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DEVELOPMENT OF A PLASTIC BOTTLE WASTE PROCESSING TOOL INTO 3D PRINTER FILAMENT BASED ON ARDUINO MICROCONTROLLER

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Abstrak. Limbah botol plastik merupakan salah satu penyumbang terbesar pencemaran lingkungan karena sulit terurai secara alami. Untuk mengurangi dampak tersebut, penelitian ini mengembangkan alat pengolah limbah botol plastik menjadi filamen printer 3D berbasis mikrokontroler Arduino. Pengembangan alat dilakukan menggunakan metode ADDIE (Analysis, Design, Development, Implementation, Evaluation) dengan tahapan analisis kebutuhan, perancangan sistem, pembuatan prototipe, implementasi, dan evaluasi kinerja. Sistem dirancang dengan integrasi sensor suhu MAX6675, elemen pemanas, motor penggerak, serta mekanisme pendinginan dan penggulung. Pengujian meliputi kalibrasi sensor suhu menggunakan thermogun sebagai pembanding pada rentang 150 °C hingga 250 °C. Hasil kalibrasi menunjukkan hubungan linear dengan deviasi pembacaan antara −4,30 °C hingga −3,50 °C yang dapat dikoreksi melalui regresi linear. Prototipe mampu menghasilkan filamen dari limbah botol PET dengan kualitas stabil dan diameter mendekati standar komersial. Hasil penelitian ini menunjukkan bahwa alat yang dikembangkan efektif untuk mendukung proses daur ulang plastik skala kecil secara efisien.

Abstract. *Plastic bottle waste is one of the major contributors to environmental pollution due to its non-biodegradable nature. To address this issue, this study developed a plastic bottle waste processing tool into 3D printer filament based on an Arduino microcontroller. The development process employed the ADDIE method (Analysis, Design, Development, Implementation, Evaluation), consisting of need analysis, system design, prototype development, implementation, and performance evaluation. The system integrates a MAX6675 temperature sensor, heating element, driving motor, and a cooling and winding mechanism. Sensor calibration was conducted using a thermogun as a reference within the temperature range of 150 °C to 250 °C. The calibration results showed a linear relationship with a deviation of −4.30 °C to −3.50 °C, which can be corrected through linear regression. The prototype successfully produced filament from PET bottle waste with stable quality and a diameter close to commercial standards. These findings indicate that the developed tool effectively supports small-scale plastic recycling processes.*

1. INTRODUCTION

Plastic bottle waste has become one of the largest contributors to global environmental pollution. The widespread use of PET plastic bottles in the beverage and packaging industries has resulted in a significant accumulation of non-biodegradable waste, causing serious environmental problems. Conventional waste management methods, such as landfilling and incineration, often generate secondary environmental impacts, including greenhouse gas emissions and soil contamination. Meanwhile, the potential to convert PET plastic bottles into valuable materials remains underutilized. In recent years, 3D printing technology has opened new opportunities to recycle PET plastic waste into filament materials for additive manufacturing [1], [2]. However, most recycling technologies are still costly, complex, and not widely accessible for small-scale or community-level applications [3]. This gap highlights the urgent need for a low-cost, simple, and efficient system for processing plastic bottles into 3D printer filament.

The conversion of plastic bottle waste into 3D printer filament involves several key processes, including shredding, heating, extrusion, and filament spooling. These processes require accurate control to maintain filament diameter consistency and quality suitable for 3D printing applications. Existing machines developed in previous studies have demonstrated the feasibility of transforming PET plastic into usable filament but are often limited by high production costs or lack of automation [4], [5]. Moreover, inadequate control systems lead to unstable extrusion temperatures and inconsistent filament outputs, reducing the quality of the final product [6]. Affordable and user-friendly technology is therefore essential to support small industries, educational institutions, and maker communities in promoting sustainable production practices [7]. Developing this technology would contribute not only to waste reduction but also to the growth of the circular economy.

Technological advancements in microcontrollers, particularly Arduino, provide a potential solution for developing an integrated plastic bottle waste processing tool. Arduino-based systems enable real-time temperature control, motor actuation, and process monitoring at a low cost [8]. This approach allows more precise filament extrusion control, improving output stability and reducing human intervention during operation. Several studies have shown that Arduino-based systems can effectively automate the extrusion process and optimize the performance of heating and cutting components. Furthermore, integrating automatic sorting and sensor-based control systems can enhance the reliability of the recycling process [9]. Thus, the development of a low-cost, Arduino-based plastic bottle waste processing tool can be an effective strategy to support sustainable manufacturing and reduce the environmental impact of plastic waste.

This study aims to develop a plastic bottle waste processing device using an Arduino microcontroller as the main control system. The device is designed to regulate heating temperature, control a stepper motor for filament pulling, and manage the cooling and spooling process automatically and precisely. The use of Arduino is expected to enhance temperature stability and filament diameter accuracy, resulting in recycled filament quality comparable to commercial products. This approach provides a cost-effective and accessible solution for communities, educational institutions, and small industries [10]. Moreover, the research represents a strategic effort to reduce dependence on commercial filaments and minimize the accumulation of non-biodegradable PET plastic bottle waste, thereby supporting sustainable environmental management [11].

2. LITERATURE REVIEW

2.1. Plastic Bottle Waste

Plastic waste has emerged as one of the most critical environmental challenges in the modern era. Among various types of plastic, polyethylene terephthalate (PET) bottles contribute significantly to the accumulation of non-biodegradable waste, particularly in urban areas. Improper disposal of these bottles has caused serious environmental impacts, including soil degradation, waterway blockages, and long-term pollution due to their slow decomposition rate. Conventional waste management strategies such as landfilling and incineration are no longer sustainable solutions, as they create secondary environmental issues and require extensive resources. As a result, alternative approaches that promote recycling and resource recovery have become essential in addressing this growing problem [12], [13]. PET plastic bottles offer high recyclability and physical durability, making them suitable for various innovative applications.

Over the past decade, several studies have explored the potential reuse of plastic bottle waste in various fields, including construction, geotechnical engineering, and transportation infrastructure. Reusing plastic bottles in building materials, soil stabilization, and asphalt modification has proven to be an effective way to reduce plastic waste while supporting sustainable development goals [14]. These applications demonstrate the versatility and potential of PET waste as a valuable secondary raw material. However, despite these advancements, the transformation of plastic bottle waste into higher-value products remains limited. Most existing recycling methods still require complex industrial processes and are not accessible to small-scale users or educational settings. This gap presents a significant opportunity for developing more affordable and practical recycling technologies [15].

The growth of additive manufacturing technology has created a new pathway for utilizing recycled PET waste as 3D printer filament. Converting plastic bottles into filament can reduce dependency on commercial filament, which is often expensive, while simultaneously addressing environmental issues related to waste accumulation. However, current low-cost extrusion systems face challenges in maintaining precise temperature control, consistent filament diameter, and stable feeding mechanisms. These technical limitations reduce the quality and usability of the recycled filament for practical 3D printing applications [16], [17]. Therefore, it is necessary to develop a low-cost, efficient, and automated recycling system using microcontroller-based technology to enhance process accuracy and product quality. An Arduino-based control system has strong potential to enable precise regulation of temperature and motor control, making it suitable for small-scale filament production and sustainable plastic waste management..

2.2. 3D Printer Filament

Plastic waste, particularly polyethylene terephthalate (PET) bottles, has become a major contributor to global environmental pollution. Due to its high durability and resistance to degradation, PET waste often accumulates in landfills and natural ecosystems, leading to serious ecological impacts. Conventional disposal methods, such as landfilling and incineration, are no longer sustainable solutions because they consume large resources and generate harmful byproducts. Recent developments in sustainable manufacturing have encouraged the transformation of PET waste into valuable products, including 3D printing filament, as an alternative strategy to reduce environmental impact [18], [19].

The integration of PET waste recycling with 3D printing technology offers a promising pathway toward a circular economy. PET bottles can be processed into high-quality 3D printing filaments, reducing dependency on commercial filaments while minimizing plastic pollution. However, current recycling processes are often complex, energy-intensive, and costly, making them less accessible for small-scale applications. This challenge highlights the need for an affordable and automated processing system that can efficiently convert PET waste into functional 3D printing filament [20], [21]. Such innovation can support sustainable production practices while addressing the global issue of plastic waste accumulation.

2.3. Heating and Extrusion

The rapid growth of 3D printing technology has significantly increased the demand for high-quality and stable filaments, especially in material extrusion systems. The extrusion process requires precise control of heating and flow behaviour in the liquefier zone to ensure filament uniformity and dimensional accuracy [22]. However, current filament production often faces problems such as unstable heat distribution, inconsistent extrusion rates, and poor temperature regulation at the hot end, which affect printing performance and product quality [23]. These technical issues become more critical when recycled plastic materials are used as filament feedstock, as their thermal behaviour is less predictable than virgin polymers. Therefore, it is essential to develop a reliable and efficient system to optimize the thermal and flow characteristics of the filament production process [24].

Figure 1. 3D printer extruder heating element

One of the main engineering challenges in designing a plastic bottle waste processing tool into 3D printer filament is achieving uniform melting and stable flow during extrusion. The extrusion head must maintain a controlled temperature and steady pressure to ensure proper filament diameter and smooth output [25]. Without proper thermal management, problems such as clogging, overheating, or uneven extrusion can occur, leading to low-quality filament and inefficient production. Integrating a microcontroller-based control system provides better regulation of heating elements and extrusion mechanisms, enabling more accurate process control. This approach supports sustainable manufacturing by transforming plastic bottle waste into usable filament with consistent quality and performance.

2.4. Arduino Microcontroller

The integration of microcontroller technology in the development of filament-making machines has become an effective approach to automate the conversion of PET bottle waste into 3D printer filament. Arduino can be used to control the heating system automatically through temperature regulation [26]. Several studies have focused on designing low-cost machines that utilize heating and extrusion mechanisms controlled by microcontrollers to ensure stable filament diameter and flow [1], [2]. The application of Arduino-based systems enables precise temperature regulation, motor control, and cutting mechanisms to produce consistent filament quality [3]. This method not only improves the production process but also reduces human error and operational complexity. Furthermore, automation facilitates efficient recycling practices, turning plastic waste into usable resources for additive manufacturing.

Figure 2. Arduino microcontroller

Various designs of automated extrusion machines demonstrate that microcontroller-based systems can control heating elements, extrusion speed, and filament tension in real time [7], [8]. Stepper motors and temperature sensors are commonly used to maintain a steady extrusion flow and prevent clogging during the filament production process. Arduino microcontrollers are particularly suitable due to their low cost, flexible programming, and ease of integration with other components. These features enable more accurate thermal control and consistent filament diameter, which are critical factors in 3D printing performance. Sensor-based systems can also support automatic sorting and monitoring of PET inputs before extrusion [8].

Recent research has also highlighted the importance of combining microcontrollers with automated heating and cooling modules to enhance production efficiency and sustainability [10]. By using programmable temperature control and stepper motor regulation, the extrusion system can maintain optimal conditions for PET processing. This technological approach supports the circular economy by providing an alternative to virgin filament production. In addition, microcontroller-based machines are scalable and adaptable for small-scale manufacturing, enabling broader access to sustainable 3D printing practices [13]. Therefore, the application of microcontrollers in filament production offers a promising pathway toward efficient, low-cost, and environmentally friendly recycling solutions.

3. METHODOLOGY

3.1. Method

This research adopts the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) as the methodological framework for developing a plastic bottle waste processing system into 3D printer filament. In the analysis stage, the main problems identified are the growing accumulation of plastic bottle waste and the high cost of commercial filaments, highlighting the need for an affordable and eco-friendly solution. In the design stage, the system integrates an extrusion mechanism, a heating unit, temperature sensors, and a stepper motor–based pulling system, with the Arduino microcontroller serving as the central control unit. This structured development approach ensures that each phase contributes to creating an efficient, practical, and educational tool for sustainable technology implementation [27].

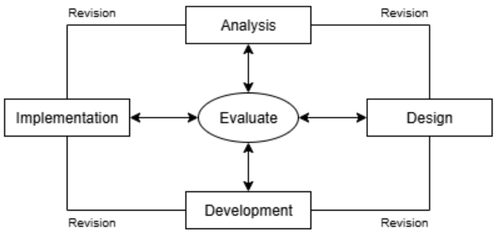

Figure 3. ADDIE model

The development stage focuses on creating a prototype that combines hardware and software to ensure that the extruder, heating process, and motorized pulling system work in coordination under Arduino control. The implementation stage is carried out by operating the prototype to process plastic bottle waste into 3D printer filament. At this stage, the Arduino microcontroller regulates heating stability, pulling speed, and alignment to ensure uniform diameter and consistent filament quality. Finally, in the evaluation stage, the filament produced is tested for its physical quality, consistency, and usability in 3D printing applications. The overall system performance is also assessed to determine its effectiveness in reducing plastic waste while providing an alternative filament source. Through the application of the ADDIE model, the implementation of the Arduino microcontroller in plastic bottle waste processing is systematically developed and evaluated, resulting in a structured and reliable approach to producing sustainable 3D printer filament.

3.2. System Design

The 3D printer filament production system from recycled plastic bottles was developed using an Arduino Uno microcontroller as the central control unit. The microcontroller receives sensor data, processes signals, and coordinates the operation of all connected actuators. A MAX6675 thermocouple sensor is integrated to accurately measure the temperature of the extruder during the heating process. This sensor is connected through a dedicated thermocouple driver module to ensure precise and stable data transmission. The temperature values are displayed in real time on a 16x2 LCD, enabling continuous monitoring of system performance. The overall control structure of the system is illustrated in Figure 4, which shows the block diagram of the developed system. This configuration provides a reliable feedback mechanism that supports stable and controlled filament extrusion.

An automatic temperature control mechanism is implemented using a relay module that functions as a switch to regulate the heater. When the measured temperature is below the predefined threshold, the Arduino activates the relay to turn on the heating element. Conversely, when the temperature exceeds the set point, the relay disconnects the power supply to maintain thermal stability. This feedback control ensures that the extrusion process operates at an optimal and constant temperature. Maintaining consistent heating conditions is essential to achieve uniform filament diameter and improve the overall extrusion quality.

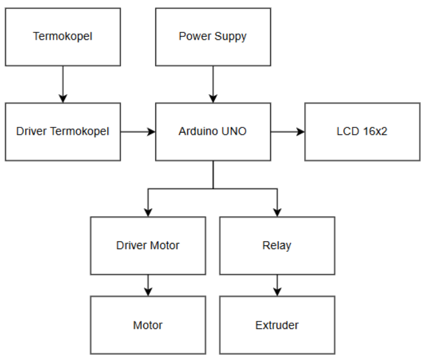

Figure 4. The block diagram of the developed system

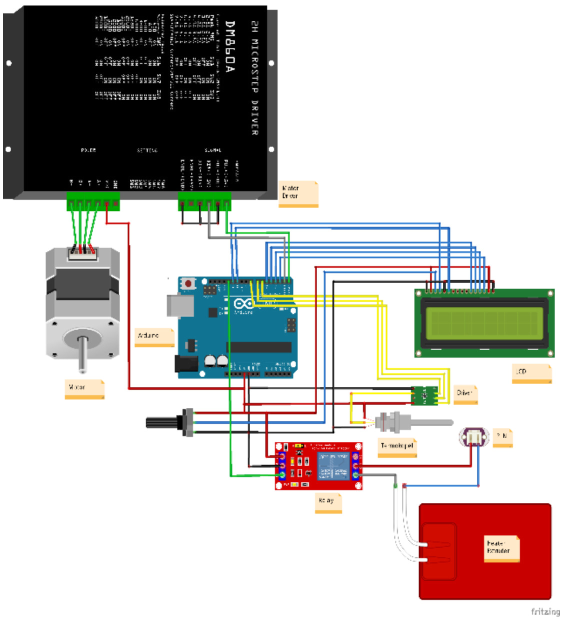

Figure 5. Wiring diagram of microcontroller circuit for 3D printer filament production process

The mechanical part of the system utilizes a stepper motor controlled by a DM860A motor driver to handle the winding process. The Arduino generates pulse signals to the driver, which regulates the motor's speed and rotation direction. The stepper motor precisely winds the extruded filament into organized rolls, ensuring consistent spooling tension and alignment. The detailed wiring configuration of the system is presented in Figure 5, which illustrates the connection between the Arduino, sensor, relay, motor driver, and LCD module. The integration of motor control with temperature regulation enables synchronized and automated operation. This combination establishes a cost-efficient, stable, and sustainable filament production system based on recycled plastic bottles and microcontroller-based control

3.3. The Manufacturing Process of 3D Printer Filament

The production process of 3D printer filament from discarded plastic bottles begins with the cleaning or sterilization stage. In this step, the bottles are thoroughly washed to remove dirt, labels, and residual liquids, ensuring clean and sterile raw materials. This is followed by the drying process and material shaping using a hot gun to flatten the bottom surface of the bottles. Once the surface is flattened, the bottles are cut at the bottom with a thickness of approximately 1 cm. The cut material is then processed using a cutter blade and bearing adjusted to a thickness of 1 cm, producing small flakes that are easier to melt.

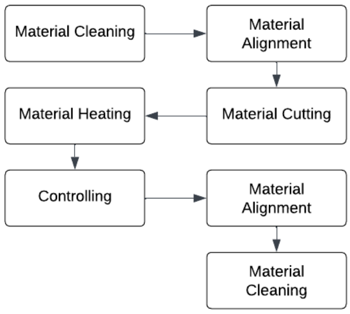

Figure 6. The process of processing used plastic bottles into 3D printer filament.

The next stage is material heating, in which the plastic flakes are melted using an extruder equipped with a ceramic heater, producing filament with a standardized diameter of 1.75 mm in accordance with 3D printing applications. This heating process is precisely controlled by an Arduino-based microcontroller system, which regulates the heating temperature, stepper motor speed, and filament diameter consistency. The heater temperature is further monitored using a DHT11 sensor to ensure process stability. Following extrusion, the filament undergoes a cooling stage using a DC fan to gradually reduce the material temperature.

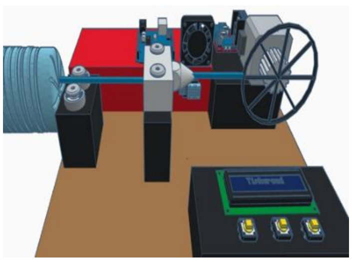

Figure 7. Design of a device for processing used bottles into 3D printer filament using the Thinker cad application

Subsequently, the filament is automatically wound with the aid of a stepper motor and winding gearbox. Before being stored as a ready-to-use spool, a final cleaning step is carried out to ensure that the filament is free from impurities or foreign particles that may affect print quality. Through this integrated process, non-biodegradable plastic bottles are successfully transformed into high-value 3D printer filament. The resulting recycled filament not only provides a practical and cost-effective alternative to commercial filaments but also represents a sustainable solution for reducing environmental pollution caused by plastic waste.

4. RESULT AND DISCUSSION

4.1. Result

The results of the developed tool are illustrated in Figure 8, which shows the complete wiring configuration and block diagram of the system. This design integrates an Arduino Uno microcontroller, a thermocouple sensor, a relay module, a stepper motor driver, and an LCD display to form a fully automated filament production system. Meanwhile, Figure 9 illustrates the production process of 3D printer filament made from recycled plastic bottles, starting from the collection of waste materials to the production of ready-to-use filaments. The tool operates in a controlled manner, allowing stable heating, extrusion, and winding processes. This integrated system demonstrates the feasibility of converting post-consumer plastic bottles into functional 3D printer filament with consistent quality.

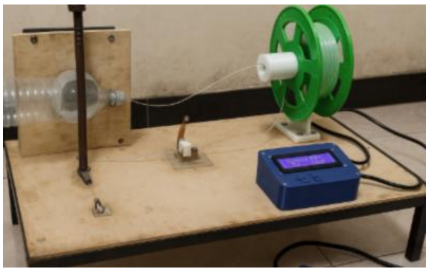

Figure 8. Plastic Bottle Recycling Machine into 3D Printer Filament

The first stage involves the collection and sorting of plastic waste. Used plastic bottles are gathered from various sources, including households, industries, and recycling centres. These materials are then sorted by type, with PET (Polyethylene Terephthalate) being the primary material used for filament production due to its availability and thermoplastic properties. The sorted plastic containers undergo washing to remove any labels, dirt, or liquid residues that might affect the extrusion quality. After cleaning, the plastic is cut into smaller pieces to facilitate further processing. This preparation stage ensures that only clean and uniform materials enter the extrusion process.

The second stage focuses on heating and extrusion. The pre-processed plastic pieces are heated to a controlled temperature, allowing the material to melt uniformly. The melted plastic is then fed into the extrusion system, where it is forced through a nozzle of a specific diameter to form continuous filaments with consistent thickness. The Arduino-based control system maintains stable heating conditions through a thermocouple sensor and relay mechanism, ensuring precision and repeatability in the extrusion process. The wiring and control configuration displayed in Figure 8 supports stable temperature regulation and synchronized motor control during filament production.

The third stage consists of cooling, winding, and quality testing. The newly extruded filament is passed through a cooling section to solidify its structure before being wound onto a spool using a stepper motor system. This process produces neat, uniform rolls of filament ready for use in 3D printers. Quality testing is then performed to ensure compliance with required standards, including checks for diameter consistency, strength, and heat resistance. The final product, as shown in Figure 9 (a–g), includes the entire process: sorting and organizing the materials, heating and extrusion, cooling, filament formation, quality testing, and the resulting 3D prints produced using the recycled filament. This process provides environmental benefits through waste reduction, resource efficiency, and the promotion of sustainable manufacturing practices in the 3D printing industry.

Extrusion The melted plastic is then put into the extrusion machine. Here, the plastic is forced through a nozzle of the appropriate size, thus forming a uniformly long and thin filament Fourth process: Cooling and Filament Forming. Cooling. The newly formed filament will be cooled so that it can harden properly before being cut into small rolls. Roll Formation The cooled filament will be cut into small rolls and put into a large spool or roll ready for use in a 3D printer. The fifth process of Testing and Quality is quality testing. Before being sold or used, the filament will be tested to ensure that the quality meets standards. This may include testing for durability, strength, thickness, and heat resistance. Storage and Distribution Filament that has passed the test will be stored properly in appropriate packaging to maintain its quality. Then, this filament is distributed to 3D printer users or markets according to need. The results of the device manufacturing process are as follows which will be displayed in the image below.

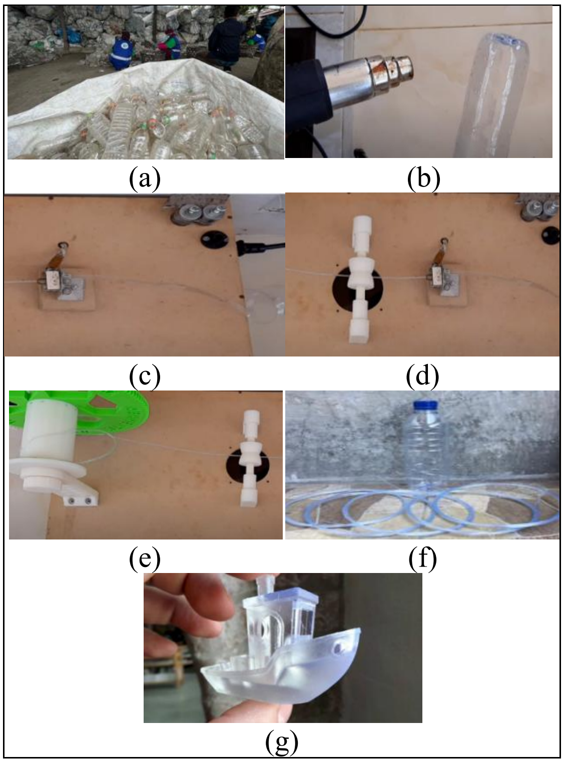

Figure 9. The process of making used plastic bottle waste into 3D printer filament (a) The process of sorting and organizing waste (b) Material Alignment (c) The process of heating and extruding materials (d) Cooling process and filament formation (e) Filament quality testing (f) 3D printer filament made from used bottles (g) 3D printing results from filament made from used bottles

Benefits of This Process Waste Reduction Converting used plastic bottles into 3D printer filament helps reduce the amount of plastic waste that enters landfills or the environment. Resource Savings Recycling plastic to make filament minimizes the use of new resources to produce 3D printer materials. Creativity and Innovation provide opportunities for people to utilize plastic waste into useful products and support the development of 3D printing technology. This process is one way that can be used to recycle plastic waste into useful products and is a step that supports environmentally friendly practices in the 3D printing industry.

4.2. Sensor Calibration

The calibration graph of the MAX6675 temperature sensor in the range of 150 °C to 250 °C illustrates a linear relationship between the reference temperature and the sensor reading. The ideal line *(y = x)* serves as a benchmark, while the calibration curve is derived from the linear regression equation $y=1.008x-6.5$. The measurement results indicate a consistent deviation of −4.30 °C to −3.50 °C below the reference temperature. This deviation gradually decreases as the temperature increases, demonstrating the sensor's stable response to temperature variations. The data trend, which closely follows the ideal line, confirms that the measurement error is systematic and can be corrected using a linear regression model. The linear pattern also reflects good precision of the sensor within the tested temperature range. Overall, the calibration results provide initial validation of the MAX6675 sensor's performance for accurate temperature monitoring. This finding is relevant to ensuring the reliability of microcontroller-based control systems that require stable temperature readings. The result of MAX 6675 sensor calibration is illustrated in Figure 10.

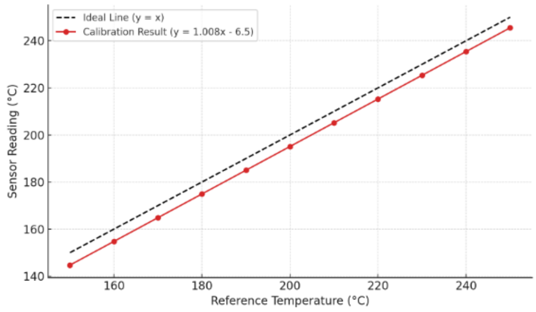

Figure 10. The result of MAX 6675 sensor calibration (150° – 160° C)

5. CONCLUSION

This study successfully developed a low-cost and automated plastic bottle waste processing tool into 3D printer filament using an Arduino microcontroller as the main control system. The implementation of Arduino-based temperature regulation and motor control ensured stable extrusion temperatures, consistent filament diameter, and minimal human intervention, supporting reliable and efficient recycling processes. The MAX6675 temperature sensor calibration within the range of 150 °C to 250 °C demonstrated a strong linear correlation between reference temperature and sensor readings, with small systematic deviations that can be corrected through linear regression modelling. This result validates the sensor's accuracy and suitability for precise thermal control in extrusion processes. The integrated system—comprising heating, extrusion, cooling, and winding—proved capable of converting PET bottle waste into functional filament with quality approaching commercial standards.

Furthermore, the developed tool offers a practical solution for small-scale industries, educational institutions, and maker communities, promoting circular economy principles and sustainable manufacturing practices. By transforming non-biodegradable plastic waste into value-added products, this technology contributes to waste reduction, resource efficiency, and environmental sustainability. Future development may focus on enhancing automation, filament quality monitoring, and multi-material compatibility to broaden the tool's application and impact.

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