed, and extrusion temperature.

Research Through Innovation

5. 3D PRINTER COMPONENTS

The fabricated low-cost FDM 3D printer consists of several essential components that work together to convert recycled filament into three-dimensional objects. These components are categorized into mechanical, electronic, and extrusion systems.

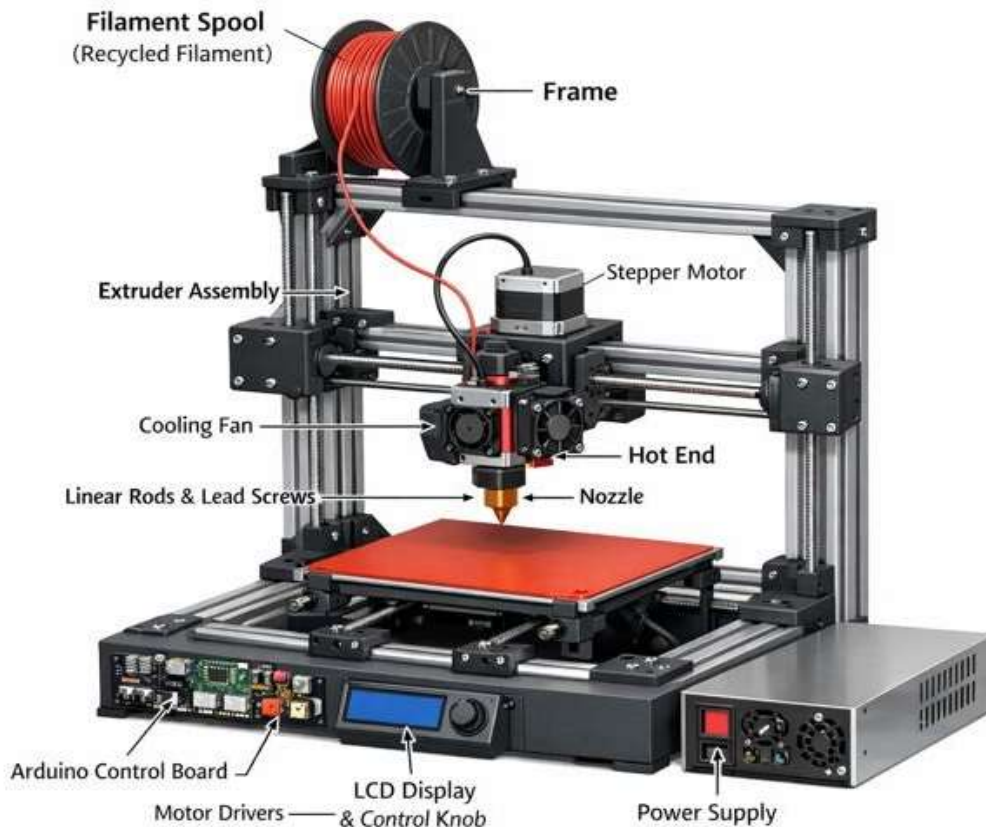


FIG 4: 3D Printer Components

1. Frame

The frame provides structural support and stability for the entire printer. It is fabricated from aluminum profiles or mild steel, ensuring rigidity and vibration resistance during printing. A stable frame minimizes deflections and improves print accuracy.

2. Motion System

The motion system controls the movement of the print head and build platform along the X, Y, and Z axes. Key components include:

Stepper motors: Provide precise rotational motion.

Lead screws or belt-pulley systems: Convert motor rotation into linear motion.

Linear bearings and guide rods: Ensure smooth, accurate movement.

3. Extruder Assembly

The extruder is responsible for melting and depositing the recycled filament:

Hot end: Heats the filament to its extrusion temperature.

Nozzle: Shapes the molten filament into a consistent diameter.

Drive gear and stepper motor: Push the filament into the hot end.

Cooling fan: Solidifies the deposited filament layers rapidly.

4. Heated Bed

A heated build platform improves first-layer adhesion and reduces warping, especially when printing with thermoplastics like PET. The bed temperature is controlled via an integrated thermistor and heating element.

5. Control System

The printer uses an Arduino-based microcontroller combined with a compatible motor driver shield (e.g., RAMPS 1.4):

- Controls stepper motor movement along all axes.
- Regulates temperature of the extruder and heated bed.
- Interprets G-code instructions generated from 3D models.

6. Power Supply

A dedicated power supply unit provides regulated voltage and current to all components, including motors, heaters, and the control board.

7. Filament Feed Mechanism

The recycled filament spool is mounted on a holder and guided into the extruder assembly. The feed system ensures smooth and continuous delivery of filament to maintain print consistency.

8. User Interface

The printer can include a simple LCD display and control knob or touchscreen, allowing users to select print files, adjust temperatures, and control printing operations manually.

6. WORKING PRINCIPLE

The working principle of the recycled-filament-based 3D printer can be understood as a two-stage process, comprising (1) production of recycled thermoplastic filament and (2) additive manufacturing using Fused Deposition Modeling (FDM). Each stage involves multiple critical steps that ensure material quality, precision, and consistency in the final printed products.

6.1. FILAMENT PRODUCTION FROM RECYCLED THERMOPLASTICS

6.1.1. Collection and Sorting

The first step involves the collection of post-consumer thermoplastic waste, predominantly polyethylene terephthalate (PET), which is widely available in bottles, packaging materials, and containers. Proper sorting is critical to remove non-PET plastics and contaminants such as metal caps, labels, or colored plastics that may affect the extrusion process or degrade filament quality.

6.1.2. Cleaning and Drying

The collected PET is thoroughly washed using water and mild detergents to remove residues, adhesives, and dust. Residual moisture is a significant concern because the presence of water in PET can cause hydrolysis during melting, resulting in bubbles, inconsistent filament diameter, and poor mechanical properties. To prevent this, the cleaned PET flakes are dried in a low-temperature oven or air-dried until moisture content is reduced below 0.1–0.2% by weight.

6.1.3. Shredding and Size Reduction

After cleaning, PET bottles are mechanically shredded into small, uniform flakes. Shredding serves multiple purposes:

Increases surface area for uniform heating during extrusion.

Facilitates consistent feeding into the extruder screw.

Reduces clogging and ensures continuous filament production.

Uniform flake size is essential to prevent localized overheating or uneven extrusion.

6.1.4. Filament Extrusion

The shredded PET flakes are fed into a filament extruder equipped with a screw-based feeding system and a heating barrel. The extruder melts the flakes at temperatures typically between 250–280 °C, which is optimal for PET. The heater, usually a cartridge or band heater, ensures uniform thermal distribution along the barrel to avoid thermal degradation or color changes in the filament.

The molten plastic is then forced through a precision nozzle, which determines the filament diameter. Standard nozzle diameters are 1.75 mm or 3 mm, with a tolerance of ± 0.05 mm to maintain consistent feeding during 3D printing.

6.1.5. Cooling and Diameter Control

Immediately after extrusion, the filament passes through a cooling system, such as a water bath or air-cooled guides, to solidify the material while preserving the cross-sectional diameter. Uniform cooling is crucial to prevent warping, ovality, or internal stresses. Optical sensors or laser micrometers are often used to monitor filament diameter in real-time.

6.1.6. Spooling / Re-rolling

The solidified filament is collected onto a motorized spool with controlled tension. Proper spooling prevents tangling, maintains filament uniformity, and ensures smooth feeding into the 3D printer. The speed of the spool is synchronized with the extrusion rate to maintain constant filament diameter.

6.2. 3D PRINTING USING RECYCLED FILAMENT

The second stage of the system focuses on layer-by-layer additive manufacturing using the recycled PET filament.

6.2.1. Filament Feeding and Extruder Assembly

The spooled filament is mounted on the printer and guided into the extruder assembly, consisting of:

Drive gear and stepper motor: Push the filament into the hot end at a controlled rate.

Hot end: Heats the filament to the extrusion temperature (250–270 °C for PET).

Nozzle: Shapes and deposits molten filament on the build surface.

Cooling fan: Solidifies layers rapidly to maintain dimensional accuracy.

The feed rate of the filament is controlled to match the movement of the print head, ensuring consistent layer thickness and avoiding over- or under-extrusion.

6.2.2. Motion Control System

The printer employs stepper motors and linear motion mechanisms (lead screws or belt-pulley systems) to precisely position the extruder along the X, Y, and Z axes. The motion system ensures:

Accurate placement of each deposited filament line.

Uniform layer height, critical for mechanical integrity.

Smooth surface finish of the printed object.

The stepper motors are controlled via an Arduino-based controller with a motor driver shield (e.g., RAMPS 1.4). The controller interprets G-code generated from 3D models, converting it into precise motor commands for movement and extrusion.

6.2.3. Heated Bed and Adhesion

A heated bed is used to prevent warping and improve the adhesion of the first layer, especially important for PET, which is prone to shrinkage during cooling. The bed temperature is usually maintained around 70–100 °C. Proper adhesion prevents defects such as curling or layer separation.

6.2.4. Layer-by-Layer Deposition

The printer deposits filament layer by layer in a controlled path as defined by the sliced CAD model. Each layer is immediately cooled by the fan to solidify the filament while preserving inter-layer bonding. PET's mechanical properties allow strong bonding between layers if the temperature and print speed are optimized.

6.2.5. Process Optimization

Key printing parameters influencing quality include:

Extrusion temperature: Ensures proper melting without degradation.

Print speed: Balances surface finish and mechanical strength.

Layer height: Determines resolution and dimensional accuracy.

Cooling rate: Controls warping and surface smoothness.

Optimizing these parameters ensures that the final printed object maintains dimensional accuracy, strength, and surface quality comparable to conventional filament.

6.3. INTEGRATION OF FILAMENT PRODUCTION AND PRINTING

The system demonstrates complete recycling-to-production integration:

Plastic waste is converted into high-quality filament.

The filament is directly used in the FDM printer without chemical modification.

Continuous monitoring and control ensure that both filament and printed parts meet quality standards.

This integration highlights a sustainable manufacturing workflow that reduces plastic waste, lowers material costs, and provides an eco-friendly solution for rapid prototyping and small-scale production.

7. ADVANTAGES

The design and fabrication of a 3D printer using recycled thermoplastic filament offers several significant benefits, particularly in terms of sustainability, cost-effectiveness, and versatility:

Reduction of Plastic Waste

By converting post-consumer PET bottles and packaging materials into usable filament, the system helps mitigate environmental pollution caused by plastic waste, contributing to a circular economy.

Cost-Effective Filament Production

Producing filament from recycled materials significantly lowers the cost compared to commercial 3D printing filaments, making additive manufacturing more accessible for educational, hobbyist, and small-scale industrial applications.

Environmentally Friendly Manufacturing

The integration of waste recycling with 3D printing reduces the reliance on virgin plastic, minimizes landfill accumulation, and decreases carbon footprint associated with conventional filament production.

Customizable and Low-Cost Printer Design

The printer uses an open-source, Arduino-based control system and readily available mechanical components, allowing easy modification and maintenance, while keeping production costs low.

Educational and Research Applications

The project provides a practical learning platform for students and researchers, offering hands-on experience in material recycling, filament production, and additive manufacturing processes.

Sustainable Prototyping and Fabrication

The system allows rapid prototyping of functional parts using recycled materials, demonstrating that sustainable manufacturing can meet practical industrial and personal requirements without compromising print quality.

Scalable and Replicable

The methodology and printer design can be scaled up or adapted for other types of recyclable thermoplastics, enabling broader applications in small-scale manufacturing and community-level recycling initiatives.

8. APPLICATIONS

The 3D printer fabricated using recycled thermoplastic filament has diverse applications across educational, industrial, and personal domains:

Rapid Prototyping

The system enables fast fabrication of prototype models and functional parts, allowing designers and engineers to test concepts and iterate designs quickly at low cost.

Educational Projects

It serves as an effective teaching and learning tool for students in engineering, materials science, and environmental studies, providing hands-on experience in additive manufacturing and plastic recycling.

Small Mechanical Parts Fabrication

The printer can produce small, customized mechanical components for hobbyist projects, repair applications, or small-scale manufacturing needs.

Sustainable Manufacturing

By utilizing recycled thermoplastic filament, the printer promotes eco-friendly production practices, reducing reliance on virgin materials and lowering environmental impact.

Personal and Commercial 3D Printing

Individuals and small businesses can use the printer for creating models, customized objects, tools, or artistic products, demonstrating the versatility of recycled filaments.

Community and Research Initiatives

The system can support community-level recycling programs and research projects focusing on sustainable materials, circular economy, and innovative 3D printing methods.;

9. CONCLUSION

This project demonstrates the feasibility of integrating plastic waste recycling with additive manufacturing by designing and fabricating a low-cost FDM 3D printer that operates using filament produced from recycled thermoplastic materials. The work highlights how post-consumer plastics, such as PET bottles, can be converted into high-quality filament, enabling sustainable and cost-effective 3D printing.

The study illustrates that recycled filaments can achieve satisfactory print quality, dimensional accuracy, and mechanical performance for prototyping and small-scale applications. Beyond material savings, the project emphasizes the environmental and educational benefits of promoting circular economy practices in manufacturing.

Overall, this work provides a conceptual framework for eco-friendly, affordable, and scalable 3D printing solutions, encouraging further research into sustainable materials, process optimization, and wider adoption of recycled filaments in industrial and community applications.

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