International Journal on Smart Material and Mechatronics
IJSMM Vol. 10 No.1 2023 DOI. 10.20342/IJSMM.10.1.500
p-ISSN: 2356-5314
e-ISSN: 2460-075X

Design and Development of a Microcontroller-Based Paper Waste Recycling Machine for Producing Multipurpose Paper

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Abstract—**Paper waste is one of the types of solid waste that continues to increase and requires effective management to prevent negative environmental impacts. This study aimed to design, develop, and test a microcontroller-based paper waste recycling machine capable of automating material weighing, water filling, paper-pulp mixing, and drying processes. The research employed a Research and Development (R&D) method using the V-Model, covering design, implementation, subsystem testing, and overall system testing. The system uses a load cell sensor to measure paper mass, an XKC-Y25-V non-contact liquid-level sensor to detect water level, and a DS18B20 temperature sensor to monitor the drying chamber, together with a DC water pump, AC motor, AC heater, and DC fan controlled by an ESP32. The test results showed a maximum power-supply voltage deviation of 2.60%, a load-cell measurement difference of 0.1–0.4 g, a liquid-level sensor response time of 0.18–0.22 s, and a DS18B20 measurement difference of 0.60–0.75 °C compared with a digital multimeter. Integration testing showed that all process stages operated according to the designed sequence. The system produced five dry A4-sized recycled-paper sheets with an average final mass of 5.37 g, indicating relatively consistent final sheet mass.**

Index Terms—**Paper Recycling, ESP32, Paper Waste, Microcontroller, V-Model**

I. INTRODUCTION

Paper waste is one of the three largest types of waste generated in Indonesia. In 2025, paper waste generation was reported at 3.57 tons. If not properly managed, accumulated paper waste and its disposal through burning can contribute to environmental pollution. Therefore, recycling paper waste is one approach to reducing waste volume while producing a useful product.

At the household and micro, small, and medium enterprise (MSME) levels, paper recycling processes are still largely performed manually. Raw-material weighing, water filling, paper-pulp mixing, and drying depend on human operation. These conditions can increase production time, reduce mixing uniformity, and cause inconsistency in the resulting paper quality.

Microcontroller technology enables recycling processes to be performed more automatically and in a controlled manner. An ESP32 can be integrated with a load cell, liquid-level sensor, DS18B20 temperature sensor, DC water pump, AC motor, AC heater, DC fan, and LCD display to automate raw-material weighing, water filling, mixing, and drying, thereby improving process control.

Several previous studies have developed paper-waste recycling machines, paper-pulp mixing devices, and drying systems. However, these studies have generally focused on individual processes and have not integrated the complete paper-recycling sequence into a single microcontroller-based system. Thus, an integrated machine for converting paper waste into multipurpose paper remains necessary.

Based on this condition, this study develops a microcontroller-based paper waste recycling machine using the V-Model development approach. The system uses an ESP32 as the main controller, a load cell to measure paper mass, a non-contact liquid-level sensor to detect water level in the mixing vessel, a DS18B20 temperature sensor to measure drying temperature, a DC water pump for water filling, an AC motor for mixing, an AC heater as the drying heat source, a DC fan to circulate hot air, and an LCD display to show the ongoing process. The V-Model was selected because the system consists of several subsystems that need to be tested before being integrated into a complete system.

The objective of this study was to design, develop, and test a microcontroller-based machine for recycling paper waste into multipurpose paper using an ESP32 as the main controller. The developed system integrates material weighing, automatic water filling, paper-pulp mixing, and drying into a single system to improve process efficiency, ease of operation, and consistency of recycled paper production.

II. THEORETICAL BACKGROUND

A. ESP32

ESP32 is a microcontroller developed by Espressif Systems and widely used in automation and Internet of Things (IoT) applications. It includes Wi-Fi and Bluetooth connectivity, allowing various sensors and actuators to be connected and controlled within one system. ESP32 also provides more GPIO pins, larger memory capacity, and better performance than its predecessor, ESP8266, making it suitable for microcontroller-based control applications (Mujahidah, 2021; Suriana et al., 2021). In this study, an ESP32 DevKit V1 was used as the main controller to integrate sensors and actuators. Sensor data were processed by the ESP32 to control the actuators according

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

to the system sequence, allowing weighing, water filling, mixing, and drying to operate automatically.

B. Arduino IDE

Arduino IDE (Integrated Development Environment) is software used to write, edit, compile, and upload programs to microcontrollers. It provides an integrated code editor, compiler, and uploader that supports microcontroller-system development (Jumri et al., 2025). In this study, Arduino IDE was used to develop the ESP32 program for sensor acquisition, data processing, and actuator control according to the designed workflow. The platform also supports libraries that simplify communication between the ESP32 and the sensors and actuators used in the system.

C. Load Cell Sensor

A load cell converts an applied load into an electrical signal through changes in strain-gauge resistance. The resistance change is converted into a voltage signal through a Wheatstone bridge and then processed as a mass value. An HX711 module is used as a signal amplifier and analog-to-digital converter (ADC) so that the output can be read by a microcontroller (Handayani et al., 2024). This study used a 10 kg load cell mounted on the support frame of the mixing vessel. The measured mass was processed by the ESP32 as the basis for automatically activating the water pump when the paper mass reached 1 kg. Before use, the sensor was calibrated against a digital scale to improve measurement accuracy.

D. Non-Contact Liquid-Level Sensor

The XKC-Y25-V non-contact liquid-level sensor detects liquid level without direct contact with the measured medium. It uses signal-processing technology to detect liquid through the wall of a non-metallic container. Because it does not contact the liquid directly, the sensor is suitable for applications requiring safer and longer-lasting liquid detection (Anam et al., 2024). In this study, the sensor was installed outside the paper-pulp mixing vessel to detect the maximum water volume of 5 L. When the water reached the specified level, the sensor sent a signal to the ESP32 to stop the water pump automatically.

E. DS18B20 Temperature Sensor

The DS18B20 is a digital temperature sensor capable of measuring temperatures from −55 °C to 125 °C and communicating through a One-Wire interface. It requires only one data line and does not require an additional ADC module, making it easy to integrate into microcontroller-based temperature-monitoring and control systems (Saputro & Prasetyo, 2022; Huda & Kurniawan, 2022). In this study, the DS18B20 monitored the temperature inside the drying cabinet in real time. The ESP32 processed the temperature data to control the heater so that the drying temperature could be maintained at a maximum of 65 °C.

F. AC Electric Motor

An AC motor converts alternating electrical energy into mechanical rotational energy. Its operation is based on the interaction of magnetic fields in the stator and rotor, producing torque to drive a load. AC motors are widely used in automation and industrial equipment because of their stable rotation and relatively high power capability (Endi Permata, 2023; Sinaga & Hutajulu, 2021). This study used a 135 W AC motor to drive the paper-pulp mixing mechanism. The motor was controlled by the ESP32 through a Solid State Relay (SSR) to provide automatic ON/OFF operation according to the system sequence.

G. DC Water Pump

A DC water pump uses a direct-current motor as its driving source. The pump can deliver water through an impeller or diaphragm mechanism, with its operating behavior affected by the applied voltage and polarity (Purba et al., 2022; Sawkare, 2023). This study used a 12 V diaphragm DC pump to fill the mixing vessel automatically. The ESP32 controlled the pump through a relay based on the load-cell and non-contact liquid-level sensor readings. The pump was activated when the paper mass reached 1 kg and stopped automatically when the specified water level was reached.

H. AC Heater

A heater is a heating element that converts electrical energy into heat through Joule heating, in which heat is generated by current flowing through a resistive element. Heating elements are commonly used in temperature-controlled systems because they can provide stable heat generation (Datu, 2024; Alfayuton, 2024). In this study, an AC heater was used as the heat source for drying recycled paper. The heater was controlled by the ESP32 through an SSR according to the DS18B20 temperature reading. The heater operated together with the DC fan to distribute hot air more evenly inside the drying cabinet.

I. DC Fan

A DC fan is an actuator that generates airflow for ventilation, cooling, and drying. DC fans can be classified according to airflow direction, including axial and centrifugal types (Fatin et al., 2023). A 12 V DC fan was used to circulate air inside the drying cabinet. The fan operated together with the heater to distribute hot air and stabilize the drying-chamber temperature. The ESP32 controlled the fan through a relay according to the programmed drying conditions.

J. Liquid Crystal Display (LCD) I2C

An LCD is a display medium used to present characters and numerical information for system monitoring. This study used a 16×2 LCD equipped with an I2C module, allowing serial communication through two lines: Serial Data (SDA) and Serial Clock (SCL). The I2C interface reduces the number of microcontroller pins required compared with parallel communication, simplifying integration with the ESP32 (Mihrab, 2022; Nurhalisah et al., 2025). The LCD displays sensor readings and system status, including paper mass, water filling, mixing, and drying temperature in real time.

III. Methodology

The study employed a Research and Development (R&D) method using the V-Model as the development model. The model was selected because each development stage is paired with a corresponding testing stage, allowing systematic verification and validation. The development stages consisted of Requirement Analysis, System Design, Architecture Design,

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

Module Design, Coding, Unit Testing, Integration Testing, System Testing, and Acceptance Testing.

The developed paper-recycling machine consists of an ESP32 as the main controller; a load cell with an HX711 module to measure paper mass; a non-contact liquid-level sensor to detect water level in the mixing vessel; a DS18B20 temperature sensor to measure drying temperature; a DC water pump for water filling; an AC motor for pulp mixing; an AC heater as the drying heat source; a DC fan to circulate hot air; and an I2C LCD to display each ongoing process. All components were integrated into one automatic system according to the developed program.

The research began with system-requirement identification, followed by hardware and physical-design development. After the design stage, the ESP32 was programmed using Arduino IDE. System testing then proceeded from individual hardware components and modules to inter-module integration, overall system testing, and acceptance testing to ensure that all functions operated according to user requirements.

The tests included power-supply testing, load-cell testing, non-contact liquid-level testing, DS18B20 temperature-sensor testing, overall system integration testing, and recycled-paper product testing. The data were analyzed using percentage error by comparing sensor readings with reference measuring instruments and by evaluating the functional success of each subsystem. The V-Model development stages are shown in Fig. 1.

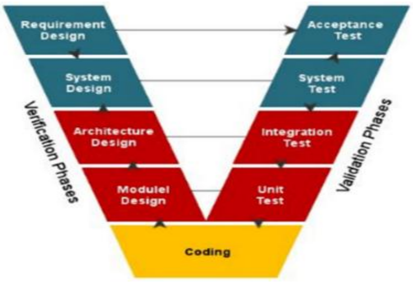

Fig. 1. V-Model development stages

IV. Results and Analysis

The microcontroller-based paper waste recycling machine was successfully realized according to the design using an ESP32 as the main controller. The system consists of a load cell to measure paper mass, an XKC-Y25-V non-contact liquid-level sensor to detect water level, a DS18B20 temperature sensor to measure drying temperature, a DC water pump for water filling, an AC motor for pulp mixing, an AC heater for drying, a DC fan to circulate hot air, and an I2C LCD to display process information. The overall machine is shown in Fig. 2.

Fig. 2. Overall view of the developed machine

A. System Operation Flowchart

The operating flow of the developed paper waste recycling machine is shown in Fig. 3. The sequence integrates material weighing, automatic water filling, pulp mixing, manual forming, and drying.

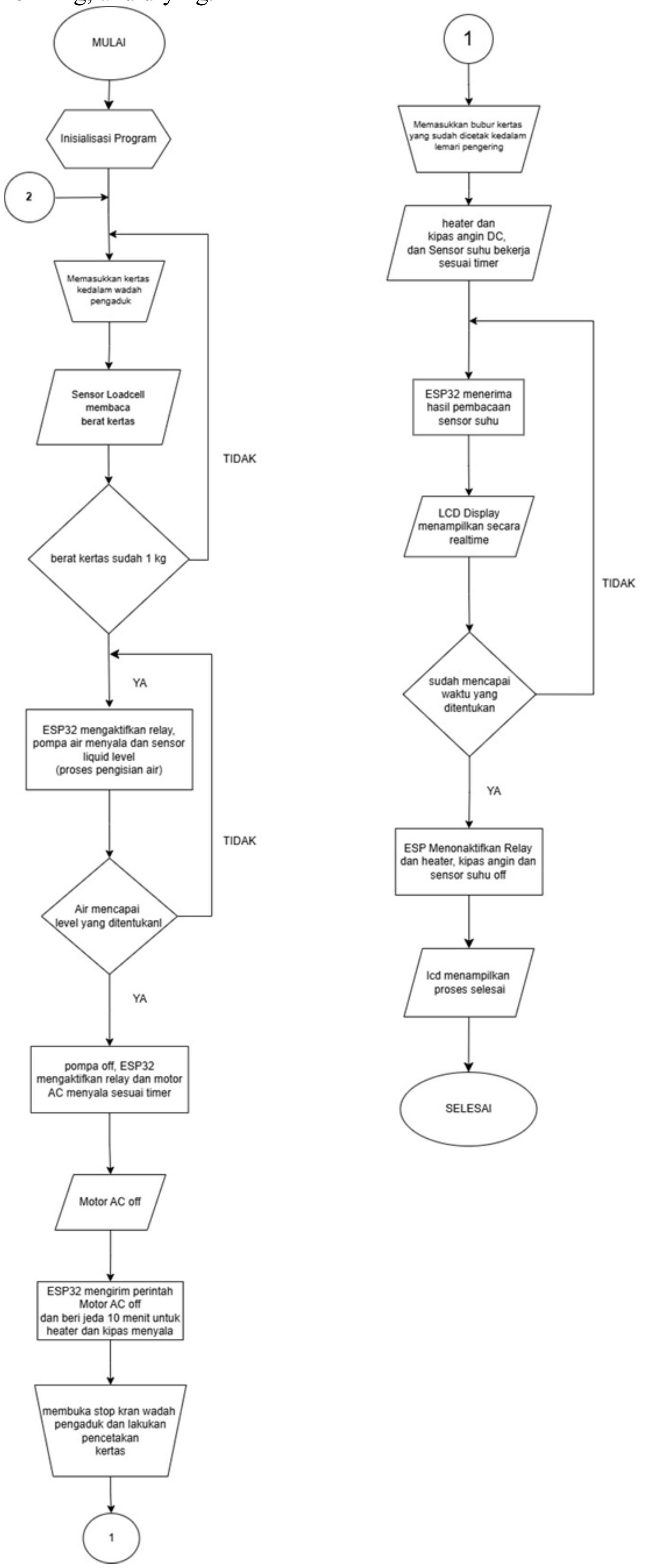

Fig. 3. System operating flowchart

The operating sequence of the developed paper waste recycling machine is as follows:

1. The system starts with ESP32 initialization, including preparation of the connected sensors and actuators: load cell, non-contact liquid-level sensor, DS18B20 temperature sensor, DC water pump, AC motor, AC heater, and DC fan.
2. The user places paper into the mixing vessel. The load cell measures the paper mass until it reaches 1 kg. The ESP32 then activates the relay to start the water pump, while the liquid-level sensor monitors the water level up to 5 L.
3. The DC water pump continues operating until the specified water level is reached. Once the liquid-level sensor detects the required level, the pump stops and the ESP32 activates the AC motor through the relay to mix the paper pulp for 10 minutes.
4. After the mixing time is completed, the AC motor stops and the pulp is considered ready for forming.
5. The forming stage is performed manually by the user by opening the stop valve connecting the mixing vessel to the pulp-forming vessel.
6. After a 10-minute forming interval, the process continues to paper drying. The ESP32 activates the AC heater and DC fan for 10 minutes. During drying, the DS18B20 sensor and LCD display the temperature in real time.
7. After the drying period is completed, the heater, fan, and temperature-sensor operation are stopped, and the system returns to the initial condition for the next cycle.

B. Power Supply Testing

Power-supply testing was performed to ensure that all components received appropriate operating voltages. The measured outputs showed maximum percentage deviations of 1.88% for the 24 V output, 1.67% for the 12 V output, and 2.60% for the 5 V output. These values remained within the specified 10% tolerance of the nominal voltage.

TABLE I. POWER SUPPLY TEST RESULTS

Power Supply Test	Trial	Standard Voltage (V)	Measured Voltage (V)	Difference (V)	Error (%)
24 V DC Power Supply	1	24	23,80	0,20	0,83%
	2	24	23,64	0,36	1,50%
	3	24	23,73	0,27	1,13%
	4	24	23,55	0,45	1,88%
12 V Step-down	1	12	12,00	0,00	0,00%
	2	12	11,86	0,14	1,17%
	3	12	11,95	0,05	0,042%
	4	12	11,80	0,20	1,67%
5 V Step-down	1	5	4,92	0,08	1,60%
	2	5	4,89	0,11	2,20%
	3	5	4,91	0,09	1,80%
	4	5	4,87	0,13	2,60%

C. Load Cell Sensor Testing

The load-cell sensor was tested using several mass values as references. The results showed measurement differences of 0.1–0.4 g, with a maximum error percentage of 0.16%. The maximum difference remained below the 0.5 g tolerance specified in the study, indicating that the sensor could measure paper mass accurately and provide a suitable basis for controlling the automatic water-filling process.

TABLE II. POWER SUPPLY TEST RESULTS

Digital Scale (g)	Load Cell (g)	Difference (g)	DC Water Pump	Error (%)
0	0,2	0,2	OFF	-
0	0,1	0,1	OFF	-
0	0,3	0,3	OFF	-
0	0,0	0,0	OFF	-
0	0,2	0,2	OFF	-
250	250,3	0,3	OFF	0,12
250	249,7	0,3	OFF	0,12
250	250,2	0,2	OFF	0,08
250	250,4	0,4	OFF	0,16
250	249,8	0,2	OFF	0,08
500	500,4	0,4	OFF	0,08
500	499,7	0,3	OFF	0,06
500	500,2	0,2	OFF	0,04
500	500,3	0,3	OFF	0,06
500	499,6	0,4	OFF	0,08
750	750,3	0,3	OFF	0,04
750	749,7	0,3	OFF	0,04
750	750,2	0,2	OFF	0,03
750	750,4	0,4	OFF	0,05
750	749,8	0,2	OFF	0,03
1000	1000,3	0,3	ON	0,03
1000	999,7	0,3	ON	0,03
1000	1000,4	0,4	ON	0,04
1000	1000,2	0,2	ON	0,02
1000	999,8	0,2	ON	0,02

D. Non-Contact Liquid-Level Sensor Testing

The non-contact liquid-level sensor was tested to determine its ability to detect water at the specified level in the paper-pulp mixing vessel. Ten trials were performed under two different water-level conditions, with a maximum allowable sensor response time of 1 s. The measured response times ranged from 0.18 to 0.22 s, indicating that the sensor was suitable for automatic water filling.

TABLE III. NON-CONTACT LIQUID-LEVEL SENSOR TEST RESULTS

Trial	Initial Condition	Final Condition	Initial Status	Final Status	Response Time (s)	Result
1	Water below sensor	Water touches sensor	OFF	ON	0,20	Successful
2	Water below sensor	Water touches sensor	OFF	ON	0,18	Successful
3	Water below sensor	Water touches sensor	OFF	ON	0,19	Successful
4	Water touches sensor	Water below sensor	ON	OFF	0,22	Successful
5	Water touches sensor	Water below sensor	ON	OFF	0,21	Successful
6	Water	Water	ON	OFF	0,20	Successful

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

Trial	Initial Condition	Final Condition	Initial Status	Final Status	Response Time (s)	Result
	touches sensor	below sensor				
7	Water below sensor	Water touches sensor	OFF	ON	0,19	Successful
8	Water touches sensor	Water below sensor	ON	OFF	0,21	Successful
9	Water below sensor	Water touches sensor	OFF	ON	0,18	Successful
10	Water touches sensor	Water below sensor	ON	OFF	0,20	Successful

E. DS18B20 Temperature Sensor Testing

The DS18B20 temperature sensor was tested to determine its ability to measure the drying-chamber temperature and to verify its readings against a reference instrument. The largest measurement difference reported in the source test was 0.75 °C, which remained below the 1 °C tolerance. Therefore, the sensor was considered capable of measuring the drying temperature accurately.

TABLE IV. DS18B20 TEMPERATURE SENSOR TEST RESULTS

Uji Ke	Pembacaan multimeter digital (°C)	Hasil Pembacaan Sensor Suhu (°C)	Selisih	Heater Status	Fan Status
1	27°C	27,12°C	0,12	ON	ON
2	39°C	39,06°C	0,6	ON	ON
3	47°C	47,06°C	0,6	ON	ON
4	56°C	56,75°C	0,75	ON	ON
5	65°C.	65,06°C.	0,6	OFF	OFF

F. Overall System Integration Testing

TABLE V. NON-CONTACT LIQUID-LEVEL SENSOR TEST RESULTS

Uji Ke	Paper Mass (kg)	Water Volume (L)	Mixing Duration (min)	Drying Duration (min)	Suhu pengeringan (°C)
1	1	5	3	10	50°C
2	1	5	3	10	50°C
3	1	5	3	10	55°C
4	1	5	3	10	55°C
5	1	5	3	10	58°C

G. Recycled-Paper Product Testing

Product testing evaluated the machine's ability to produce recycled-paper sheets that could be reused as multipurpose paper. The results showed that the machine produced dry A4-sized recycled paper with relatively consistent final mass.

TABLE VI. NON-CONTACT LIQUID-LEVEL SENSOR TEST RESULTS

Trial	Paper Size	Final Paper Mass (g)	Condition	Documentation
1	A4	5,36	Dry	
2	A4	5,38	Dry	
3	A4	5,35	Dry	
4	A4	5,40	Dry	
5	A4	5,37	Dry	

H. Analysis

Based on all test results, the developed machine met the study objective of recycling paper waste into multipurpose paper using a microcontroller-based system. The load cell, non-contact liquid-level sensor, and DS18B20 temperature sensor demonstrated good measurement performance. The actuators and overall system integration operated according to the programmed sequence, and the machine produced dry paper sheets with relatively consistent final mass. The main limitations were the limited production capacity, the relatively long drying time, which is not yet optimal for large-scale production, and variations in paper thickness and texture caused by the characteristics of the pulp used.

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusion

Based on the design, development, and testing results, the microcontroller-based paper waste recycling machine was successfully realized using an ESP32. The system was able to automate raw-material weighing, water filling, paper-pulp mixing, and paper drying within one integrated system.

The tests showed a maximum power-supply voltage deviation of 2.60%, a maximum load-cell error of 0.16% with a maximum measurement difference of 0.4 g, a maximum non-contact liquid-level response time of 0.22 s, and a maximum DS18B20 measurement difference of 0.75 °C. Overall system integration operated successfully according to the programmed sequence, and the machine produced dry paper sheets with relatively consistent final mass. Therefore, the developed system fulfilled the study objective of providing a microcontroller-based machine for recycling paper waste into multipurpose paper.

B. Recommendations

Future development should add an Internet of Things (IoT)-based monitoring system so that the entire recycling process can be monitored in real time through a web or smartphone application. The control system could also be developed to adjust mixing and drying times according to pulp characteristics. Additional improvements include adding a humidity sensor to the drying cabinet, increasing machine capacity for higher production volume, testing different types of paper waste, adding automatic paper-forming and cutting mechanisms, and conducting further research on pulp composition and natural adhesives to improve paper strength, thickness, and overall quality.

ACKNOWLEDGMENT

The authors gratefully acknowledge the Department of Electronic Engineering Education, Faculty of Engineering, Universitas Negeri Jakarta, for its valuable support, including the provision of laboratory facilities, research resources, and academic assistance throughout this study. The authors also extend their sincere appreciation to everyone who contributed ideas, assistance, and encouragement during the research and completion of this work.

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