CENTIVE
Conference on Electrical Engineering, Informatics
, Industrial Technology, and Creative Media
ISBN : 978-602-53004-0-0

Data Acquisition System to Support Predictive Maintenance on Soft Laminator Machines in an Electronics Manufacturing Company

Deni Rahmat[1], Firdaus[2*], and Dwi Ana Ratna Wati[3]
[1,2,3]Department of Electrical Engineering,
Faculty of Industrial Engineering, Universitas Islam Indonesia
[1,2,3]Sleman, DI Yogyakarta, Indonesia
[*]firdaus@uii.ac.id

Abstract — This study presents the design and implementation of an Internet of Things (IoT)-based data acquisition system for a soft laminator (profile wrapping) machine used in electronic audio device manufacturing. The system aims to enable real-time monitoring of critical process parameters, including heater roll temperature, heater dry zone temperature, and roll spacing, which are essential for maintaining product quality and reducing machine downtime. The proposed system employs an ESP32 microcontroller integrated with DS18B20 temperature sensors and VL53L0X distance sensors, supported by an Ethernet W5500 module for reliable data transmission to a MySQL-based server. A web-based dashboard was developed to visualize sensor data, display alerts, and log historical records. Experimental results show that the system achieved high accuracy, with mean absolute errors of 0.38 °C (0.63%) for heater roll temperature, 0.44 °C (0.73%) for heater dry zone temperature, and 0 mm (0%) for all distance sensors, well within the industrial tolerance of ¡ 1%. Additionally, the indicator subsystem—consisting of LEDs and buzzers—responded consistently to simulated fault conditions such as sensor failure and network disconnection. Overall, the developed system demonstrates reliable performance for industrial monitoring applications and offers a foundation for implementing predictive maintenance in manufacturing environments.

Keywords – Internet of Things (IoT), Data Acquisition System, Soft Laminator, Sensor Monitoring, Predictive Maintenance

I. INTRODUCTION

One of the main machines used in the production of electronic audio devices is the soft laminator machine, also known as a profile wrapping machine, which plays a vital role in the manufacturing process (see Fig. 1). This machine is employed to coat the surface of wooden materials with a layer of PVC film (see Fig. 2). Lamination serves to protect the product from physical damage, moisture and UV exposure, while also improving the esthetic value of the final product [1]. The success of the lamination process is strongly influenced by the proper configuration of technical parameters such as the temperature of the heater roll, the temperature of the dry zone of the heater and the spacing between the rolls, all of which must be precisely controlled to achieve optimal results [1], [2].

Fig. 1. Soft laminator (profile wrapping) machine.

However, the current machine monitoring system remains manual, where operators periodically record parameters using conventional methods [3]. This approach introduces several issues, including inconsistent recording intervals, operator subjectivity, and potential errors or negligence during data logging [4]. These factors can lead to a decrease in lamination quality, delays in fault detection, and increased downtime that disrupts the production flow [5]. Downtime refers to a condition in which the machine cannot operate or perform its assigned tasks, caused by technical factors

Fig. 2. Lamination process performed by the Soft Laminator (Profile Wrapping) machine.

such as obsolescence, design failure, and wear, as well as social factors such as human error, fatigue, and lack of experience. Downtime negatively affects production rates and business profitability, therefore requiring minimization through optimization efforts such as planned maintenance to improve overall equipment effectiveness and company profitability [6].

The implementation of Internet of Things (IoT) technology offers a promising solution to address these challenges. By integrating temperature and distance sensors with a microcontroller-based system, the critical parameters of the laminator machine can be monitored in real time and transmitted directly to a central server without manual intervention [2], [4]. This system not only improves the accuracy and continuity of data, but also enables the application of predictive maintenance, a maintenance strategy based on the real-time assessment of machine conditions [4], [5].

Based on the background, this study aims to design and develop an IoT-based data acquisition system for the soft laminator machine at the partner company. The proposed system integrates temperature and distance sensors with a microcontroller and utilizes wireless connectivity for data transmission to a web-based user interface. This system is expected to improve operational efficiency, reduce potential recording errors, and support data-driven decision making within the industrial environment.

II. RESEARCH METHOD

The design of this data acquisition system aims to enable real-time and accurate monitoring of critical parameters in the soft laminator machine, including heater roll temperature, heater dry zone temperature, and roll spacing. The system is designed using an ESP32 microcontroller as the main processing unit, which is connected to a DS18B20 temperature sensor and a VL53L0X distance sensor.

The DS18B20 sensor was selected due to its ability to measure temperature within a range of 55 °C to 125 °C with an accuracy of ± 0.5 °C, meeting industrial measurement requirements and complying with the ISO 7726 standards on ergonomics of the thermal environment [7], [8]. This sensor is used to detect the temperature of the heater roll and the dry zone. Meanwhile, the VL53L0X sensor measures the distance between rolls with millimeter-level precision using time-of-flight (ToF) technology, according to the system's technical specifications.

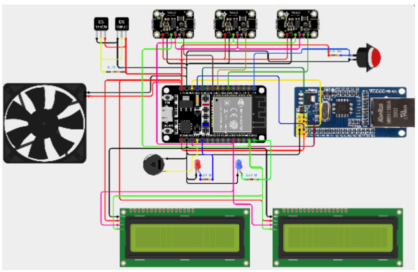
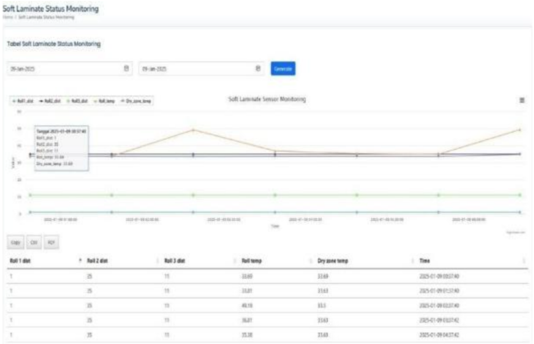


Fig. 3. Wiring diagram of the system.

For stable and reliable data transmission, the Ethernet W5500 module is utilized to communicate with ESP32 through the SPI protocol. Sensor data is periodically acquired, processed by the microcontroller, and transmitted to a local MySQL-based server using the HTTP protocol. The user interface is implemented as a web-based dashboard that displays temperature and distance readings in both graphical and numerical formats, and provides features such as abnormal condition notifications, historical data log, and data export to CSV or PDF formats.



Soft Laminate Status Monitoring

Tabel Soft Laminate Status Monitoring

Fig. 4. User interface of the system.

As a local alert mechanism, an LED indicator with color codes (red and blue) is integrated to display normal, warning, or critical status, along with a buzzer to signal error conditions—such as sensor read failures or network disconnection. The entire system has undergone a series of tests to evaluate sensor reading accuracy, Ethernet connection stability, and system response time to generate alerts.

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Fig. 5. Final implementation of the system on the Soft Laminator (Profile Wrapping) machine.

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III. RESULT

To ensure that the designed data acquisition system operates according to the specified technical requirements, a series of performance tests were conducted on several key parameters. These tests included evaluating the accuracy of sensor readings by comparing them with reference data obtained from the existing calibrated measurement instruments installed on the machine. In addition, the functionality of the system indicators—such as LEDs and buzzers—was tested to verify their ability to provide warnings under abnormal conditions, including sensor read failures or network connection interruptions. The results of these evaluations are presented and discussed in the following subsections.

A. *Sensor Data Accuracy*

The accuracy test was conducted to assess the performance of the temperature sensor (DS18B20) and the distance sensor (VL53L0X) used in the system. DS18B20 sensors were placed in the heater roll and heater dry zone areas, while VL53L0X sensors were installed to monitor the spacing between rolls (from Roll 1 to Roll 3). Data collection was performed 20 times over two consecutive days to obtain representative results that reflect the actual operating conditions of the machine.

Comparisons were made using calibrated reference instruments installed on the machine. The deviation between the sensor readings and the reference values was calculated using the Mean Absolute Error (MAE) method, as shown in Eq. (1). The results were then converted into a percentage error relative to the average reference value using Eq. (2).

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n} |\mathrm{Measurement}_i - \mathrm{Reference}_i| \qquad (1)$$

$$\mathrm{Error} = \frac{\mathrm{MAE}}{\text{Mean Reference}} \times 100 \qquad (2)$$

The Mean Absolute Error (MAE) was selected because it offers advantages over other evaluation methods in assessing sensor accuracy. MAE is a simple and easily interpretable metric as it calculates the average of the absolute differences between the sensor readings and the reference values, without considering the direction of the error. Consequently, MAE provides a clear indication of the magnitude of the measurement errors. Moreover, MAE is less sensitive to outliers and retains the same unit as the original data, making it more intuitive to interpret the level of precision of the measurement system [9].

The results of the temperature tests presented in Table 1 indicate that the average MAE of the DS18B20 sensor in the heater roll was 0.38 °C, with a corresponding percentage error of 0.63%, while the dry zone of the heater recorded an MAE of 0.44 °C and a percentage error of 0.73%. These error ranges are considered minimal and remain within acceptable tolerance limits for industrial applications [7].

Table 1. Data sensor DS18B20

No	Temperature (Heater Roll) (°C)			Temperature (Heater Dry Zone) (°C)		
	Ref	Sensor	Error	Ref	Sensor	Error
1	55.2	55.5	0.3	55.5	55.9	0.4
2	56.0	56.4	0.4	56.3	56.7	0.4
3	57.3	57.6	0.3	57.0	57.5	0.5
4	58.1	58.5	0.4	57.8	58.3	0.5
5	59.0	59.5	0.5	58.5	58.9	0.4
6	59.8	60.0	0.2	59.2	59.7	0.5
7	60.4	60.8	0.4	60.0	60.4	0.4
8	61.2	61.6	0.4	60.6	61.0	0.4
9	62.0	62.3	0.3	61.3	61.7	0.4
10	62.7	63.1	0.4	62.1	62.5	0.4
11	63.5	63.8	0.3	62.8	63.2	0.4
12	64.0	64.5	0.5	63.6	64.0	0.4
13	64.7	65.0	0.3	64.3	64.9	0.6
14	65.2	65.6	0.4	65.0	65.5	0.5
15	63.8	64.2	0.4	63.5	63.9	0.4
16	62.4	62.9	0.5	62.0	62.5	0.5
17	61.0	61.3	0.3	60.7	61.0	0.3
18	59.6	60.1	0.5	59.3	59.8	0.5
19	58.2	58.6	0.4	58.0	58.5	0.5
20	56.9	57.3	0.4	56.6	57.0	0.4

Meanwhile, testing of the three VL53L0X distance sensors used to measure the roll spacing yielded an MAE value of 0 mm with an error of 0%, as presented in Table 2 and summarized in Table 3. This result demonstrates that the distance sensors performed exceptionally well and remained highly stable under the tested operating conditions.

In general, the accuracy level of all sensors indicates that the designed data acquisition system demonstrates high performance and reliability to monitor the lamination process in an industrial manufacturing environment.

B. *System Indicator Function*

To ensure that the system can respond to abnormal conditions in real time, functional tests were conducted on the LED and buzzer indicators. These tests involved

Table 2. Data sensor VL53L0X

Distance Roll 1			Distance Roll 2			Distance Roll 3		
Ref (mm)	Sensor (mm)	Error (mm)	Ref (mm)	Sensor (mm)	Error (mm)	Ref (mm)	Sensor (mm)	Error (mm)
10	10	0	9	9	0	10	10	0
11	11	0	10	10	0	11	11	0
12	12	0	11	11	0	12	12	0
13	13	0	12	12	0	13	13	0
14	14	0	13	13	0	14	14	0
15	15	0	14	14	0	15	15	0
16	16	0	15	15	0	16	16	0
17	17	0	16	16	0	17	17	0
18	18	0	17	17	0	18	18	0
19	19	0	18	18	0	19	19	0
20	20	0	19	19	0	20	20	0
21	21	0	20	20	0	21	21	0
22	22	0	21	21	0	22	22	0
23	23	0	22	22	0	23	23	0
24	24	0	23	23	0	24	24	0
25	25	0	24	24	0	25	25	0
22	22	0	21	21	0	22	22	0
20	20	0	19	19	0	20	20	0
18	18	0	17	17	0	18	18	0
16	16	0	15	15	0	16	16	0

Table 3. MAE score

No	Sensor	Parameter	*MAE*	Error (%)
1	DS18B20	Temperature of *Heater Roll* (°C)	0.38	0.63
2		Temperature of *Heater Dry Zone* (°C)	0.44	0.73
3	VL53L0X	Distance of *Roll 1* (*mm*)	0	0
4		Distance of *Roll 2* (*mm*)	0	0
5		Distance of *Roll 3* (*mm*)	0	0

simulating several fault scenarios, including sensor read failures by the microcontroller and loss of internet connectivity.

Table 4 shows that when any sensor failed to transmit data or when the internet connection was disrupted, the system successfully activated the red LED and the buzzer according to the programmed logic.

In contrast, under normal operating conditions, the system indicated a safe status by turning on the blue LED, turning off the red LED, and deactivating the buzzer. The system's response to these condition changes was rapid and consistent.

These results confirm that the indicator features integrated into the developed data acquisition system can provide early warnings against operational disturbances. Consequently, this improves the reliability of the system and enables operators to respond more quickly to potential failures.

IV. CONCLUSSION

Based on the results of the design, implementation, and testing phases, several key conclusions can be drawn. The developed IoT-based system successfully monitored the temperature and distance parameters in accordance with the specified requirements. The testing results demonstrated high precision, with percentage errors of 0.63% for the heater roll temperature sensor, 0.73% for the heater dry zone temperature sensor and 0% for all distance sensors installed between Roll 1 and Roll 3. These error values meet the predefined specification threshold of less than 1%, confirming that the system performs reliably within industrial standards.

In addition, the indicator subsystem—consisting of LED and buzzer components—functioned effectively to provide alerts during fault conditions such as sensor read failures or loss of network connection. Beyond physical indicators, the system also demonstrated the ability to deliver real-time notifications through a web-based dashboard whenever any sensor parameter exceeded the predefined thresholds. This feature facilitates continuous monitoring and enables the operator team to take prompt corrective actions.

To further reduce machine downtime and enhance operational cost efficiency, several system improvements are recommended. First, upgrading components to industrial-grade versions is expected to improve overall system reliability. Second, integrating additional sensors—such as adhesive usage sensors and pull-test sensors—would allow comprehensive monitoring of all production parameters within the IoT system, allowing operators to focus on other critical tasks without the need for manual checks. Lastly, integrating the IoT system with the company's internal alarm infrastructure would allow alerts of abnormal conditions to be immediately displayed through audio or visual alarms in the production area, reducing the need for continuous dashboard monitoring.

Table 4. Indicator system functionality data

System Condition	Red LED	Blue LED	*Buzzer*	Expectation	Result
All sensors normal, good internet connection	Off	On	Off	LED Blue ON, LED Red OFF, *buzzer off*	**In line**
Sensor DS18B20-1 sensor off	On	Off	On	LED Red ON, *buzzer on*	**In line**
Sensor DS18B20-2 sensors off	On	Off	On	LED Red ON, *buzzer on*	**In line**
Sensor VL53L0X-1 sensor off	On	Off	On	LED Red ON, *buzzer on*	**In line**
Sensor VL53L0X-2 sensors off	On	Off	On	LED Red ON, *buzzer on*	**In line**
Sensor VL53L0X-3 sensors off	On	Off	On	LED Red ON, *buzzer on*	**In line**
No internet connection	On	Off	On	LED Red ON, *buzzer on*	**In line**
All sensors normal, good internet connection	Off	On	Off	LED Blue ON, LED Red OFF, *buzzer off*	**In line**

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