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Smart manufacturing system based on industrial internet of things

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Abstract

The primary challenge in the manufacturing industry today is the subpar productivity and efficiency in production processes. This predicament can be attributed to the widespread utilization of suboptimal production systems and the underutilization of advanced technology in manufacturing. Furthermore, the lack of accurate production data, limited employee involvement in production processes, and the high costs associated with production and machine maintenance have emerged as significant concerns in the contemporary manufacturing landscape. In response to these challenges, the adoption of Smart Manufacturing Systems (SMS) based on the Industrial Internet of Things (IIoT) has become crucial to address these issues andenhance overall production quality and efficiency. The SMS IIoT system empowers companies to gather real-time data from various industrial devices and machines. This data is subsequently analyzed to optimize production processes, resulting in increased efficiency and productivity. With this system in place, companies can closely monitor production processes in real-time and promptly detect and address defective or non-compliant products at the onset of production. The research results show an availability value of 88%, indicating that the machine operates 88% of the scheduled time. A Performance value of 100% indicates that the engine is operating at the desired maximum speed. Overall Equipment Effectiveness(OEE) is calculated as the product of availability, performance, and quality of rate. With a value of 88%, OEE reflects the overall level of effectiveness of the machine in the production process. This paper highlights the significance of IIoT-based smart manufacturing systems in addressing the prevailing challenges encountered by the manufacturing industry.

Keywords:
Industry, IIOT, smart manufacturing, sensor.

1 Introduction

The manufacturing industry is a highly significant sector in the Indonesian economy. According to data from the Central Statistics Agency (BPS) [1][2], the manufacturing sector is the second-largest contributor to Indonesia's Gross Domestic Product (GDP), following the trade sector. In the fourth quarter of 2021, the manufacturing sector accounted for approximately 19.22 percent of Indonesia's total GDP [3]. This sector comprises a wide range of industries, including food, textiles, apparel, wood, paper, chemicals, pharmaceuticals, electronics, and automotive, among others [2].

Currently, the manufacturing industry in Indonesia faces various challenges, such as issues with infrastructure, complex bureaucracy, and a shortage of skilled labor. Despite Indonesia's substantial manufacturing sector, many manufacturing companies still carry out production processes manually [3][4]. This is due to several factors, including a lack of investment in technology and a shortage of skilled labor in industrial technology.

Therefore, we propose a research study titled “Smart Manufacturing System (SMS) based on the Industrial Internet of Things (IIoT)”. This IIoT-based smart manufacturing system is an intelligent manufacturing system that utilizes IoT technology to enhance efficiency and productivity in the manufacturing environment [5][6][7]. It includes IoT devices such as sensors, software, and hardware interconnected through networks, enabling them to monitor, control, and optimize manufacturing processes [6][8][9]. The system also incorporates technologies like Artificial Intelligence (AI) [10][11], machine learning, data analytics, and cloud computing to collect and analyze data from various sources in real-time [12][13][14].

The stages in designing an IIoT-based SMS include determining requirements, selecting IoT devices, creating network systems, developing applications, connecting to servers, conducting testing and validation, and maintenance and improvement [7][15]. By harnessing the gathered data, this system can optimize production, predict machine failures before they occur, and reduce production downtime. The advantages of the smart manufacturing system IIoT include enhanced production efficiency and quality, reduced production costs, accelerated time to market for products [13], and improved production management [10][16][17]. This system also enables manufacturers to quickly adapt to changing market demands and strengthen their competitiveness in the global marketplace.

Overall, to address challenges in the manufacturing industry related to efficiency, quality, and production process monitoring, this research introduces a study aimed at designing a prototype of a Smart Manufacturing System (SMS) based on the Industrial Internet of Things (IIoT). This prototype is intended to enable automated monitoring and control of the production process. The primary focus of this research is on four key aspects: designing an automated SMS prototype based on IIoT, selecting suitable sensors and IIoT devices for integration with existing production systems, developing an intuitive user interface, and designing an effective strategy for real-time sensor data collection, transmission, and analysis. By tackling these issues, this research aims to advance the manufacturing industry by providing innovative and efficient solutions through the implementation of IIoT-based technology.

2 Methodology

2.1 Research Stage

The research methodology applied in this study is as follows:1) Literature review: begin with an extensive literature review to identify the existing research and technologies related to smart manufacturing systems and production process monitoring. 2) Proof of concept: develop a proof of concept for the smart manufacturing system. This involves designing and implementing a prototype or simulation of the system to demonstrate its unique features and functionalities. 3) Comparative analysis: conduct a comparative analysis of existing production process monitoring methods and conventional manufacturing systems. 4) Expert interviews: engage in interviews with industry experts, practitioners, and researchers in the field of production process monitoring and smart systems.5) User surveys and feedback: administer surveys or gather feedback from potential users or stakeholders who would benefit from the smart manufacturing system.

2.2 System Overview

A smart manufacturing system based on the Industrial Internet of Things (IIoT) using a mobile app involves integrating mobile technology into the industrial environment for monitoring, control,and management. Here are the key working principles of such a prototype: sensors are strategically placed on machinery and equipment to capture real-time data on variables like temperature, pressure, vibration, and production metrics. Then,mobile devices (smartphones or tablets) are integrated into the IIoT ecosystem using secure communication protocols (e.g., MQTT or HTTP) to connect with sensors and edge devices.Furthermore, data collected from sensors is transmitted to cloud-based storage for centralized storage and processing, it also features a user-friendly interface designed for easy monitoring and control of manufacturing processes. Next,the app displays real-time data, alerts, and notifications related to production status, machine health, and other critical metrics. Furthermore,the app provides real-time alerts for abnormal conditions or potential issues in the manufacturing process, enabling quick response and preventive actions.The mobile app may include basic analytics features, providing insights into historical data trends and performance metrics such as graphs, charts, and other visualization tools to help users interpret data and make informed decisions.By combining IIoT principles with mobile technology, this smart manufacturing system prototype enhances accessibility, flexibility, and responsiveness, allowing stakeholders to monitor and control manufacturing processes conveniently using their mobile devices.

Fig. 1shows anoverview system, where a smart manufacturing system is a digital tool that helps manufacturers improve their production processes by providing real-time visibility into equipment status, performance, and production line activity. The system typically consists of a hardware device that is installed at each machine or workstation, along with a software platform that collects and displays data from the devices. The alert is then displayed on a dashboard, allowing managers to identify the issue and take corrective action quickly. Smart manufacturing systems can also provide real-time performance metrics, such as Overall Equipment Effectiveness (OEE), cycle time, and downtime, which can be used to identify trends and areas for improvement.

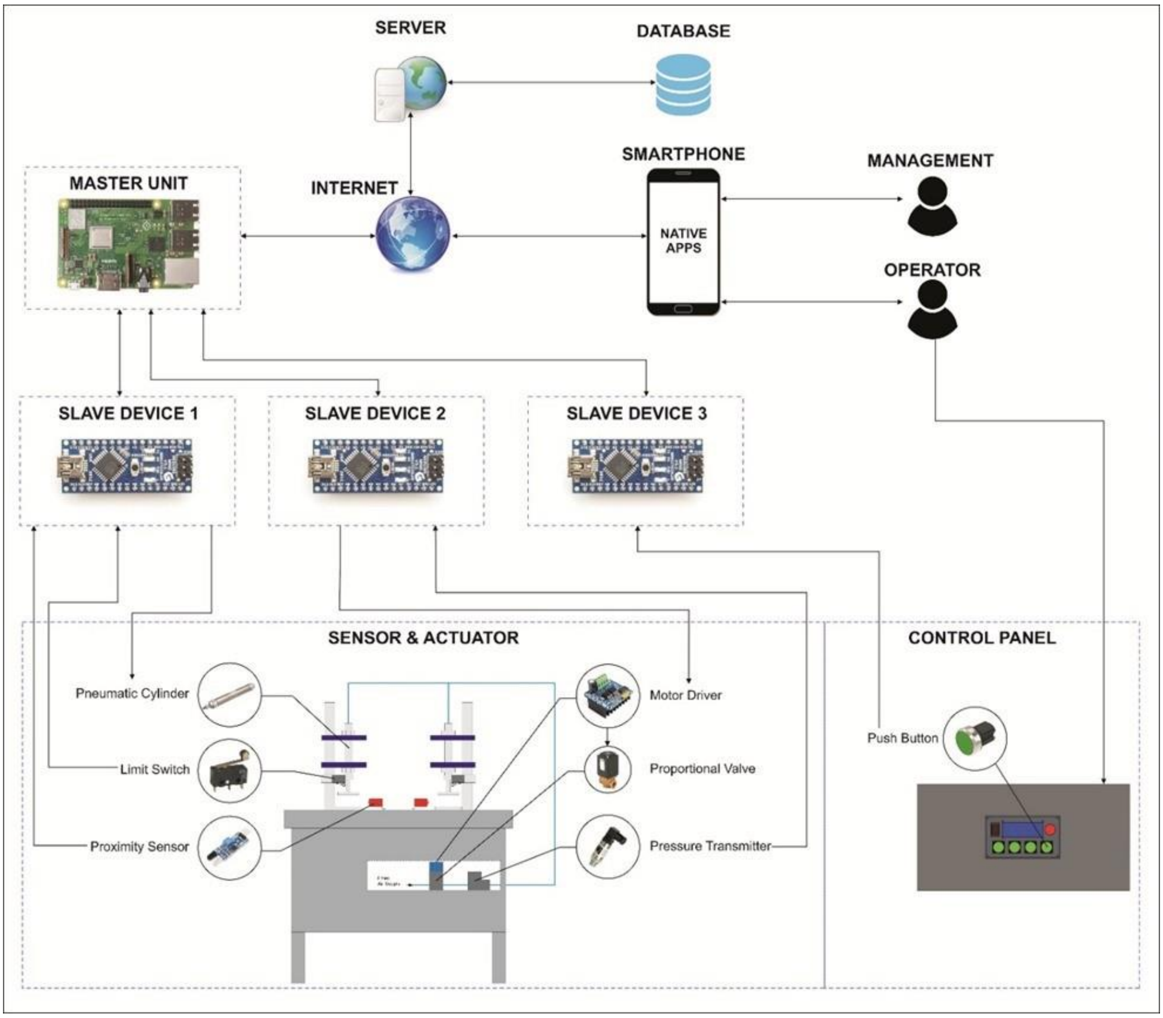


Fig. 1. System overview.

3 Result and Discussion

3.1 Prototype of Smart Manufacturing System

Fig. 2 provides a front view of the previously designed prototype of the press machine. The materials used in its construction include aluminum plates, aluminum profiles, and acrylic. Notably, the image reveals the presence of the control panel, limit switch, infraredsensor, proportional valve, and pressure transmitter.The prototype of a mobile-based smart manufacturingsystem typically includes the following components and functionalities: 1)User Interface (UI): the prototype features a mobile-friendly and intuitive user interface that allows users, such as production managers or supervisors, to easily access and navigate the system. 2)Real-time production monitoring: the prototype demonstratesthe system's capability to monitor the production process in real-time through the based on IIoT. 3)Alert generation and notification: the prototype showcases how the system detects anomalies, issues, or predefined events in the production process and generates alerts. 4)Data visualization and analysis: the prototypemay include data visualization features that present production data in an easily understandable format on the mobile screen. 5) Collaboration and communication: the prototype may incorporate features that enable collaboration and communication among team members. 6)Mobile device integration: the prototype showcases how the smart manufacturingsystem can integrate with the capabilities of mobile devices.

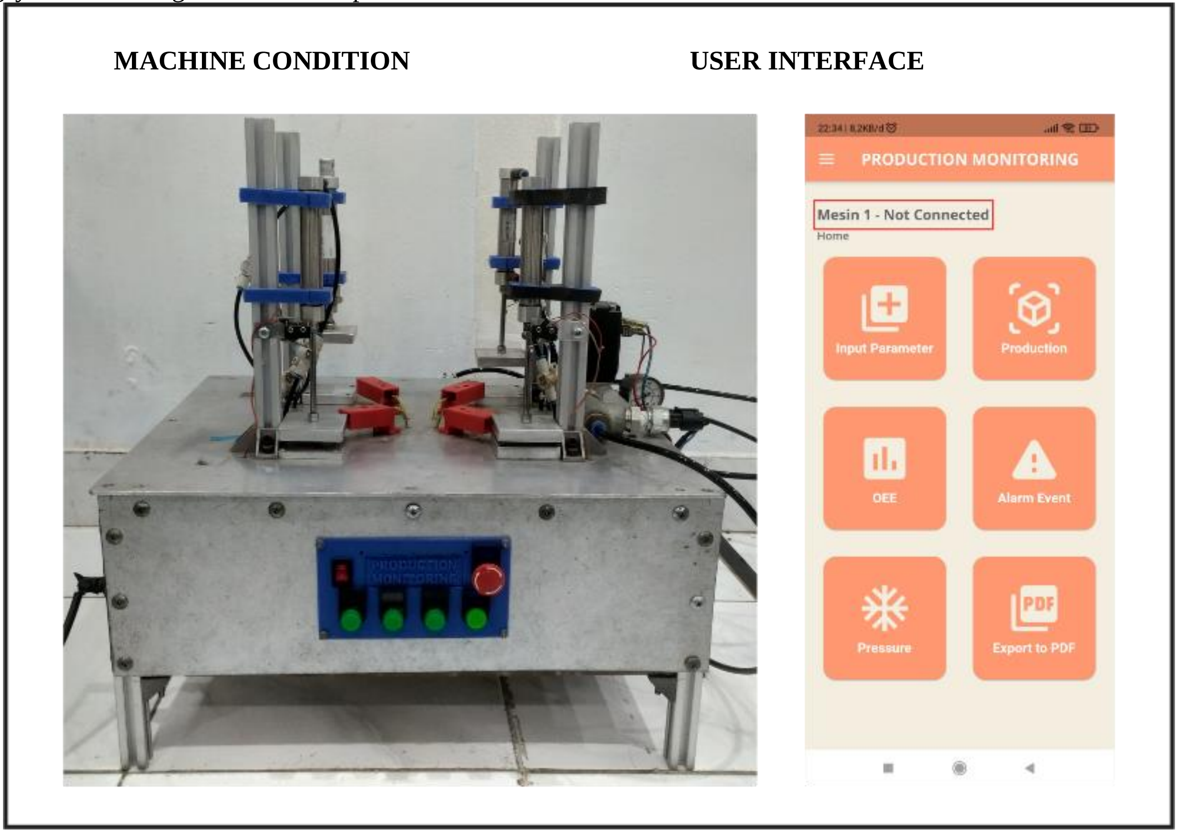


Fig. 2. Prototype of smart manufacturing system.

3.2 System Requirement Analysis

System requirement analysis is a systematic process of gathering, understanding, and documenting the needs and expectations of stakeholders for a particular system [11]–[13]. Overall, system requirement analysis is a key phase in system development, enabling a clear understanding of what the system should achieve and guiding the subsequent design and implementation phases. It helps mitigate risks, enhance communication among stakeholders, and deliver a system that meets the desired objectives and user expectations. Table 1 shows researchers designed an Android-based information system that can be used by several users.

Table 1. System needs and requirement

Page	Access right	1	2	3	4	5
Login page	There is a username, password, and login button input page.	√	√	√	√	√
Dashboard page	On this page, the user can select pages in detail, such as parameter input, production monitoring, OEE monitoring, alarm events, pressure, and export to PDF.	√	√	√	√	√
Parameter input page	Display the parameters that have been set	√	√	√	√	√
	Input values for loading time, cycle time, target OEE and object type. Parameter input and reset buttons	√	X	X	√	X
Smart manufacturing page	Display machine status, type of workpiece being processed, and machine lifetime	√	√	√	√	√
	Display the production table, production time, and parameters	√	√	√	√	√
	Display production history	√	√	√	√	√

Description: 1) super admin, 2) manager, 3) maintenance, 4) operator, 5) QC.

3.3 Software Testing

Software testing is a process of evaluating the quality of a software product by executing it to find defects, bugs, errors, or other issues that might affect its functionality, usability, security, or performance [14] [15]. It involves running the software in various environments, under different conditions and scenarios, and comparing the actual results with the expected ones to verify if it behaves as intended and meets the specified requirements. Table 2 shows the software testing using black box testing that aims to find errors from each program execution.

3.4 Notification Testing

Notification testing via WhatsApp involves verifying that the notifications sent by the application are being delivered to the intended recipients in a timely and accurate manner [16]. This can be done by setting up a test environment and sending notifications to a group of testers or a test account. Table 3 shows notification testing is done by inputting an alarm message in the application to find out the time reached to be able to send one notification.

3.5 Validation OEE Testing

Validation of OEE testing typically involves verifying whether the OEE calculation in the software system is accurate and aligns with the actual production data [7] [17]. This may involve comparing the OEE values generated by the software with manually calculated OEE values for the same production runs. Additionally, validation of OEE testing may also involve verifying that the software system is correctly capturing and storing the necessary data required for accurate OEE calculation, such as production count, cycle time, and downtime. Table 4 shows that OEE calculation testing is carried out by simulating production and then comparing the readings in the application with the results of manual calculations. The results of the OEE calculation test as shown in Tabel 4.

Table 2. Software testing

Page	Testing	Target	Results	Conclusion
Login page	Entering correct and incorrect username and password	The system is able to validate data, if the username and password are correct then the system will move to the machine selection page, but when the username and password are wrong then the system will display an error notification	The system is able to validate data, if the username and password are correct then the system will move to the machine selection page, but when the username and password are wrong then the system will display an error notification	Successful
Dashboard page	Choose features between input parameter, production, OEE, alarm event	The system will move to the page selected by the user	The system will move to the page selected by the user	Successful
Input parameter page	Reset parameter data and input new parameter data	The system will display the data "00.00" when the user presses the reset button and after pressing the input button, the system will display new data according to the input from the user	The system will display the data "00.00" when the user presses the reset button and after pressing the input button, the system will display new data according to the input from the user	Successful
Production page	User views production data	The system displays the production data	The system displays the production data	Successful
Production page	Quality control user inputs product defect data	The system will add defect product data	The system will add defect product data	Successful
OEE page	User views OEE data	The system displays the OEE data	The system displays the OEE data	Successful

Table 3. Notification testing

Testing	Input Button Pressed	Received Time	Results	Differ
1	09:00:00	09:00:05	Retrieved	5 sec
2	09:05:00	09:05:06	Retrieved	6 sec
3	09:10:00	09:10:06	Retrieved	6 sec
4	09:15:00	09:15:05	Retrieved	5 sec
5	09:20:00	09:20:06	Retrieved	6 sec
6	09:25:00	09:25:05	Retrieved	5 sec
7	09:30:00	09:30:05	Retrieved	5 sec
8	09:35:00	09:35:06	Retrieved	6 sec
9	09:40:00	09:40:05	Retrieved	5 sec
10	09:45:00	09:45:06	Retrieved	6 sec

Table 4. Validation of OEE testing

Trial to-	Data	Reading result	Calculation result	Error (%)
1	Loading time (minutes)	5	5	0
	Cycle time (minutes)	0.2	0.2	0
	OEE target (%)	85	85	0
	Running time (minutes)	5	5	0
	Operation time (minutes)	4.88	4.88	0
	Downtime (minutes)	0.12	0.12	0
	Flawless (unit)	24	24	0
	Defect (unit)	0	0	0
	Availability (%)	97.6	97.6	0
	Performance (%)	98.36	98.36	0
	Quality of rate (%)	100	100	0
	OEE (%)	95.9	95.9	0
2	Loading time (minutes)	5	5	0
	Cycle time (minutes)	0.2	0.2	0
	OEE target (%)	85	85	0
	Running time (minutes)	4.93	5	1.42
	Operation time (minutes)	4.4	4.47	1.59
	Downtime (minutes)	0.53	0.53	0
	Flawless (unit)	22	22	0
	Defect (unit)	0	0	0
	Availability (%)	88	89.4	1.59
	Performance (%)	100	98.43	1.57
	Quality of rate (%)	100	100	0
	OEE (%)	88	87.9	0.11

Overall Equipment Effectiveness (OEE) is a key performance indicator used to measure the efficiency of production processes [17]–[19]. It takes into account three factors: availability, performance, quality, and provides a score that reflects the overall effectiveness of a manufacturing process. The production process can have a significant impact on the value of OEE. For example, if there are frequent equipment breakdowns, availability will decrease, which will lower the OEE score. OEE is a metric used to measure the efficiency of manufacturing equipment [20]–[24]. It takes into account three factors: availability, performance, quality, and provides a score that reflects the overall effectiveness of the equipment.

Eq. 1 can be used to calculate OEE.

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \quad (1)$$

where:

$$\text{Availability} = \frac{\text{Total Run Time} - \text{Downtime}}{\text{Total Run Time}} \quad (2)$$

$$\text{Performance} = \frac{\text{Total Count/Ideal Run Time}}{\text{Availability}} \quad (3)$$

$$\text{Quality} = \frac{\text{Good Count}}{\text{Total Count}} \quad (4)$$

Mean Time Between Failures (MTBF) is a metric that represents the average time between equipment failures. It is calculated by dividing the total uptime by the number of failures(Eq. 6).

$$\text{MTBF} = \frac{\text{Total Uptime}}{\text{Number of Failures}} \quad (6)$$

Mean Time To Repair (MTTR) is a metric that represents the average time required to repair equipment after a failure. It is calculated by dividing the total downtime by the number of repairs (Eq. 7).

$$\text{MTTR} = \frac{\text{Total Downtime}}{\text{Number of Repairs}} \quad (7)$$

To calculate losses, Eq. 8 can be used:

$$\text{Losses} = \text{Planned Production Time} - \text{Actual Production Time} \quad (8)$$

where:

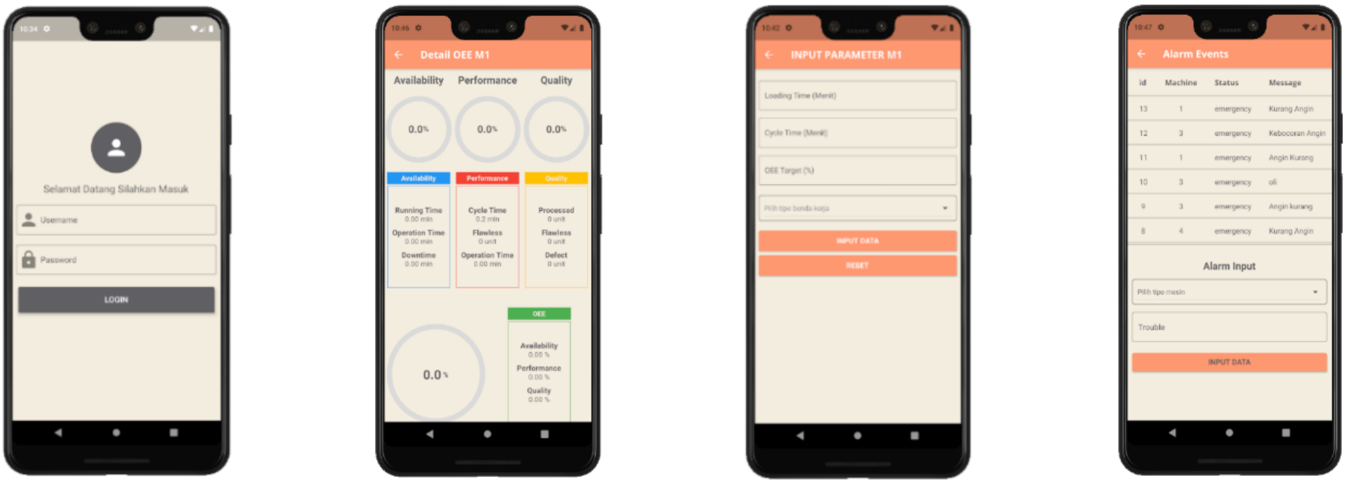
$$\text{Planned Production Time} = \text{Total Run Time} - \text{Scheduled Downtime} \quad (9)$$

$$\text{Actual Production Time} = \text{Total Run Time} - \text{Downtime} \quad (10)$$

By calculating OEE, MTBF, MTTR, and losses, businesses can identify areas for improvement in their manufacturing processes and take action to increase efficiency, reduce downtime, and improve quality.

3.6 User Interface Display

The following is an explanation of each part of the User Interface (UI) display in asmart manufacturing system based on IIoT in a mobile application using Flutter.Fig. 3(a) shows the login page in the smart manufacturingsystem would likely include two input fields for the user's username and password, as well as a login button that initiates the authentication process.Fig. 3(b) shows the OEE monitoring page in the smart manufacturingsystem based on the IIoTthat is designed to provide users with real-time data on the performance of the production process. This page typically displays the OEE score, as well as other Key Performance Indicators (KPIs) such as availability, performance, and quality [20], [21], [25], [26]. The OEE monitoring page may also include alerts and notifications to inform users when performance falls below a certain threshold, allowing them to take corrective action quickly [18][9]. Fig. 3(c) shows the parameter input page in the smart manufacturing system based on the industrial internet of things would allow users to input various parameters that are used to monitor the production process. Fig. 3(d) shows the alarm event page in the smart manufacturing system which is designed to provide real-time notifications and alerts to users when there are issues with the production process.



(a) Login page (b) OEE monitoring page (c) Input parameter (d) The alarm event page

Fig. 3. User interface display.

4 Conclusion

The smart manufacturing system based on the IIoTis a powerful tool for monitoring and optimizing the production process. It provides real-time visibility into the production line, allowing for quick identification and resolution of any issues that may arise. By calculating the OEE metric, the system enables a data-driven approach to production optimization and improvement. The research results show an availability value of 88%, indicating that the machine operates 88% of the scheduled time. A performance value of 100% indicates that the engine is operating at the desired maximum speed. OEE is calculated as the product of availability, performance, and quality of rate. With a value of 88%, OEE reflects the overall level of effectiveness of the machine in the production process. Overall, the smart manufacturing system based on the industrial internet of things can significantly improve the efficiency and productivity of production processes, leading to cost savings and increased customer satisfaction.

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