Advancing Textile Factory Efficiency: Implementing a Cost-Effective IoT-Based Alert System for Timely Machine Maintenance

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Abstract
This research aims to address the persistent challenge of delayed machine fault notification in textile factories through the development of a cost-efficient alert system tailored specifically for this industry. Delayed notification of machine faults often leads to substantial downtime and diminished operational efficiency in textile manufacturing settings, where workers must navigate cumbersome communication channels to inform management and request technical assistance. To overcome this obstacle, the project proposes the implementation of an alert system integrating Internet of Things (IoT) devices and wireless communication technologies. This system ensures the seamless transmission of real-time alerts, thereby enabling swift response to machine malfunctions. Accessible through intuitive user interfaces on handheld devices or strategically positioned control panels near machinery, the system streamlines the fault reporting process and reduces the time and manual effort required to notify floor supervisors and technicians. By facilitating rapid communication, this project aims to enhance operational efficiency and minimize production disruptions in textile factories.

Keywords
Machine Breakdown Maintenance, Alert System Implementation, Cost-efficiency, Downtime Reduction, Internet of Things (IoT) Integration.

1. Introduction
In many textile factories, the responsibility of reporting machine breakdowns falls on the workers or supervisors, who typically use their mobile phones or relay the information manually to managers or technicians. However, the time taken in this information transfer process can be substantial, leading to increased lead times and missed production deadlines. Thus, there is a clear need for an affordable system in this sector that streamlines the process, independent of the varied working procedures of the machinery, by allowing manual input from workers to notify technicians of breakdowns promptly. This project aims to develop such a system to facilitate breakdown maintenance, improving communication between supervisors and workers and ensuring swift notification of machine failures. By minimizing downtime and establishing an efficient fault resolution system, it will enhance operational productivity. Moreover, it will address challenges posed by remote machine placements, reducing repair delays and enhancing responsiveness. The target customers for this system are industrial and manufacturing companies with diverse production processes, including both large corporations and small-scale factories across various industries such as automotive, electronics, and consumer goods. The primary objective is to mitigate these shortcomings while ensuring a cost-effective implementation approach. However, many machines in textile and other factories lack such systems and are predominantly operated manually.

Concerns may arise regarding the use of traditional communication methods, such as manual phone calls between workers and managers to report machine faults, which can result in time wastage and communication gaps. The proposed Alarm System for Machine Maintenance addresses this challenge by offering a proactive solution that integrates manual alerts with real-time layout plan visualization. By doing so, it aims to substantially enhance maintenance efficiency and operational productivity.

2. Literature Review
Industrial machinery maintenance has traditionally relied on periodic inspections and reactive measures, resulting in costly downtime and reduced productivity. Recent technological advancements have spurred the development of innovative systems aimed at enhancing maintenance practices. Sensor-based monitoring systems, for instance, have gained traction for their ability to automatically detect and predict machine faults by leveraging data from various sensors monitoring parameters like temperature, vibration, and power consumption.

For instance, Venkata Subbaiah et al. (2018) introduced an IoT system based on Raspberry Pi, monitoring industrial environments through temperature, gas, and pressure sensors, though not addressing machine breakdowns directly [1]. Similarly, Islam et al. (2023) proposed an IoT-based industrial fault detection system using sensors for fire, gas, and temperature, limited to specific categories of adversaries [2]. Additional sensors or diagnostic technologies may be required to address machine breakdowns comprehensively.

Several other studies have explored similar sensor-based approaches, monitoring parameters such as power line currents, motion, and magnetic flux, to detect deviations from normal machine operations [3] [4] [5] [6]. Despite their promise, sensor-based systems may not capture all potential issues, particularly those stemming from external factors or irregular anomalies.

Real-time monitoring and visualization of industrial machines have been investigated extensively through IoT-based solutions. For instance, studies like "An advanced Internet of Things-based Security Alert System for Smart Home" [7] and "GUI-based Industrial Monitoring and Control System" [8] have addressed challenges in existing systems while proposing advanced monitoring solutions. Similarly, "Real-time Manufacturing Machine and System Performance Monitoring Using Internet of Things" introduced a framework for real-time performance assessment [10].

Moreover, specific systems like the one presented in "Smart Monitoring System using NodeMCU for Maintenance of Production Machines" utilize sensors to detect machine failures and notify technicians promptly [11]. Additionally, Joshi and Kulkarni (2019) developed a system utilizing Raspberry Pi, Arduino, and NodeMCU for manual input of machine breakdowns, mitigating communication delays [12].

Artificial intelligence (AI) has also been explored for fault prediction and detection. Bhavana et al. (Year) proposed an IoT-enabled fault prediction system using machine learning [13], while Ciaburro demonstrated machine fault detection using AI algorithms [14].

Certain studies focus on specific machine types, such as CNC machines, with systems like "IoT Enabled Real-Time Availability and Condition Monitoring of CNC Machines," providing real-time data for preventive maintenance [15]. Moreover, some systems aim to prevent theft and unauthorized access using motion detectors and IoT platforms [16][17].

Overall, these studies reflect a growing interest in enhancing machine maintenance systems, with a trend toward sensor-based detection, AI-driven fault prediction, and real-time visualization. Our proposed Alarm System for Machine Maintenance aims to contribute to this trend by providing a comprehensive solution that combines manual alerts with real-time visualization, thereby improving maintenance efficiency and productivity significantly.

3. Methodology
3. 1 Workflow of the system
The system features easily accessible alert buttons positioned near each machine, enabling prompt reporting of malfunctions when triggered. Its operation is structured around two primary modules: the NodeMCU, tasked with alert generation, and Unity, serving as the user interface. Specifically, the NodeMCU module generates HTTP responses and JSON files upon button activation, while the Unity module intercepts and presents these signals within the interface, ensuring users can readily access and respond to pertinent alerts.

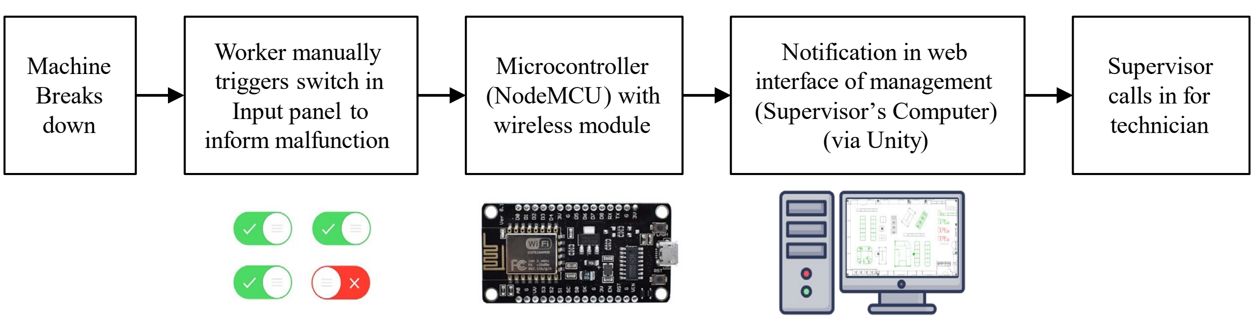


Figure 1: Workflow of the system

3. 2 Survey

To develop a system that resonates with industry demands, a comprehensive understanding of customer requirements is essential. So, we've taken customer responses regarding a prospective industry system to uncover the most critical features and qualities that should be integrated into the envisioned system. The subsequent summary includes the responses, highlighting key elements most resonating industry's needs in the form of Pareto chart to prioritize customers' most wanted features.

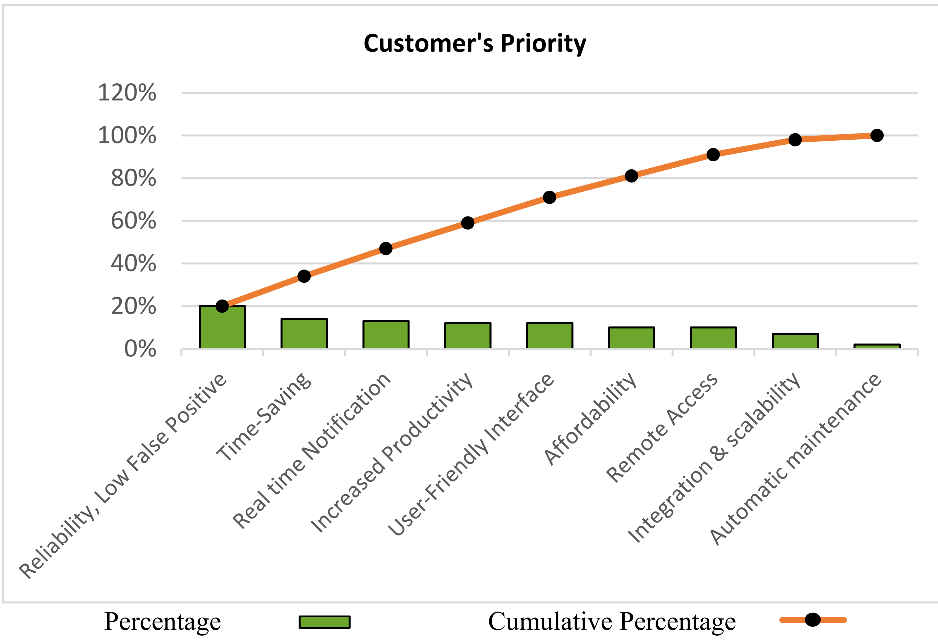


Figure 2: Pareto chart of customer's priorities

Using the pareto chart, we can assume that Increased Reliability, Time-saving, Real-time response, User-friendliness, Alert system for maintenance, Notification via mobile/web, Flexibility, and Communication are the benefits and features customers will prioritize when deciding to implement a system like this. So, these benefits and features should be focused on when developing the system.

3. 3 Quality Function Deployment (QFD)

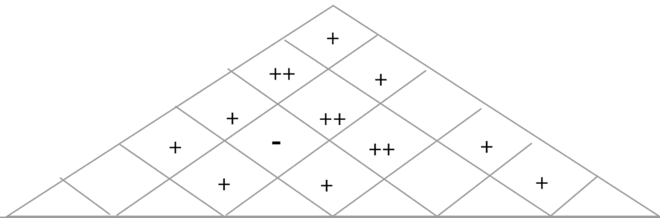
In our research, we applied Quality Function Deployment (QFD), commonly referred to as the House of Quality, to synchronize customer requirements obtained from surveys with the technical characteristics of our alert system. By utilizing the House of Quality, we pinpointed the essential technical prerequisites, emphasizing customers' priorities such as remote access to the computerized layout, the delivery of clear notifications to designated personnel's mobile devices, and improved comprehensibility for workers. Consequently, these identified design specifications have been prioritized in our developmental process, directing resource allocation towards these critical technical dimensions.

Correlation:

++	+	-	--
Very Positive	Positive	Negative	Very Negative

Relationships:

10	5	2	0
Strong	Moderate	Weak	Null
●	○	▲	



	1: low, 5: high Customer importance rating (out of 5)	Functional Requirements (How's) → Customer Requirements - (What's) ↓	Micro Controller	LED & Buzzer	Wireless Module	Computerized Layout	Battery	Better Input panel	Weighted Score
		Desired direction of improvement (↑,0,↓)							
1	5	Inrceased Productivity	●	○	●	●		○	200
2	5	Reliability	○	○			●		100
3	4	Time-saving	●	●	●	●		○	180
4	2	Real Time Response	●	●	●	●			80
5	5	User friendliness		●		●		●	150
6	1	Flexibility of scaling	○		○	●		○	25
7	3	Notification alert	○	○	●			●	90
8	3	Affordability	○	○			▲		21
9	2	Automatic maintenance							0
		Technical importance score	190	155	145	170	56	130	846
		Importance %	22%	18%	17%	20%	7%	15%	100%
		Priorities rank	**1**	**3**	**4**	**2**	**6**	**5**	

Figure 3: Quality Function Deployment table

3. 4 Black Box

Employing the black box methodology in product design redirects attention towards the system's input and output dynamics, rather than delving into its internal workings. This strategic shift provides valuable insights into the product's functionality, facilitating a more transparent comprehension of its operational intricacies.

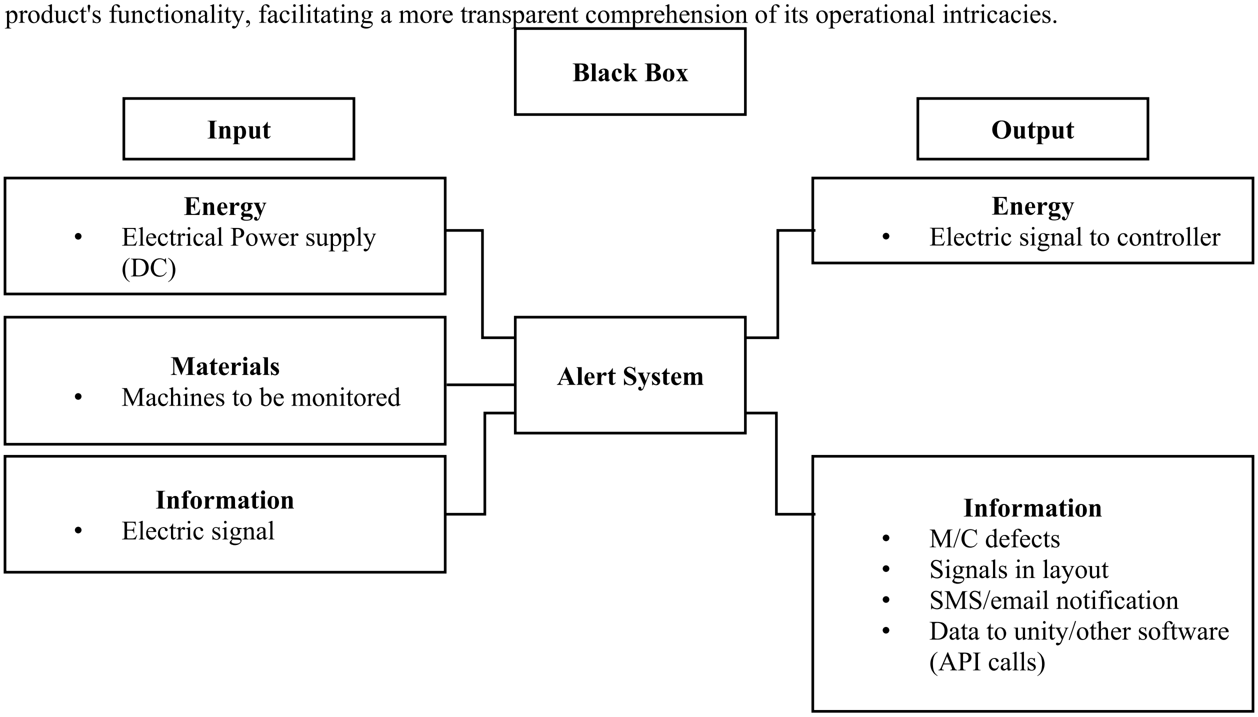


Figure 4: Black Box model

3. 5 Functional Decomposition

The alert system's functional breakdown reveals a dual structure of software and hardware components. Software elements encompass the Unity Module for interface development, a database for data storage, output layout generation, and a notification system. Hardware components are divided into the base (including plastic body, wiring, Veroboard, AC/DC electric supply, and NodeMCU), human interface (featuring power and signal switches), and signal unit (comprising signal light and buzzer). This concise overview emphasizes the system's integrated approach, combining software and hardware functionalities for efficient operation.

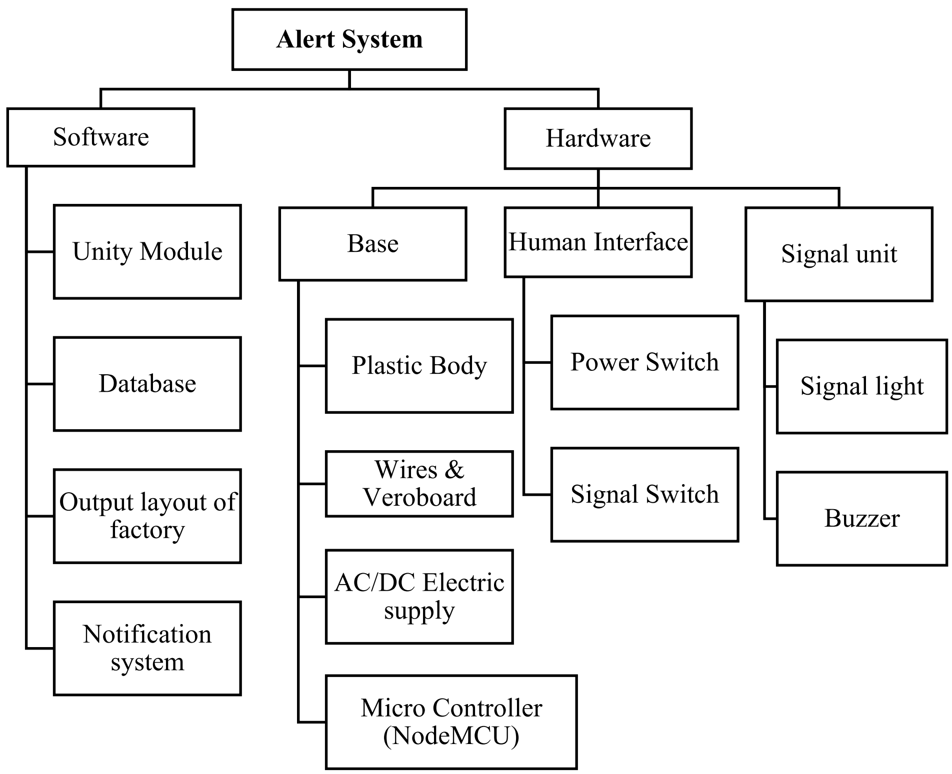


Figure 5: Functional Decomposition

3. 6 Design Analysis

We've conducted a design analysis of a product developed using SolidWorks. This assessment delves into the product's form, function, and engineering aspects. Our design is created in SOLIDWORKS 2020 program, consisting of Parts design, and Assembly design. We have created a box that can be assembled and disassembled easily. This box contains a buzzer, notification lights, and switches for the workers to press. It also contains the microcontroller and electronic circuits for the product.

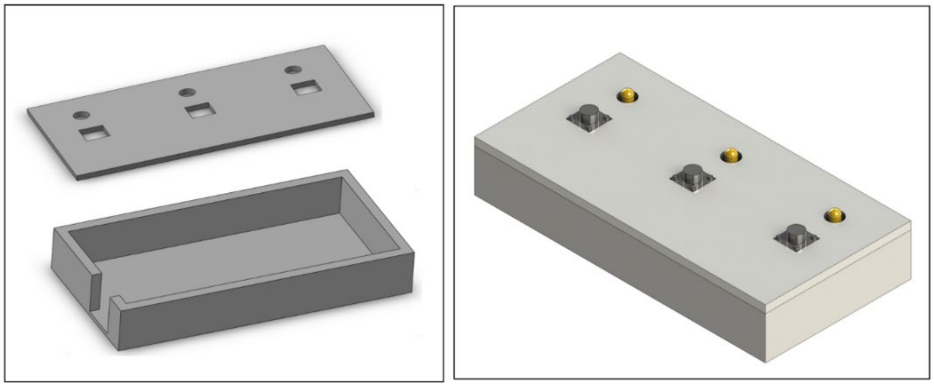


Figure 6: Design of module

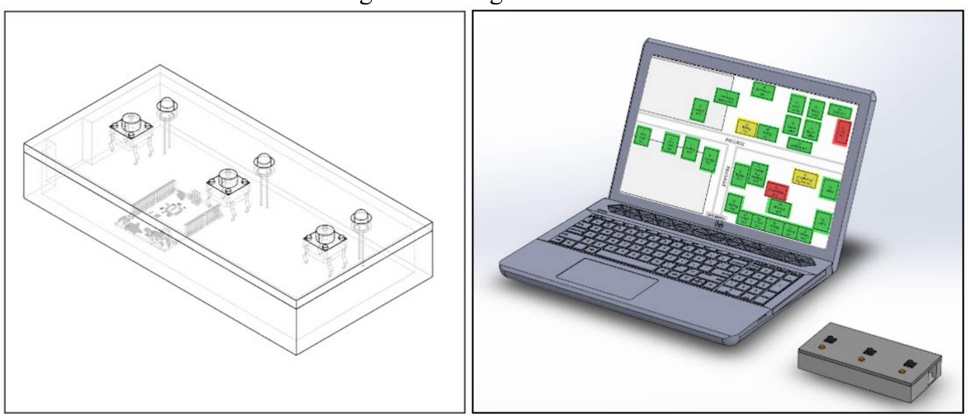


Figure 7: Design of module

3. 7 Material Selection

In the process of material selection for manufacturing, it is crucial to consider the diverse functions and technical requirements of each product component. Achieving optimal performance entails aligning materials with the specific needs of individual parts. The Weighted Average Method serves as a valuable tool in this selection process by assigning weights to technical properties and achieving a balanced solution. By considering both properties and weights, this method enables the identification of the most suitable material for each part based on a weighted average assessment. This approach is exemplified in the selection process for the enclosure of the box and the Microcontroller.

3. 7. 1 Material Selection for Switch and Body/Enclosure

The selection criteria undergo comparative analysis to identify the most significant factors within each pair, culminating in the determination of the most influential criteria. These criteria, along with their respective emphasis levels, are crucial for employing the weighted average method to ascertain the optimal material choice. In this context, handling comfort and cost emerge as the primary considerations guiding the material selection process.

Table 1: Determination of relative performance of selection criteria using Digital Logic Method

Selection Criteria	Number of positive decisions, N = n(n-1)/2 = 6(6-1)/2 = 15																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Positive Decisions	Relative emphasis co-efficient, α
Cost	1	1	0	1	1											4	0.267
Environment Conditions	0					1	0	1	0							2	0.133
Mechanical Strength		0				0				0	1	1				2	0.133

Handling Comfort			1			1			1			0	1			4	0.267
Electrical Properties				0			0			0		1		1		2	0.133
Chemical Resistance					0			1			0		0	0		1	0.067
																∑ Positive Decisions = 15	∑α = 1

In our research, Table 2 will serve as the basis for comparative analysis of different properties outlined in Table 3.

Table 2: Relative evaluation values

Very High	5
High	4
Medium	3
Low	2
Very Low	1

Properties of materials were assessed utilizing data from Machinery's Handbook and online sources. Comparative ratings between 1 and 5 were assigned to each material, as detailed in Table 3.

Table 3: Chart for evaluation

Selection Criteria	Stainless Steel	Plastic
Cost	4	2
Environment Conditions	4	3
Mechanical strength	5	1
Handling Comfort	3	4
Chemical resistance	4	3
Electrical Properties	3	3

In Table 4, a weighted average calculation is conducted to determine the most impactful material choice for the alert system. Analysis of the results indicates that plastic demonstrates a superior performance index compared to stainless steel. Consequently, plastic is selected as the preferred material for the enclosure over stainless steel.

Table 4: Calculation of Performance Index:

Selection Criteria	Weighting Factor, α	Stainless Steel		Plastic	
		Scaled Property, β	Weighted Score, α β	Scaled Property, β	Weighted Score, α β
Cost	0.267	50	13.35	100	26.7
Environment Conditions	0.133	100	13.3	75	9.98
Mechanical Strength	0.133	100	13.3	20	2.66
Handling Comfort	0.267	75	20.02	100	26.7
Electrical Properties	0.133	100	13.3	100	13.3
Chemical Resistance	0.067	100	6.7	75	5.03

Performance Index (γ)			∑ α β=79.97		∑ α β=84.37

3. 7. 2 Material Selection for Micro-controller

The evaluation of selection criteria involves a comparative assessment to identify the dominant factor within each criterion pair. Ultimately, the most significant criteria and their relative importance are determined. As illustrated in the table, cost emerges as the primary consideration in this context.

Table 5: Determination of relative performance of selection criteria using Digital Logic Method

Selection Criteria	Number of positive decisions, N = n(n-1)/2 = 5(5-1)/2 = 10											
	1	2	3	4	5	6	7	8	9	10	Positive Decisions	Relative Emphasis Co-efficient , α
Cost	1	1	0	1	1						4	0.4
Processing Power	0					1	0	0	1		2	0.2
Memory		0				0				1	1	0.1
Power consumption			1				1			0	2	0.2
Longevity				0				1			1	0.1
									∑ Positive Decisions		= 10	∑α = 1

Table 6 will serve as the basis for comparative analysis of different properties outlined in Table 7.

Table 6: Relative evaluation values

Very High	5
High	4
Medium	3
Low	2
Very Low	1

The properties of different materials were researched using internet sources and reference books, and comparative ratings between 1 and 5 were assigned to each material, as outlined in Table 7.

Table 7: Chart for evaluation

Selection Criteria	NodeMCU	Arduino
Cost	2	4
Longevity	3	3
Power Consumption	3	4
Memory	3	4
Processing Power	3	4

The table provided facilitates the calculation of weighted averages to determine the most suitable material for the alert system. Analysis from Table 8 indicates that NodeMCU exhibits a superior performance index compared to Arduino. Consequently, NodeMCU has been selected as the preferred microcontroller for the system.

Table 8: Calculation of Performance Index

Selection Criteria	Weighting Factor, α	NodeMCU		Arduino	
		Scaled Property, β	Weighted Score, α β	Scaled Property, β	Weighted Score, α β
Cost	0.4	100	40	50	20
Processing power	0.2	75	15	100	20
Power Consumption	0.2	100	20	75	15
Memory	0.1	75	7.5	100	10
Longevity	0.1	100	10	100	10
Performance Index (γ)			∑ α β=92.5		∑ α β=75

4. Result & Discussion

The iterative development process of the alert system involved several design iterations aimed at ensuring alignment with specified requirements and cost constraints. Through these iterative cycles, adjustments and refinements were made to enhance the system's functionality and efficiency. Subsequently, the finalized prototype underwent rigorous testing to validate its performance and functionality. The testing phase involved various scenarios to assess the system's robustness and reliability under different conditions. Results from these tests demonstrate the successful performance of the manufactured prototype, affirming its readiness for practical deployment and potential scalability. This iterative approach to design and testing underscores the system's robustness and effectiveness in meeting the intended objectives, laying a solid foundation for future advancements and applications in real-world settings.

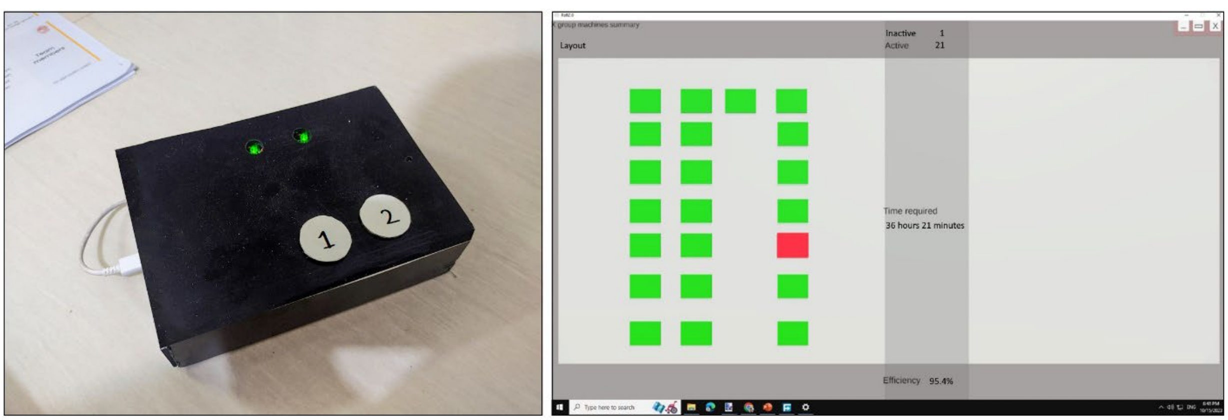


Figure 8: Prototype module and software

5. Conclusion

In contexts where conventional plug-and-play sensor-based breakdown monitor systems exhibit limitations, the present system stands out for its simplicity, cost-effectiveness, and semi-automated capabilities. Through rigorous validation, this system has effectively achieved its stated objectives. However, to maximize its utility and overcome potential limitations, the imperative pursuit of a fully automated iteration emerges as a pivotal priority. Moving forward, it is strongly recommended to prioritize the development of a fully automated system to unleash its full potential and ensure seamless adaptability across diverse operational environments. This strategic focus aligns with the trajectory of advancing technology and underscores the commitment to continuous improvement in system performance and efficacy.

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