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Motor control system and material direction of belt conveyor on Dosimat Feeder based on IoT with ESP32 at PT Semen Padang

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ABSTRACT

Uneven material distribution on the dosimat feeder belt conveyor at PT Semen Padang causes the belt to tilt, resulting in material spillage and decreased production efficiency. To address this issue, an Internet of Things (IoT)-based control system was designed to detect belt tilting and automatically guide the material back to the center of the belt. This system utilizes an ESP32 microcontroller, a load cell sensor to read load distribution, four limit switches (two for detecting tilting and two for detecting material that veers off the track), two servo motors to direct material from the right and left sides, and a buzzer to provide an alert when material goes off the track. Real-time monitoring is conducted through the Blynk platform. Testing results showed that the load cell sensor had an average error of 1.68%, with the highest error of 3.3% at a 100-gram load and the lowest error of 1.17% at 200 and 400 grams. The limit switches for tilt detection were activated at an 85-gram load to trigger the servo, while the limit switches for material off-track were activated at a 100-gram load to stop the system and activate the buzzer. This system has proven effective in reducing material loss and improving production efficiency.

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1. INTRODUCTION

Cement is a primary component in infrastructure development, with demand continuously increasing alongside economic growth in Indonesia [1]. As a hydraulic binder material, cement is produced from a mixture of clinker, gypsum, and additives such as limestone and pozzolan [2]. To support large-scale production processes, PT Semen Padang utilizes belt conveyors as the main means of transporting materials from mining sites to processing units [3]. One important stage in cement production is at the finish mill unit [4]. In this unit, raw materials are ground using grinding balls until the particle size meets the cement product standards [5]. Before entering the grinding process, materials such as gypsum, pozzolan, and limestone are first precisely regulated in terms of quantity and flow through the dosimat feeder system [6],[7]. This system heavily depends on the stability of material flow, especially when positioned on the belt conveyor.

However, in the dosimat feeder system, particularly in the belt conveyor section, issues of uneven material distribution are frequently observed [8]. This is generally caused by irregular or asymmetrical shapes of the material, making them prone to shifting as the belt moves [9]. This imbalance results in the material not being centered on the belt, which ultimately causes the conveyor to tilt and increases the risk of material spillage during transportation [10],[11]. If the tilt is too steep, material distribution becomes increasingly erratic and can reduce the overall conveyor carrying capacity [12],[13].

To address this problem, the implementation of Internet of Things (IoT) technology presents a potential solution. IoT technology enables integration between sensors, actuators, and network-based control systems, allowing real-time and remote monitoring and control of material distribution [14],[15]. In this context, the ESP32 microcontroller is an ideal choice due to its wireless connectivity capabilities that support IoT-based system implementation.

Through this research, an IoT-based control system was designed using ESP32 as the data processing center and main controller. The system is equipped with load cell sensors to read material load distribution, limit switches to detect tilt and material position, and servo motors to automatically direct the material to the center position. The main objective of developing this system is to maintain stable material distribution on the belt conveyor automatically, precisely, and efficiently. With the implementation of this system, it is expected that material spillage can be minimized, productivity increased, and operational efficiency at PT Semen Padang can be optimally improved.

2. METHOD

This research was conducted by designing and testing a prototype Internet of Things (IoT)-based system intended to automatically detect and direct material on the belt conveyor. The system was developed to address the problem of uneven material distribution, which often causes the belt conveyor to tilt during the transportation process. To help understand the relationship between the components used, an overall system block diagram is presented as shown in Figure 1.

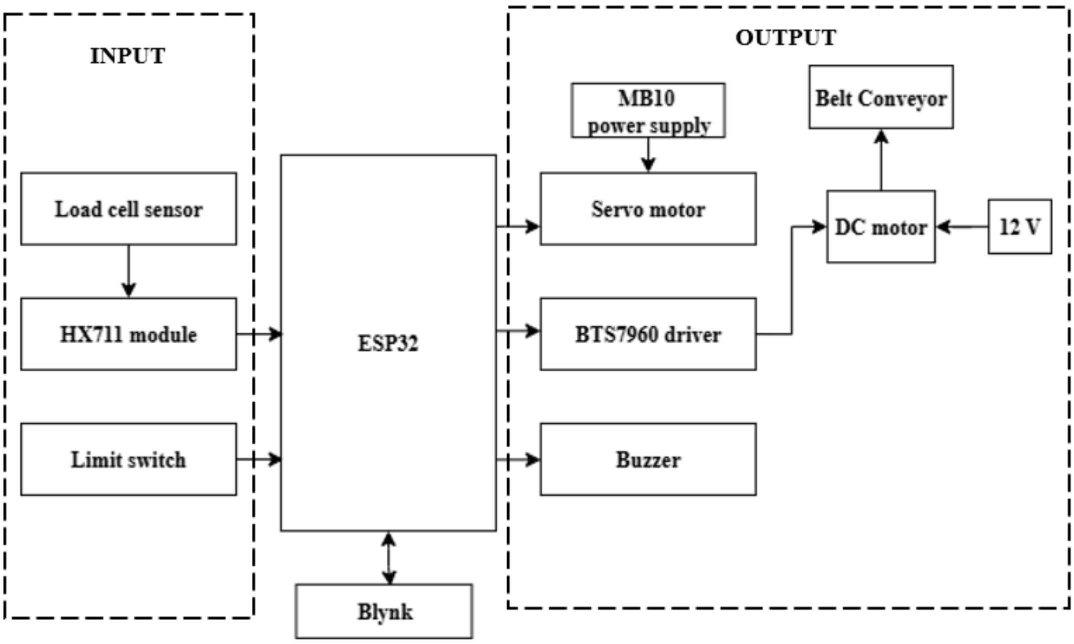

Figure 1. Block Diagram

Figure 1 shows the block diagram of the dosimat feeder system prototype. This diagram provides a basic overview of how the device works. It illustrates how all the components are interconnected, with the ESP32 microcontroller as the central controller. The input components in this system consist of a load cell sensor connected to the HX711 module and limit switches. Meanwhile, the output components include servo motors, the BTS7960 motor driver, a DC motor that drives the belt conveyor, and a buzzer. Below is an explanation of the functions of each block in the diagram. MB10 power supply as the voltage source for the servo motor. ESP32 as the main microcontroller that controls and manages the entire system. Load cell sensor to measure the weight of the material on the belt conveyor. HX711 module used to read signals from the load cell and send the data to the ESP32. Limit switch used to detect belt tilting and materials that fall out of alignment. Servo motor functions to redirect the material back to the center of the belt conveyor. BTS7960 motor driver used to control the speed of the DC motor. DC motor functions to drive the belt conveyor. Belt conveyor serves as the medium for transporting material from one process to another. Buzzer functions as an indicator when material is spilled. Blynk is used to monitor the entire system in real time.

This system operates automatically by relying on sensors and is controlled by an ESP32 microcontroller. A load cell sensor is used to measure the weight of the material, then sends the data to the ESP32 via the HX711 module. In addition, there are limit switches that function to detect belt tilting and material going off track. All sensor data is processed by the ESP32. Based on this data, the ESP32 adjusts the speed of the DC motor using a PWM signal sent to the BTS7960 motor driver, allowing the conveyor belt speed to be adapted to the material weight. If a tilt is detected, the ESP32 will activate the servo motor to redirect the material back to the center of the belt. However, if the material completely goes off track, the limit switch will trigger the ESP32 to stop the system and activate the buzzer as a warning. The entire process can be monitored in real time through the Blynk application, as the ESP32 is connected to a Wi-Fi network. The complete electrical circuit of this system is shown in Figure 2.

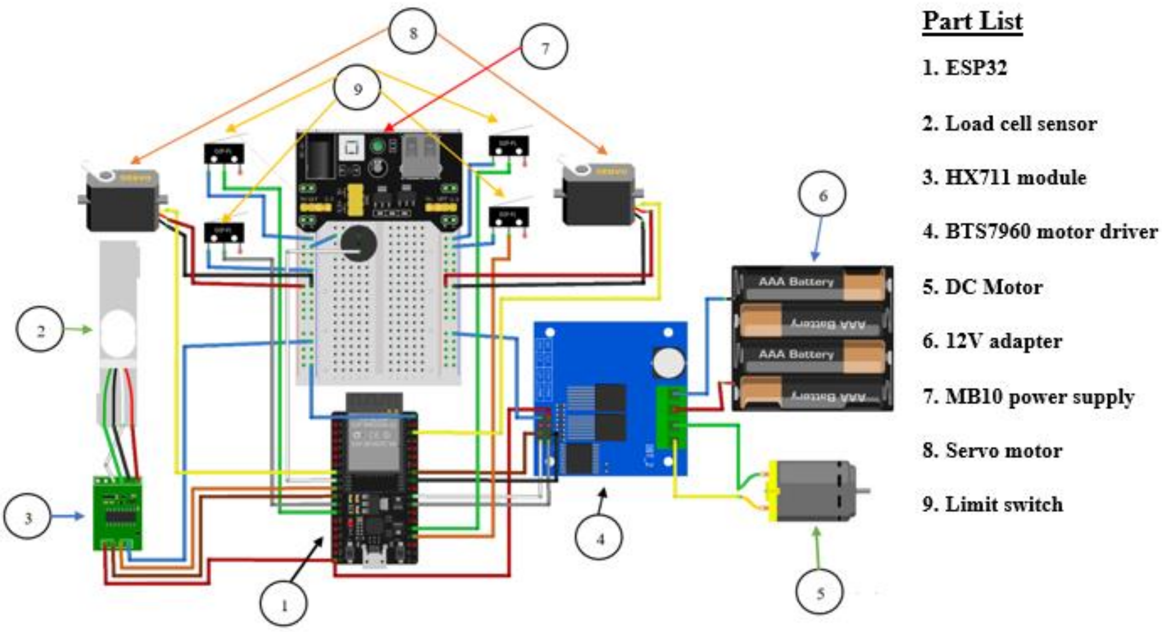

Figure 2. Overall Electrical Design of the System

In addition to the electrical design and system workflow, the mechanical aspect was also thoroughly designed by carefully arranging each component to function efficiently and in an integrated manner. This design includes the placement of the belt conveyor motor as the main component, along with the positioning of sensors, servo motors, and other supporting components. The mechanical design aims to ensure system stability and ease of assembly. The mechanical design of the system is shown in Figure 3.

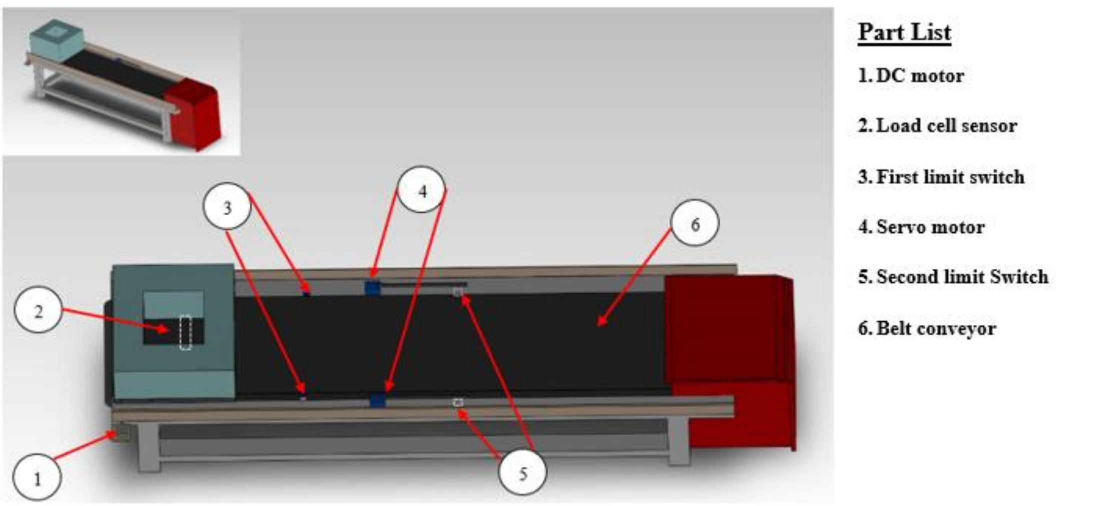

Figure 3. Overall Mechanical Design of the System

The operation of this system begins when the device is powered on and all components are initialized to be ready for operation. The DC motor drives the belt conveyor, while the load cell sensor becomes active and starts weighing the material moving on the belt. The weight readings are used to automatically adjust the motor speed. Throughout the process, the first set of limit switches, installed on the lower right and left sides of the conveyor belt, functions to detect any tilting. If no tilt is detected, the system continues to operate normally. However, if a tilt is detected, the servo motor will activate to redirect the material to the center of the belt. If the material still goes off track and hits the second set of limit switches, the system will stop, and the buzzer will turn on. The system can only resume after the off-track material is cleared, and the user presses the reset button on the Blynk application. The overall system workflow is illustrated in the flowchart shown in Figure 4.

Figure 4. Overall System Flowchart

The Blynk design is also an important part of this system, where the Blynk application is used to monitor and control the device in real time via an internet connection. The application interface displays material weight data, motor PWM values, the status of the servo and buzzer, and provides buttons for resetting the system and controlling the DC motor. The Blynk interface design is shown in Figure 5.

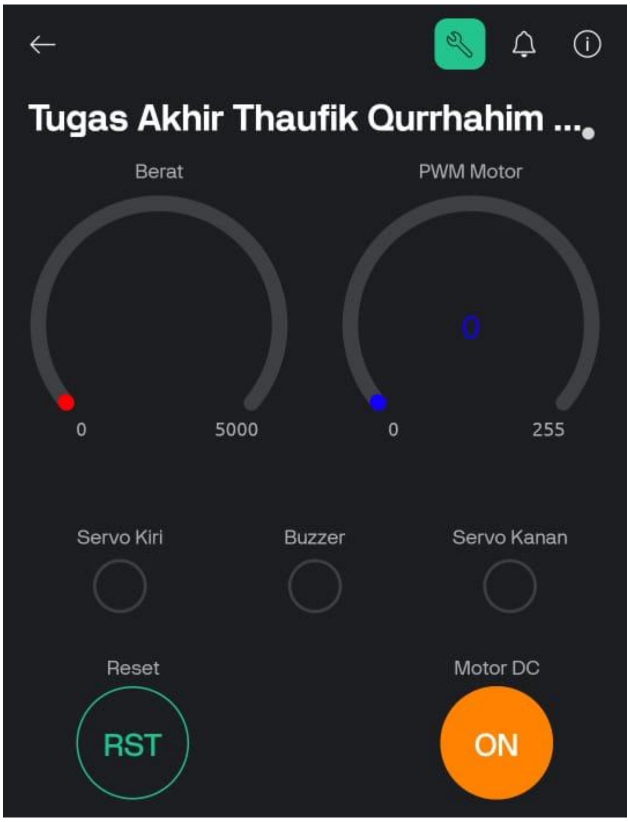

Figure 3. Overall Blynk Design of the System

3. RESULTS AND DISCUSSION

The testing focused on detecting belt conveyor tilt, reading the weight of the material, and evaluating the system's response to disturbances such as material going off track. The testing was carried out by placing pre-weighed materials and then comparing the results with the readings from the load cell sensor. The test results can be seen in Table 1. The PWM values were recorded according to the changes in weight, and the percentage error was calculated using the following formula:

$$Error\ (\%) = \left| \frac{Load\ cell\ reading - Actual\ Weight}{Actual\ Weight} \right| x\ 100\ ) \quad (1)$$

Table 1. Load Cell Testing Results Against Motor PWM

No	Material Weights (grams)	Materian Position	Load Cell Reading (grams)	Motor PWM	Weight Error
1	100	Center	105	252	3,3%
		Left	103	252	
		Right	102	252	
2	200	Center	204	249	1,17%
		Left	201	249	
		Right	202	249	
3	300	Center	306	246	1,2%
		Left	302	246	
		Right	303	246	
4	400	Center	408	243	1.17%
		Left	404	243	
		Right	402	243	
5	500	Center	509	240	1.4%
		Left	505	240	
		Right	507	240	
6	600	Center	614	237	1.86%
		Left	608	237	
		Right	612	237	
			Average error		1,68%

The testing for tilt detection aims to observe the system's response to belt tilting by placing material on either the right or left side under various load conditions. The activation of the first limit switch and the movement of the servo motor were then observed. The test results are presented in Table 2. The Testing for Off-Track Material Detection aims to observe the system's response when material goes off track on either the right or left side of the belt. The activation of the second limit switch and the buzzer was then observed. The test results are presented in Table 3.

Table 2. Performance Testing Results of the Tilt Detection System

No	Material Weights (grams)	Tilt Direction	First Limit Switch	Servo Motor
1	50	Right	Inactive	Off
2	85	Right	Active	Moving
3	100	Right	Active	Moving
4	50	Left	Inactive	Off
5	85	Left	Active	Moving
6	100	Left	Active	Moving

Table 3. Performance Testing Results of the Off-Track Material Detection System

No	Material Weights (grams)	Direction of Discarded Material	Second Limit Switch	Buzzer
1	50	Right	Inactive	Off
2	100	Right	Active	Sounding
3	150	Right	Active	Sounding
4	50	Left	Inactive	Off
5	100	Left	Active	Sounding
6	150	Left	Active	Sounding

Blynk Testing was conducted to compare the data displayed on the Blynk application with the direct readings from the serial monitor on the ESP32. The tested parameters included the material weight, motor PWM signal values, and LED indicators for the servo and buzzer status on the application. The servo LED lights up when the servo is actively moving, while the buzzer LED blinks when the buzzer emits a sound. The complete test results are presented in Table 4.

Table 4. Overall Blynk Testing Results

No	Data on Serial Monitor	Data on Blynk Application	Status
1	Weight: 153 g PWM motor: 251 Right servo: Off Left servo: Off Buzzer: Off	Weight Gauge: 153 g PWM motor Gauge: 251 Right Servo LED: Off Left Servo LED: Off Buzzer LED: Off	Match
2	Weight: 155 g PWM motor: 251 Right servo: Off Left servo: Off Buzzer: Off	Weight Gauge: 155 g PWM motor Gauge: 251 Right Servo LED: Off Left Servo LED: Off Buzzer LED: Off	Match
3	Weight: 152 g PWM motor: 251 Right servo: Off Left servo: Off Buzzer: Off	Weight Gauge: 152 g PWM motor Gauge: 251 Right Servo LED: Off Left Servo LED: Off Buzzer LED: Off	Match
4	Weight: 302 g PWM motor: 246 Right servo: Active Left servo: Off Buzzer: Off	Weight Gauge: 302 g PWM motor Gauge: 246 Right Servo LED: On Left Servo LED: Off Buzzer LED: Off	Match
5	Weight: 305 g PWM motor: 246 Right servo: Off Left servo: Active Buzzer: Off	Weight Gauge: 305 g PWM motor Gauge: 246 Right Servo LED: Off Left Servo LED: On Buzzer LED: Off	Match
6	Weight: 301 g PWM motor: 246 Right servo: Active Left servo: Active Buzzer: Off	Weight Gauge: 301 g PWM motor Gauge: 246 Right Servo LED: On Left Servo LED: On Buzzer LED: Off	Match

This test aims to evaluate the overall performance of the system, including the weight measurement by the load cell, motor PWM values, tilt and off-track material detection by the limit switches, as well as the responses of the servo motor and buzzer. The test results are presented in Table 5.

Table 5. Overall System Performance Testing Results

No	Material Weights (grams)	Load Cell Reading (grams)	First Limit Switch	Motor PWM	Second Limit Switch	Servo Motor	Buzzer
1	150	153	Inactive	251	Inactive	Off	Off
		153	Inactive	250	Inactive	Off	Off
		153	Inactive	251	Inactive	Off	Off
2	300	302	Right active	247	Inactive	Right Moving	Off
		305	Left active	247	Inactive	Left Moving	Off
		301	Both active	247	Inactive	Both Moving	Off
3	500	506	Both active	241	Inactive	Both Moving	Off
		507	Both active	241	Inactive	Both Moving	Off
		510	Inactive	240	Right active	Off	Sounding

After conducting a series of tests, an analysis of the obtained results was carried out to evaluate the overall performance of the system. Based on the data in table 1, the load cell sensor demonstrated fairly good accuracy in detecting the weight of materials in various positions, although there was a slight discrepancy due to calibration factors or mechanical conditions. This discrepancy was consistent, indicating that the load cell remains reliable. A comparison graph of the actual weight and the load cell readings is shown in Figure 6. The data show variations in sensor reading errors compared to the actual weight, with an average error of 1.68%. The highest error occurred at a 100 gram load with 3.3%, while the lowest was 1.17% at 200 and 400 grams. These values are still within the acceptable accuracy tolerance of 5%, indicating that the system is reasonably accurate. Factors such as reading stability and sensor calibration affect the level of accuracy.

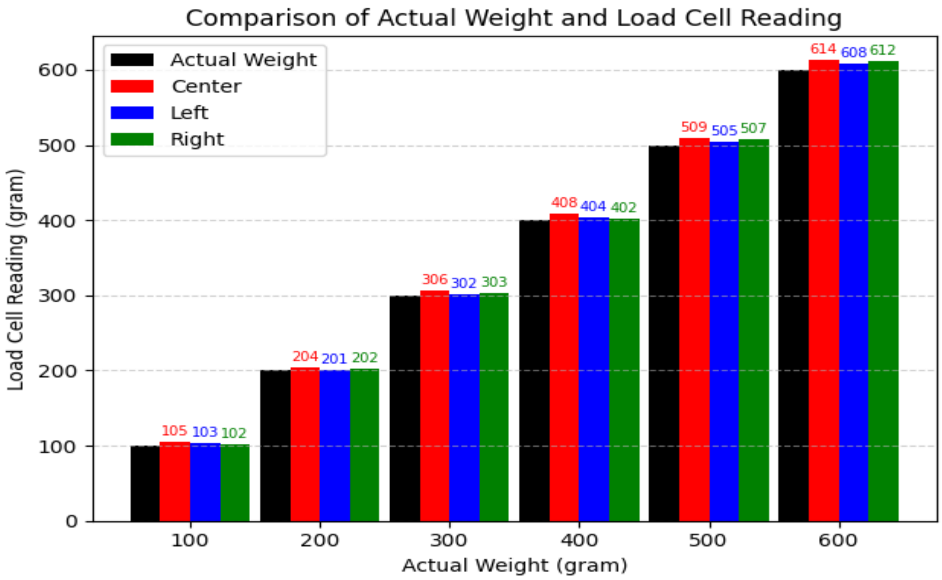

Figure 4. Comparison Chart of Actual Weight and Load Cell Readings

In addition, the data also show that the PWM value decreases as the material weight increases. This pattern indicates that the control system is functioning as intended slowing down the motor to maintain a stable material flow. This relationship is also visualized in the graph shown in Figure 7. Based on the data in table 2, the system did not respond to tilting when the material weighed 50 grams, as the limit switch was not activated. However, at 85 and 100 grams, the limit switch was triggered, and the servo motor accurately responded to the tilt direction, indicating that the system performed as expected. This suggests that tilt detection depends on the pressure exerted by the load, where lighter materials are not sufficient to activate the limit switch. Nevertheless, the system is still considered to function properly when the load is adequate, which is important to ensure that only materials with the potential to disrupt the flow are corrected by the system.

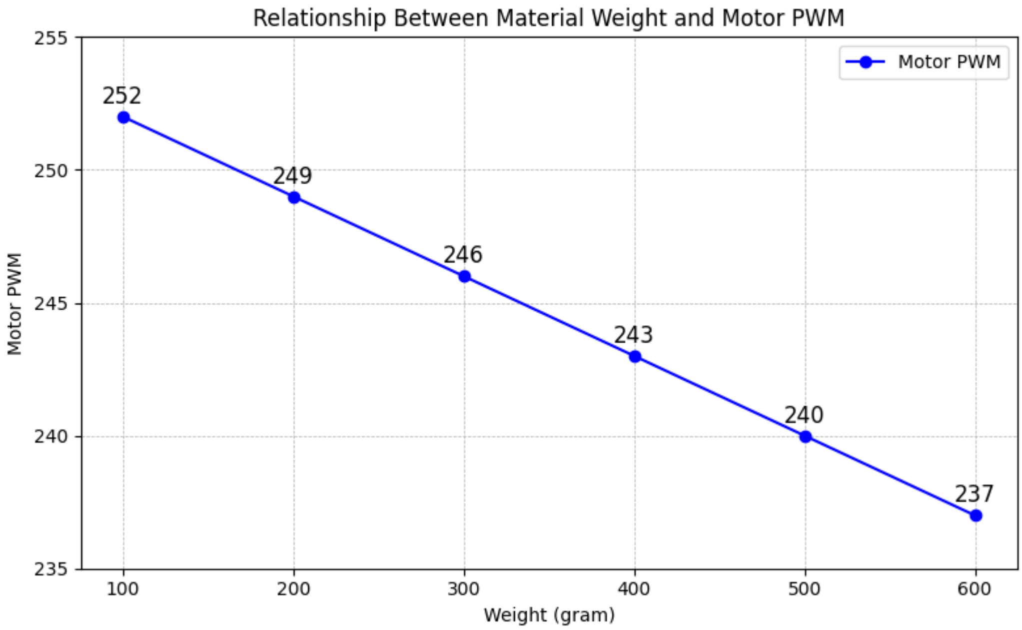

Figure 5. Chart of Material Weight Against Motor PWM Output

Based on the data in table 3, the test results show that when a 50-gram material went off track, the limit switch was not activated, as indicated by the buzzer remaining silent and the motor continuing to run. In contrast, at 100 and 150 grams, the limit switch was triggered, the buzzer sounded, and the motor stopped automatically indicating that the minimum load required to activate the limit switch is approximately 100 grams. Overall, the system was able to detect off-track material effectively. Although it did not respond to lighter loads, this is still acceptable, as the system is designed to handle materials with sufficient weight that could potentially interfere with its primary operation. Based on the data in Table 4, the system shows that the data from the serial monitor and the Blynk application are consistent and synchronized in terms of weight readings, motor PWM values, and the status of the servo and buzzer. Only in the eighth test was there a slight difference in values, which is suspected to be caused by a delay in data transmission, although this did not affect the overall performance of the system. The RST and ON/OFF buttons also functioned properly in controlling and resetting the system, indicating that remote control through the Blynk application is quite optimal, even though a slight delay occasionally occurs. The Blynk application is also able to represent the device's condition in real-time through the available LED indicators and gauges. Overall, the system was successfully tested and demonstrated reliable performance in both monitoring and automatic control. This proves that the integration between the hardware and the application works as expected.

Based on the data in Table 5, the system showed good responsiveness to the position of the material. At a load of 150 grams, the load cell reading was fairly accurate, but it was not sufficient to activate the first limit switch, so the servo motor did not operate. The second limit switch also remained inactive since the material had not gone off track, as indicated by the buzzer remaining silent. When the load reached 300 grams, the first limit switch began to activate whether from the right, left, or both sides indicating that the applied pressure was sufficient. This activation triggered the servo motor to redirect the material back to the center. Since the material had not gone off track, the second limit switch and buzzer remained inactive. At 500 grams, the material spread to both sides, causing both first limit switches to activate and both servo motors to move. In one of the tests, material went off track to the right side and activated the second limit switch, triggering the buzzer as a warning. The decrease in motor PWM values as the weight increased indicates that the system was able to adjust the motor speed in accordance with the control scheme. Overall, the system performed well in detecting tilt and redirecting the material. However, the placement of the limit switches still needs refinement to ensure responsiveness to lighter loads, so the system can operate more stably under various conditions.

3. CONCLUSION

Based on the results of the design, testing, and analysis, the system was successfully developed using the ESP32 as the main controller. The load cell was able to measure the material weight with an average error of 1.68%, with the highest error of 3.3% at a 100-gram load and the lowest of 1.17% at 200- and 400-gram loads. The first limit switch detected tilting and was activated at a load of 85 grams to trigger the servo motor, while the second limit switch was activated at 100 grams to stop the system and activate the buzzer when the material went off track. The system operated responsively and accurately, and supported real-time monitoring through the Blynk application. Overall, the system was found to be effective in reducing material waste and improving production efficiency. However, it is recommended to use a limit switch with a more sensitive actuator or to add a mechanical element that can more optimally transfer pressure to the limit switch, to ensure the system remains responsive under varying load conditions.

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