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Design and Development of a Microcontroller-Based UV Conveyor Control System and Plastic Shred Moisture Monitoring Prototype

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Abstract

Plastic waste poses a serious environmental challenge, especially in Indonesia, which generates about 64 million tons annually. Of this, 10% ends up in the ocean, disrupting marine ecosystems. Recycling plastic into reusable products offers a potential solution, but Indonesia's recycling industry processes only 5 million tons per year, far below the total generated waste. A key obstacle in recycling is the drying process for shredded plastic after washing. Many facilities rely on sunlight, which prolongs production and raises costs. To address this, a conveyor-based heating system has been proposed to expedite moisture removal. Heating rods in the system provide thermal radiation, similar to an electric oven. Drying rates vary with the moisture content of each batch, making moisture monitoring essential. This system incorporates sensors to measure moisture levels before and after drying, displayed on a 2.4" Nextion screen. Operators manually control the heater and conveyor motor using a potentiometer, ensuring easy adjustments. This study introduces a microcontroller-based UV conveyor system for drying shredded plastic. The design optimizes production time and reduces costs compared to traditional methods. By improving efficiency, this innovation could significantly enhance plastic recycling practices in Indonesia, addressing critical environmental and operational challenges.

Keywords: Heater, Water Content, Control, Plastic waste

1. Introduction

Plastic waste is a significant challenge faced by countries worldwide due to its non-biodegradable nature, and its accumulation continues to increase annually (Hakim, 2019). In Indonesia, the amount of plastic waste dumped into the ocean is estimated at nearly 200 million tons, second only to China, which generates approximately 262.9 million tons of plastic waste. Simultaneously, only about 64% of Indonesia's total annual plastic demand of 5 million tons is met. The plastic waste being discarded into the ocean could potentially be utilized to address this demand. Existing plastic waste needs to be processed to be repurposed as production-ready plastic (Anggraeni and Latief, 2018). Recycling plastic waste has emerged as an innovative solution to mitigate the plastic waste crisis in Indonesia.

The plastic recycling process involves several stages, including sorting, shredding, washing, drying, melting, and molding the plastic into finished products (Jeklin, 2016). Among these, the drying process for shredded plastic poses a significant challenge for many recycling industries. The moisture content in shredded plastic must be reduced by 95% from its initial level; failure to achieve this reduction can make the plastic pellet production process hazardous. Residual water in the shredded plastic will be heated to 300°C, producing high-pressure steam that can endanger operators. Consequently, the drying process after washing must be optimized to ensure the moisture content in the shredded plastic approaches the 95% target (Arifuddin et al., 2024) (Darni et al, 2020).

To address this issue, a prototype for a simple plastic shred dryer has been designed and developed. In this system, shredded plastic is suspended and dried by hot air. Enhancements include implementing a control system for the heater and monitoring the moisture content of the shredded plastic. These controls are intended to simplify operator tasks, enabling them to operate the band heater and monitor the percentage of moisture in the shredded plastic (Nurprasetio et al., 2017).

The use of a conveyor-based system for the drying process offers greater efficiency and precision, as the drying rate can be manually controlled by the operator operating the machine. The heat generated by the heating rods can effectively reduce the moisture content of the shredded plastic. Additionally, the conveyor motor, equipped with sufficient torque, can handle the substantial weight of wet shredded plastic, ensuring smooth operation (Purwadi and Kusbandono, 2016).

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This study aims to design and develop a microcontroller-based UV conveyor system integrated with monitoring capabilities for the moisture content of shredded plastic. By incorporating adaptive controls and real-time monitoring, the system enhances operational efficiency and ensures compliance with safety standards, ultimately supporting the broader goal of reducing plastic waste through recycling innovations (Ruddianto et al., 2021).

2. Material and methods

2.1. Methods

The research methodology outlines the approach used to solve the identified problem. The approach adopted in addressing the issue involves the design and development of a specific device.

This section further elaborates on the research workflow, detailing the steps undertaken from problem identification to the preparation of the final report (Nugraha et al., 2021c) (Nugraha et al., 2021d). Each phase of the research process is systematically described to provide a comprehensive understanding of the methodology employed.

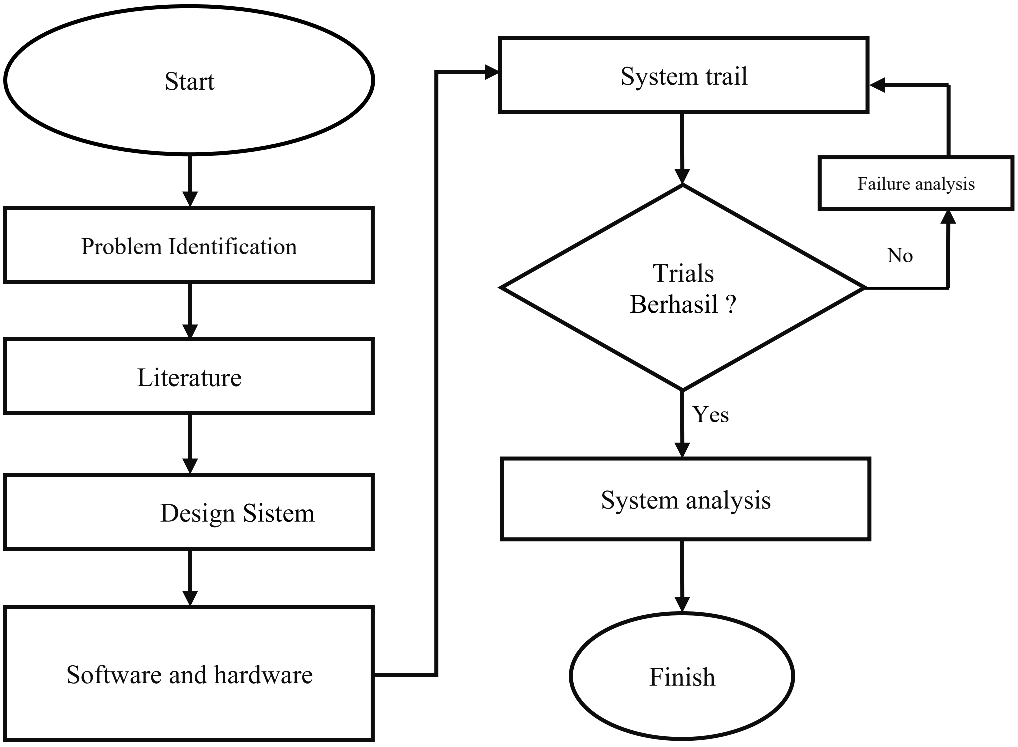

Figure 1. Flowchart

The issue addressed in this project originates from observations during the On-the-Job Training (OJT) at PT. Wahyu Jaya Sakti Plastic Recycle. The problem identified lies in the inefficiency of the plastic drying process, which currently utilizes a rotary drum machine. This method often fails to achieve optimal drying results (Nugraha & Priyambodo, 2021). The proposed solution involves designing a conveyor system to enhance the drying process, tailored specifically for materials such as shredded plastic.

The primary focus of this project is to develop a simple control system for the conveyor, ensuring it is easy for operators to use and understand. The conveyor drying system's control includes a motor control mechanism to enable the conveyor's rotation (Mustangin & Saputra, 2018)(Utomo & Nugraha, 2021). Additionally, a UV heater control system, implemented through manually adjustable heating rods, is introduced. This approach ensures greater flexibility and reliability in the drying process, as the moisture content of plastic pellets varies with each production batch.

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The manual temperature adjustment of the heating rods provides an adaptable solution, accommodating different moisture levels and ensuring consistent drying results (Putra & Nugraha, 2021). This feature addresses the variability in moisture content, which significantly impacts the effectiveness of the drying process (Febrianto & Nugraha, 2021). The conveyor system's control design prioritizes user-friendliness while maintaining operational efficiency.

Various calculations are employed in developing this prototype to optimize its performance (Nugraha et al., 2021e). These calculations include determining the appropriate heating requirements, conveyor speed, and energy consumption to ensure that the system operates effectively and efficiently (Nugraha & Sugianto, n.d.) (Zaibah & Nugraha, 2021). By addressing these factors, the project aims to deliver a practical and innovative solution to the challenges in plastic drying processes.

Calculation of drying rate for plastic shreds:

$$md = \frac{Wo - Wf}{t}$$

Where: md = internal drying rate (Kg/hour)
W0 = weight of material before drying (Kg)
Wf = weight of material after drying (Kg)
t = time required during the drying process (dt)

Calculation of the percentage error on the sensor:

$$error = \frac{measuring\ instrument - Sensor}{measuring\ instruments} \times 100\,\%$$

3. Results and discussion

3.1. Result

Each sensor has been tested and compared with conventional measuring instruments commonly used in laboratories. This comparison was conducted to ensure the accuracy and reliability of the sensor readings under real-world conditions. The results of these tests provide valuable insight into the performance of the sensors relative to standard measurement tools.

The comparative data between the sensors and conventional instruments are presented in the table below. This table highlights the differences, if any, in the readings, as well as the consistency of the sensors when used in practical applications. These findings demonstrate the extent to which the sensors can replicate the precision of conventional equipment.

By analyzing the data, the accuracy of each sensor can be evaluated, helping to identify areas for calibration or improvement. This process not only validates the sensors' performance but also ensures their suitability for integration into the system, particularly in environments that demand high precision.

Table 1. YL 69 Sensor Measurement Results on container 1

No.	Result (%)		Difference	Error
	Grain Moisture AR991	Sensor Yl 69		
1	38.3	37	1.3	3.39%
2	39.5	39	0.5	1.27%
3	29.8	28	1.8	6.04%
4	28.0	28	0.0	0.00%
5	33.0	33	0.0	0.00%
6	46.5	46	0.5	1.08%
7	52.4	50	2.4	4.58%
8	58.9	58	0.9	1.53%
9	44.4	43	1.4	3.15%
10	45.5	45	0.5	1.10%
Error Average				2.21%

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The measurements mentioned above were conducted on shredded plastic samples that had undergone centrifugal drying. These samples were obtained from ten different centrifugal drying cycles performed on separate production days. This approach ensured that the data captured represented a variety of operational conditions and drying outcomes.

The type of shredded plastic tested during the measurement process was polypropylene. This material was chosen due to its widespread use in plastic recycling and its unique drying characteristics. By focusing on polypropylene, the study aimed to provide insights into optimizing the drying process for this specific type of plastic, which is often challenging to handle due to its properties.

Table 2. Results of YL 69 sensor measurements on container 2

No.	Result (%)		Differenc e	Error
	Grain Moisture AR991	Sensor Yl 69		
1	10.4	10	0.4	3.85%
2	9.6	9	0.6	6.25%
3	8.4	8	0.4	4.76%
4	11.0	11	0.0	0.00%
5	15.0	15	0.0	0.00%
6	11.2	11	0.2	1.79%
7	10.8	10	0.8	7.41%
8	9.6	9	0.6	6.25%
9	10.7	10	0.7	6.54%
10	12.3	12	0.3	2.44%
Error Average				3.93%

The measurements mentioned above were conducted on shredded plastic after undergoing the drying process using a UV conveyor system, with varying conveyor speeds and temperatures. By adjusting these parameters, different drying conditions were simulated to assess their impact on the drying efficiency of the plastic.

Both sets of measurement data can be used to determine the drying rate that occurred in each trial. These data provide valuable insights into how different conveyor speeds and temperatures influence the overall moisture reduction in the shredded plastic. By analyzing the results, the optimal settings for the UV conveyor system can be identified to improve the drying process.

Table 3. DS18B20 Temperature Sensor Measurement Results

No.	Result (°C)		Differenc e	Error
	Thermogun	Sensor DS18B20		
1	135.0	135	0.0	0.00%
2	140.0	140	0.0	0.00%
3	90.0	90	0.0	0.00%
4	87.0	87	0.0	0.00%
5	91.0	90	1.0	1.10%
6	95.0	92	3.0	3.16%
7	89.0	87	2.0	2.25%
8	99.0	99	0.0	0.00%
9	100.0	99	1.0	1.00%
10	100.0	99	1.0	1.00%
Error Average				0.85%

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The above measurements were carried out on a rod heater that was set randomly using a potentiometer

Table 4. Speed Sensor Measurements

No.	Result (Rpm)		Differenc e	Error
	Tachometer	Optocoupler		
1	0	0	0	0%
2	15	14	1	7%
3	30	30	0	0%
4	40	40	0	0%
5	65	65	0	0%
6	70	68	2	3%
7	100	99	1	1%
8	140	139	1	1%
9	160	160	0	0%
10	250	250	0	0%
Error Average				1%

The above measurements were carried out at random set points on the conveyor motor

No.	Conveyor Speed	Container Moisture Content 1	Container Moisture Content 2	Heater	Temperature Drying Time (s)	Drying Rate
1	50	37	10	80	0.42	1.2
2	60	39	9	80	0.50	0.9
3	70	28	8	76	0.58	0.7
4	80	28	11	76	0.67	0.8
5	90	33	15	82	0.75	1.0
6	100	46	11	87	0.83	0.7
7	120	50	10	90	1.00	0.5
8	140	58	9	110	1.17	0.4
9	160	43	10	89	1.33	0.4
10	200	45	12	87	1.67	0.4

The above test took an average sample of 5kg of post-centric chopped plastic with different water contents and different heating results. The drying rate of the plastic shreds was obtained with these results.

3.2. Discussion

Based on the results of testing each sensor, the average error for each sensor was determined. The error for the YL-69 sensor in Container 1 was 2.21%, while for Container 2, the error increased to 3.93%. The average error for the temperature sensor was 0.85%, and the error for the optocoupler sensor was 1%. These errors were influenced by several factors. One key factor was the humidity in the room, which affected the moisture content of the shredded plastic before and after it underwent heating. Environmental temperature variations also played a significant role, as fluctuations in the surrounding temperature could cause the heater's temperature to rise or fall, leading to inaccuracies in the readings. Additionally, the error in the optocoupler sensor was related to the conveyor shaft speed, which was set at a 1:2.5 ratio using a gearbox. The slip factor in the motor shaft and conveyor shaft rotations also contributed to a delay in sensor readings, further impacting the accuracy of the measurements.

This study aims to reduce the moisture content in shredded plastic, which remains high after the initial drying process. By improving the drying efficiency, the subsequent processes of melting or forming the shredded plastic into pellets can become more efficient. Reducing the moisture content will optimize the plastic recycling process, leading to better quality pellets and more energy-efficient production, ultimately enhancing the overall productivity of the recycling system.

4. Conclusion

1. Accuracy of Sensors: The study found that the average errors in the sensor readings were relatively low, with the YL-69 sensor showing errors between 2.21% and 3.93%, the temperature sensor at 0.85%, and the optocoupler sensor at 1%. These errors were influenced by factors such as humidity, environmental temperature, and mechanical inconsistencies, highlighting the need for further refinement in sensor calibration and system setup.
2. Impact of Environmental and Mechanical Factors: Several factors, including ambient humidity, surrounding temperature, and mechanical delays in the conveyor system, contributed to variations in sensor readings. These factors need to be considered when designing more accurate and efficient drying systems for plastic recycling to ensure reliable and consistent performance.
3. Improvement in Drying Efficiency: The research suggests that by reducing the moisture content in shredded plastic more effectively, the overall efficiency of plastic pellet production can be improved. This will lead to better processing and formation of plastic pellets, enhancing the effectiveness of the recycling process and contributing to more energy-efficient and cost-effective operations.

Credit authorship contribution statement

Author Name: Conceptualization, Writing – review & editing. **Author Name**: Supervision, Writing – review & editing. **Author Name**: Conceptualization, Supervision, Writing – review & editing.

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