International Journal on Smart Material and Mechatronics
IJSMM Vol. 12 No.2 2025 DOI. 10.20342/IJSMM.12.1.380

p-ISSN: 2356-5314
e-ISSN: 2460-075X

Design and Development of a Plastic Bottle Waste Recycling Device into 3D Printing Filament

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Abstract*—One of the problems disturbing society and the environment is plastic waste. Plastic waste consists of various types, including PET (Polyethylene Terephthalate). PET-type plastic is one of the materials most widely used for beverage bottle packaging. PET plastic has superior characteristics such as heat resistance, good mechanical strength, and ease of recycling, making it the most suitable candidate for use as a raw material for 3D printing filament. This research was conducted with the aim of designing and testing a device for recycling plastic bottle waste into 3D printing filament. The design of the plastic bottle waste recycling device was carried out using the Research and Development (R&D) research method. After conducting the research, it can be concluded that the plastic bottle waste recycling device for 3D printing filament was successfully developed. The device integrates two input sensors, namely the NTC 3950 Thermistor Sensor as a temperature sensor and the Infrared Sensor as a detection sensor, which work synergistically to monitor the plastic melting process in real time. The data obtained from both sensors is used as a reference for controlling five output actuators, namely the Heating Ceramic Cartridge to heat the plastic to its melting temperature, the DC Motor to extrude the molten plastic into filament, the 12V Fan to stabilize the resulting temperature, the Buzzer as an indicator that the process has been completed, and the 20x4 LCD Display to directly show process parameter information to the user. The remote control system is implemented through the Blynk platform, which is connected wirelessly, thereby enabling remote monitoring and operation of the device via a smartphone.

Index Terms*—ESP32, Temperature Sensor, Infrared Sensor, Blynk.

I. Introduction

Plastic waste production in Indonesia continues to increase every year. Based on data from the National Waste Management Information System (SIPSN), total national waste reaches 22.1 million tons per year, with Indonesian residents producing a total of 60.5 thousand tons of waste per day. Of this amount, 20.5%, or approximately 4.53 thousand tons per day, is plastic waste [1].

PET-type plastic is one of the materials most widely used for beverage bottle packaging. PET plastic has superior characteristics such as heat resistance, good mechanical strength, and ease of recycling, making it the most suitable candidate for use as a raw material for 3D printing filament. The resulting filament must also meet strict quality standards. High-quality filament for 3D printing requires very tight tolerances, with industry-standard diameter tolerances of around ±0.05 mm for a nominal diameter of 1.75 mm, and premium manufacturers can even achieve a precision of up to ±0.02 mm or ±0.03 mm [2]. Mineral water packaging has the potential to be a promising filament raw material due to its abundant availability. The use of mineral water packaging as a filament raw material is considered capable of reducing the amount of plastic waste while presenting an economical and sustainable material alternative for the 3D printing industry [3]. Therefore, this research aims to produce filament from unused plastic bottle waste.

II. Theoretical Basis

A. 3D Printing Filament

Design results created through a computer device are used by a 3D printing machine to print filament. Filament comes in various diameter sizes, including the most common ones of 1.75 mm, 2.85 mm, and 3 mm. Strong, tough, and easily shaped thermoplastic characteristics are essential in determining filament quality [4].

3D printing is carried out using filament in a 3D printing machine to print objects that can be seen, held, and that have volume [5]. The use of 3D printing has increased rapidly in recent years, as with other technologies. Many small and large businesses have begun using it because of its low cost for prototyping. Major industries such as architecture, automotive, and healthcare now use 3D printing [4].

B. Related Research

Research entitled Design of a 3D Printer Filament Forming Device from Crystalin and Club Brand Plastic Bottles built a used-bottle recycling device that converts bottles into plastic sheets measuring 9 mm, which are then heated to become 3D printing filament. The results of this research show that cutting bottles into plastic sheets is relatively simple, making it easy to implement, and the use of a NEMA 17 stepper motor provides better rotational precision in the filament winding process [6].

Research entitled Utilization of Plastic Waste in the Manufacture of 3D Printer Filament Using an Extrusion Machine at the Energy Conversion Laboratory of Universitas Sriwijaya aims to build a used-bottle recycling device that turns plastic bottle waste into small plastic granules, which are then heated to become 3D printing filament. The results of this research show that a 200-watt heating element is able to produce more stable heat for the extrusion process, and is equipped with a 12V fan as an active cooling system to maintain temperature stability [7].

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Previous research entitled Engineering of a Filament-Making Machine from PET Bottle Waste for 3D Printing aims to build a used-bottle recycling device that heats 3 mm plastic bottle waste sheets into 3D printing filament. The results of this research show the use of Autodesk Fusion 360 software in designing the device, producing a more precise and validated design prior to physical production, as well as a systematic manufacturing process carried out in five structured stages [8].

All of the studies conducted share the same basic concept, namely recycling PET-type plastic bottle waste into filament that can be used in 3D printing machines. This shows that the utilization of plastic bottle waste as a raw material for 3D printing filament is a relevant topic that continues to be developed by researchers as a solution to the increasing problem of plastic waste.

III. Methodology

The following is the system block diagram used by the researcher in building the Plastic Bottle Waste Recycling Device, shown in Fig. 1 below:

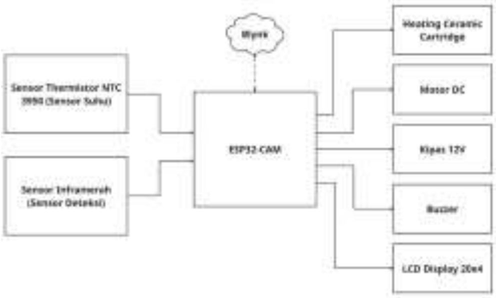

Fig. 1. Block Diagram of the System

The block diagram serves to define each subsystem of the system to be built, making the device design process easier and consistent with the plan. The input device in the system uses sensors to issue commands that are forwarded to the ESP32-CAM, such as the detected temperature and the detected bottle. The control device, the ESP32-CAM, is used to control the activation and deactivation of the sensors and actuators. The output devices in the system consist of a Heating Ceramic Cartridge to heat the nozzle, a DC motor to pull the plastic sheet to be converted into filament at the nozzle, a 12V DC fan to maintain the nozzle temperature, a Buzzer that sounds once the bottle has finished being recycled, and a 20x4 LCD Display to show the nozzle temperature on screen.

In addition to the system block diagram, there is a system workflow flowchart that serves as the initial design for building the plastic bottle waste recycling device, illustrated in Fig. 2 as follows:

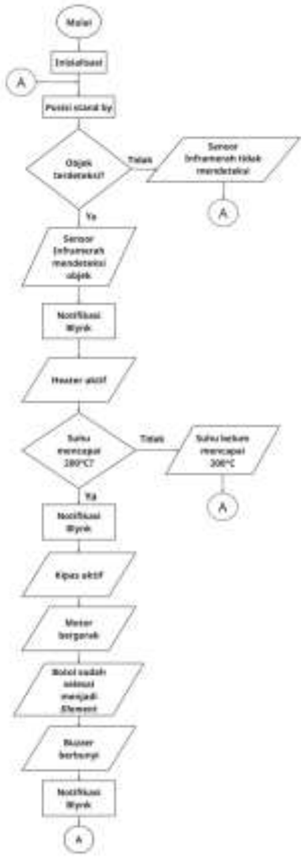

Fig. 2. System Flowchart

IV. Results and Analysis

This section discusses the test results of each component of the plastic bottle waste recycling device for 3D printing filament, covering the tests of the infrared sensor, the ESP32-CAM, the NTC 3950 Thermistor temperature sensor, the relay and Heating Ceramic Cartridge, as well as a recap of the overall system test results.

A. Infrared Sensor Test Results

TABLE I. Infrared Sensor Test Results

Bottle Distance from Ruler	Successful Detections (out of 6 Trials)	Sensor Status	Detection Accuracy (%)
1 cm	6/6	Detected	100%
2 cm	6/6	Detected	100%
3 cm	6/6	Detected	100%
4 cm	6/6	Detected	100%
Not Placed	0/6	Not Detected	100%

Based on Table I, testing was carried out with six repetitions to obtain valid and consistent data, with a success criterion of 90%–100% detection accuracy. The infrared sensor detection results at distances of 1 cm–4 cm achieved 100% detection accuracy in detecting the presence of a plastic bottle. When no plastic bottle was present, the sensor also correctly registered non-detection with 100% accuracy.

B. ESP32-CAM Test Results

TABLE II. ESP32-CAM Test Results

p-ISSN: 2356-5314
e-ISSN: 2460-075X

Repetition	Image Capture Evidence and Real-time Blynk Display
1	
2	
3	
4	
5	
6	

Based on Table II, ESP32-CAM testing was carried out with six repetitions for each status to obtain valid and consistent data. The test parameters included the ability to capture images, the quality of the real-time video display, and the delay between the device's actual condition and the display received on the Blynk application. The ESP32-CAM was declared successful in displaying real-time video with a delay not exceeding 2 seconds, with Blynk notifications successfully sent for every change in device status.

C. NTC 3950 Thermistor Temperature Sensor Test Results

TABLE III. NTC 3950 THERMISTOR TEMPERATURE SENSOR TEST RESULTS

Temperature Value	Digital Thermometer	NTC 3950 Thermistor Reading	Difference (°C)	Error (%)
200°C			1°C	0.5%
200°C			0.5°C	0.25%
200°C			0.3°C	0.15%
200°C			0.8°C	0.4%
200°C			0.3°C	0.15%
200°C			0.5°C	0.25%

Based on Table III, the NTC 3950 Thermistor sensor readings are shown together with the difference relative to the digital thermometer reading, divided by the digital thermometer value and multiplied by 100%. The NTC 3950 Thermistor sensor was declared successful, obtaining an error value not exceeding the ±5°C tolerance relative to the digital thermometer reading at a temperature of 200°C.

D. Relay and Heating Ceramic Cartridge Test Results

TABLE IV. RELAY AND HEATING CERAMIC CARTRIDGE TEST RESULTS

Relay Status	AC Voltage (VAC)	Heater Status	Temperature (°C)	Trial 1	Trial 2	Trial 3
High	AC Digital Watt-hour Meter	ON	200°C	200°C	200°C	200°C
Low	AC Digital Watt-hour Meter	OFF	0°C	0°C	0°C	0°C

Based on Table IV, the relay and Heating Ceramic Cartridge testing was carried out to determine how effectively the relay could be activated based on High and Low status, and how effectively the Heating Ceramic Cartridge could heat the plastic bottle waste to reach the PET melting temperature of 200°C.

E. Overall System Test Recap

TABLE V. OVERALL SYSTEM TEST RECAP

Test Parameter	Condition	Result	Delay (seconds)	Evidence
NTC 3950 Thermistor Sensor	Real-time temperature data	Successful	0	

Infrared Sensor	Bottle detected / not detected	Successful	0	
ESP32-CAM	Video active / inactive	Successful	2	
DC Motor	DC motor speed data	Successful	0	
Overall Display	All real-time data	Successful	0	

The recap in Table V shows that all system test parameters — the NTC 3950 Thermistor Sensor, the Infrared Sensor, the ESP32-CAM, the DC Motor, and the overall data display on the Blynk dashboard — were successfully displayed in real time, with the highest delay of 2 seconds occurring on the ESP32-CAM.

V. CONCLUSION

Based on the research that has been conducted, it can be concluded that the plastic bottle waste recycling device for 3D printing filament was successfully developed using the Research and Development (R&D) method. The device integrates two input sensors, namely the NTC 3950 Thermistor Sensor as a temperature sensor and the Infrared Sensor as a detection sensor, which work synergistically to monitor the plastic melting process in real time. The data obtained from both sensors is used as a reference for controlling five output actuators, namely the Heating Ceramic Cartridge, DC Motor, 12V Fan, Buzzer, and 20x4 LCD Display. The test results show that the Infrared Sensor achieved 100% detection accuracy, the ESP32-CAM was able to display real-time video with a delay not exceeding 2 seconds, and the NTC 3950 Thermistor Sensor had a temperature reading error below the ±5°C tolerance. The remote control system via the Blynk platform was proven to be usable for remotely monitoring and operating the device via a smartphone.

ACKNOWLEDGMENT

The authors would like to thank the Electronics Engineering Study Program, Faculty of Engineering, Universitas Negeri Jakarta, as well as the thesis supervisor, for their guidance and support of the laboratory facilities during this research.

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