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DESIGN AND DEVELOPMENT OF A MODULAR 3D-PRINTED EXTRUDER FOR RECYCLED PET FILAMENT PRODUCTION

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ABSTRACT

This paper presents the design, fabrication, and functional validation of a low-cost, modular extruder system capable of converting manually cut PET-bottle strips into 3D-printing filament. The extruder is composed of 3D-printed structural elements, a metal heating barrel, a digital thermostat with an ON/OFF control, and a direct-drive 12 V DC motor for material feeding. The heating profile was stabilized at 230 °C to ensure proper melting and extrusion. The resulting system successfully produced filament of consistent diameter, suitable for non-load-bearing applications. This work demonstrates the feasibility of decentralized, small-scale PET recycling using accessible components and open-source design principles, contributing to circular-economy practices in the context of Fused Deposition Modeling (FDM).

KEYWORDS: PET recycling, 3D printing, modular extruder, additive manufacturing

1. Introduction

The global growth of additive manufacturing (AM) has sparked increasing interest in sustainable material sourcing and localized recycling systems. Among the various AM technologies, Fused Deposition Modeling (FDM) stands out as the most accessible technique, especially among desktop 3D printers. A particularly promising strategy involves repurposing post-consumer polyethylene terephthalate (PET) into filament for material extrusion processes [1-3]. This approach not only mitigates plastic waste but also supports circular-economy objectives by reintroducing consumer materials into manufacturing workflows [4, 5].

Open-source initiatives such as the RecycleBot and Lyman extruder have demonstrated that it is feasible to process PET waste into printable filament using compact, modular systems [6-8]. These decentralized recycling setups often rely on low-cost components and 3D-printed structures, enabling affordable deployment in educational and research environments [5, 6]. The democratization of both recycling and fabrication technologies is further supported by distributed manufacturing models and community-based innovation [9, 10].

Despite these advancements, recycled PET presents significant challenges related to material degradation, process variability, and geometric instability. Thermal degradation during extrusion, poor melt flow, and inconsistent feedstock properties often result in uneven filament diameter and reduced mechanical performance [11-13]. Inadequate temperature control can further amplify these issues, leading to unreliable output and increased porosity in printed parts [14, 15].

Recent research has focused on developing modular extruder architectures with digital temperature regulation, interchangeable components, and integrated feedback systems that allow fine-tuning of processing conditions [16, 17]. Thermal management is particularly important: non-uniform heat distribution across the extrusion assembly can cause premature chain scission and diminished filament quality [18]. Advanced design methodologies - including thermal imaging and simulation - are increasingly employed to optimize heating profiles and improve thermal stability within open-source extruders [19].

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This paper presents a low-cost, 3D-printed extruder designed for processing manually cut PET strips from recycled bottles into 1.75 mm filament. The system incorporates distributed heating, a modular guiding mechanism, and feedback-based temperature control. Emphasis is placed on design accessibility, thermal consistency, and extrusion repeatability – all essential features for expanding decentralized PET recycling in FDM printing ecosystems.

2. Experimental Procedure

This study focused on the design and fabrication of a modular extrusion system, with an emphasis on the development of 3D-printed structural components enabling the processing of recycled PET strips. The process followed four main stages: design in CAD software, additive manufacturing (FDM) of the components using PLA filament, mechanical assembly, and functional validation. The printed parts include the main support structure, PET strip guide, cartridge heater mount, control unit enclosure, and feed alignment system. These components were designed for ease of assembly, low material usage, and functional modularity. Standard off-the-shelf hardware - such as threaded rods, screws, and bearings - was used to complete the mechanical structure.

The modular extruder developed in this study combines 3D-printed structural elements and standard off-the-shelf components, designed to facilitate the low-cost production of PET filament from manually cut plastic strips. The main structure of the system was fabricated entirely through Fused Deposition Modeling (FDM) using PLA filament, and it includes a printed front panel designed to host all user interface elements. This panel integrates slots and mounting features for a digital thermostat module (W1209-type), a dual digital display for voltage and temperature, ON/OFF toggle switches for activating the motor and heating element, as well as a rotary dial for adjusting the motor speed.

A rear panel, also 3D-printed, incorporates ventilation slots to allow passive airflow and prevent overheating of internal components. Internally, the printed housing features dedicated channels for cable routing, as well as support structures for securely mounting electronic modules. Threaded insert cavities were included in key locations to allow the use of metal screw inserts, enhancing mechanical durability where repeated assembly is required.

A custom-designed filament guide system, also printed in PLA, ensures stable feeding and alignment of PET strips into the extrusion barrel. The system operates at a fixed working temperature of 230 °C, which was selected based on preliminary tests for stable PET extrusion. At the extrusion point, the setup includes a replaceable nozzle (primarily 1.75 mm) mounted at the end of the heating barrel, allowing for control over filament output diameter. This arrangement enables continuous filament formation suitable for non-load-bearing 3D printing applications.

Overall, the extruder's design emphasizes modularity, simplicity, and accessibility, making it a functional platform for testing recycled thermoplastic processing in distributed or educational settings.

3. Results and Discussion

The developed modular extruder system was evaluated primarily in terms of design feasibility, component integration, and functional operation. A significant emphasis of this study was placed on the physical construction and validation of a fully operational extrusion system composed of 3D-printed structural elements and low-cost off-the-shelf hardware. All major parts - housing, feed guide, PET strip holder, and component mounts - were printed using standard PLA and assembled with minimal post-processing. This approach demonstrates the potential of additive manufacturing in creating low-cost, customizable fabrication tools, in line with open-hardware principles [5-7].

The extruder was successfully assembled and commissioned with a digital thermostat module providing ON/OFF temperature control. Thermal insulation and spatial separation of heat zones were carefully considered in the design phase. The working temperature was set to 230 °C, which falls within the optimal processing range for PET [11, 12]. The system was able to operate continuously for up to 30 minutes without experiencing jamming, overheating, or misalignment. Manually cut PET strips - sourced from post-consumer transparent bottles - were loaded via the printed guide system. Although no forced drying step was applied, the strips performed adequately during extrusion, suggesting that short-term drying may suffice for small-batch tests.

The resulting filament had a visually consistent appearance and a diameter averaging 1.75 ± 0.08 mm, measured with a digital calliper. While not calibrated to commercial tolerances, this consistency is considered sufficient for non-load-bearing prints or prototyping purposes, as supported by similar studies [9, 14]. Additionally, the use of 3D-printed parts contributes to lightweight construction, easier customization, and lower fabrication costs.

Although this study focused primarily on hardware development and assembly validation, future improvements will involve integrating active cooling, automated filament spooling, and advanced sensors for temperature and diameter feedback.

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Functional validation was carried out through full system assembly, thermal stability testing at 230 °C, manual PET feeding, visual extrusion assessment, and filament diameter measurements using a digital calliper - confirming basic operational reliability under real-use conditions.

Figure 1 shows the fully assembled front control panel of the modular extruder. The enclosure is entirely 3D-printed and includes designated slots for each electronic interface component. The panel integrates a digital temperature display, a voltmeter/ammeter display, and on/off buttons for the heating element and motor. The printed geometry reflects ergonomic and modular design principles that facilitate easy assembly and component replacement.

***Fig. 1.** Front control panel - printed view*

Figure 2 shows the front control panel in a partially assembled state. It reveals the internal cable-routing channels, modular mounting brackets, and housing compartments for electronic modules. This figure illustrates how the structural design supports both mechanical stability and ease of wiring during installation.

***Fig. 2.** The control panel during assembly*

Figure 3 highlights the cavity designed to host metallic threaded inserts. These inserts are useful for enhancing the mechanical fastening strength of the 3D-printed PLA components, particularly in areas subject to repeated assembly and disassembly.

***Fig. 3.** Threaded insert - section view*

The completed assembly of the front panel with the thermostat module installed is depicted in Figure 4. The digital thermostat enables precise control of the barrel temperature. The alignment of the thermostat within the enclosure ensures easy access for user operation and clear visibility of temperature readings.

***Fig. 4.** The front panel with thermostat module installed*

Figure 5 presents a close-up of the rotary speed control dial, installed in its dedicated housing. This control allows manual adjustment of the DC motor rotation speed, which directly influences the feed rate of the PET strip through the extruder. The dial's integration into the PLA enclosure showcases functional design tailored for user interactivity.

***Fig. 5.** Speed control switch motor interface*

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Figure 6 shows the installed digital control unit combining a toggle switch and a monitoring display. This unit provides real-time feedback on voltage and temperature, essential for safe operation and process stability. Its location in the panel is optimized for quick access and readability.

Fig. 6. *ON/OFF switch with display fully installed*

Figure 7 illustrates the PLA-printed rear housing, which includes ventilation slots for heat dissipation. These airflow pathways help regulate the internal temperature of the control chamber, prolonging the lifespan of the electronics and reducing the risk of thermal buildup.

Fig. 7. *The rear panel with cooling openings 3D printed PLA*

The mechanical clip system designed for rapid assembly/disassembly, essential for modular maintenance and upgrades, is presented in Figure 8. The system consists of printed hooks and slots engineered to maintain alignment and structural integrity without tools, making module replacement quick and tool-free.

Fig. 8. *The side view of the locking system 3D printed*

Figure 9 shows the filament spool support used in the extrusion module. It includes a large printed gear mounted concentrically with the spool, allowing optional coupling with rotation monitoring or assisted feeding mechanisms. The support structure was custom-designed and fabricated using PLA to ensure strength and stability.

Fig. 9. *3D-printed spool holder with integrated gear ring*

A custom bracket for securing axial fans near the heated zone, ensuring stable thermal control during operation is presented in Figure 10. This bracket ensures proper airflow over the extrusion barrel, maintaining temperature stability and preventing overheating during continuous filament production.

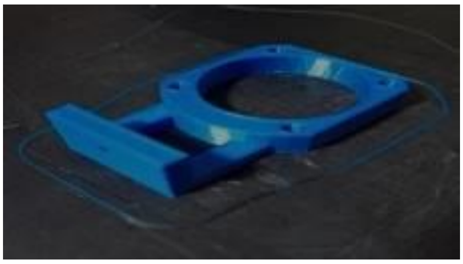

Fig. 10. *The ventilation fan support 3D printed*

A 3D-printed alignment bracket designed to guide manually cut PET strips into the extruder intake is presented in Figure 11. The component ensures proper positioning and stability of the feed material during operation, reducing the risk of misalignment or jamming at the input stage.

Fig. 11. *PET strip guide bracket*

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Figure 12 illustrates the large gear blank used in the extrusion drive module. This component was 3D printed using PLA and features a flat circular profile with a central bore, intended to be mounted on a keyed shaft. Although shown before finishing and integration, the gear is designed to transmit torque from the motor to the feeder mechanism, working in conjunction with a smaller interlocking gear within the gearbox assembly. The printed geometry reflects the custom adaptability provided by additive manufacturing in creating functional transmission parts with tight dimensional tolerances.

Fig. 12. *3D-printed large gear blank for the extrusion drive assembly*

Figure 13 shows the interface fully mounted and wired. It features a temperature display, adjustment buttons, and a power switch. The figure emphasizes ergonomic layout and visibility, ensuring intuitive use and quick operator feedback.

Fig. 13. *The display interface and switch installed*

A detailed close-up of the digital panel is shown in Figure 14, displaying real-time temperature and voltage data. This visual feedback is essential for maintaining consistent operating parameters and for detecting any system faults promptly.

Fig. 14. *The digital monitoring panel close-up*

A complete perspective of the extruder system in its operational configuration is depicted in Figure 15. All subsystems, including the control panel, extrusion barrel, drive system, and filament guiding module, are integrated. The modular design facilitates component swapping and compact desktop use.

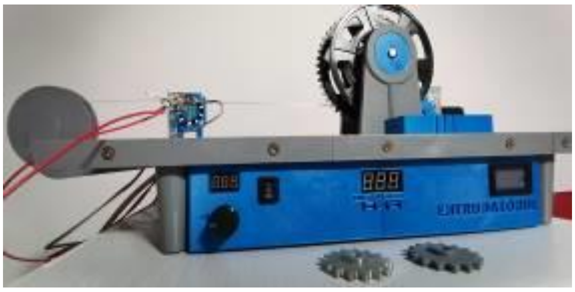

Fig. 15. *The extruder system assembled view*

4. Conclusions

This paper presented the design, fabrication, and functional validation of a modular extrusion system capable of processing manually cut PET strips into 3D printing filament. Emphasis was placed on mechanical modularity, ease of assembly, and the use of 3D-printed structural components alongside low-cost electronics and hardware.

Functional testing demonstrated that the extruder could operate continuously at a working temperature of 230 °C without jamming or thermal instability. The resulting filament showed stable diameter and surface quality, suitable for further evaluation in non-critical 3D printing applications. The findings support the feasibility of repurposing PET waste into usable filament using open-source, low-cost extruder designs.

The modular system provides a scalable and replicable platform for small-scale recycling, making it appropriate for academic, research, and community-based settings. In the educational domain, this extruder can serve as a hands-on tool for learning about material processing, thermal management, and digital manufacturing. Its customizable, open design encourages adaptation for various experimental and eco-design projects aligned with circular economy principles.

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