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Implementation of a Production Monitoring System Using IIoT Based on Mobile Application

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Abstract

Productivity is a key factor in the success of a company, and real-time monitoring systems are necessary to achieve this goal. Manual data collection is time-consuming and exhausting. Industrial Internet of Things (IIoT) technology has been rapidly advancing in monitoring and optimizing industrial processes. Production processes can be disrupted due to machine problems, hence the need for analyzing machine efficiency using the Overall Equipment Effectiveness (OEE) method. This study implements a system using Industrial Internet of Things technology based on mobile application to monitor production processes, report production results, assess machine performance using the OEE method, and provide maintenance notifications based on time-based maintenance. The research findings indicate that the implemented production monitoring system on a prototype press machine based on an interactive mobile application interface, is capable of monitoring production processes and reporting production results. The system is also able to assess machine performance using the OEE method, with a calculation accuracy of 99.95% and maintenance notifications with a delay time of 1.04 seconds.

Keywords: *production monitoring system, IIoT, OEE, mobile application, notification*

1. Introduction

The main factor in achieving high efficiency and accuracy in the utilization of available resources is productivity [1]. To achieve high efficiency and accuracy in productivity, a real-time monitoring system is required [2]. Collecting data manually takes up a lot of time and is exhausting [3]. Therefore, an intelligent system should take over the task of manual monitoring performed by humans because in the manufacturing process, there are many interactions between humans and machines that determine the performance of a machine and the production quality in a company[4]. The Industrial Internet of Things (IIoT) technology is currently rapidly developing to monitor, control, and optimize industrial processes. By utilizing IIoT-based systems, machines can be monitored for preventive maintenance and productivity improvement [5]. The Industrial Internet of Things (IIoT) will play a crucial role in transforming and updating traditional industries [6].

The purpose of the production machine monitoring system is to enhance production efficiency, production planning, and forecasting, as well as to reduce waste production [7]. Sometimes, the halt in the production process is caused by issues with the production machines, which make data processing and productivity complex problems [8]. Therefore, an analysis of machine efficiency needs to be conducted to minimize downtime and determine machine efficiency according to the Overall Equipment Effectiveness (OEE) method [9]. OEE is a measurement of the level of efficiency and effectiveness of a machine/equipment by calculating machine availability, efficiency, and the quality of the produced products [10].

There are several relevant previous studies that serve as the foundation for this research. One of them is a study conducted in 2020 entitled "*Desain Implementasi Andon Untuk* Production Monitoring System *Berbasis* Internet of Things" [2]. The VDI2206 method was used in this research. The study resulted in a system capable of remotely monitoring the production process using a web interface. Another study conducted in 2020 titled "*Sistem Penghitung Nilai Efektivitas Mesin* Forming *Menggunakan Metode* Overall Equipment Effectiveness" [11]. The method used in this research

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was the Overall Equipment Effectiveness method. The study resulted in OEE calculations for the die form machine with availability values ranging from 69.15% to 97.43%, performance values ranging from 82.45% to 98.94%, and quality values ranging from 98.33% to 100%. Based on the obtained values, the OEE value depicted the efficiency of the die form machine as ranging from 59.05% to 97.17%. Another study titled "*Perancangan Sistem Perawatan Preventif* Time-Based Maintenance *di Laboratorium Pemesinan Dasar Polman Babel*" [12]. The method used in this study was time-based maintenance.

Based on previous studies, utilizing IIoT technology, this research aims to develop a production monitoring system for an Android-based prototype press machine capable of monitoring the production process and generating production reports. The developed system will also measure machine effectiveness using the OEE method and provide machine maintenance schedules based on specified time intervals. Several components required to support this research include Flutter [13] as the framework for developing the Android application to monitor the production process and machines. MongoDB [14] is used as the database for storing the required data. Raspberry Pi 3 [15] acts as the master device that receives data from the slave devices and sends it to the database. Arduino Nano [16] functions as the slave device, receiving inputs from sensors and controlling actuators. The PZEM-004T module [17] transmits voltage, current, power, and energy values to Arduino. The limit switch [18] is used with a pull-down circuit to count the processed products. Additionally, the pressure transmitter [19] reads the incoming air pressure values for the stamping process.

The VDI2206 method is used in this research to categorize each domain specifically [20], namely the mechanical domain, electrical domain, and informatics domain. This method is suitable for users as it provides a detailed breakdown of each domain, ensuring organized workflow. In the informatics domain, the Rapid Application Development method [21] is employed to facilitate rapid and stable application development. This method consists of three stages: requirements, system design, and implementation. Functional testing is conducted on the application to identify any errors and ensure the desired outcomes are achieved. By implementing the monitoring system on the prototype press machine, users can remotely monitor a production machine, assess its performance, and schedule maintenance activities.

2. Research Methods

The research adopts the VDI2206 method, and the detailed description of each process can be seen in Figure 1. This process is divided into three stages: (i) requirements elicitation; (ii) system architecture and design; (iii) implementation and testing.

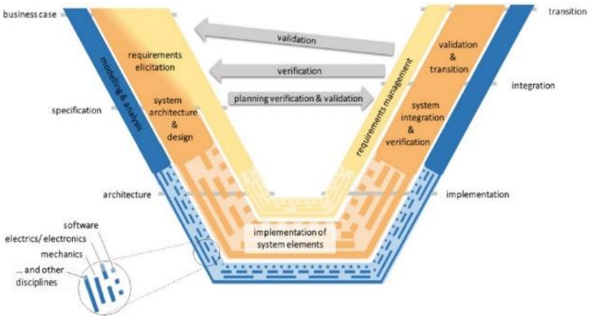

Figure 1. VDI2206 Method [20]

2.1 Requirements Elicitation

In the requirements elicitation, each system requirement from the users is defined as a demand that needs to be addressed. Table 1 is the system requirements that need to be implemented.

Table 1. System Requirements Specifications.

Domain	Requirements
Mechanic System	The system is capable of performing stamping to change the shape of the workpiece.
Electric System	The system can read each sensor. The system can control the stamping process.
Informatic System	Sending sensor readings to the database. Real-time sensor readings on the user interface. Displaying production process data and generating reports. Automatically calculating OEE values. Sending preventive maintenance notifications and machine issue alerts.

2.2 System Architecture and Design

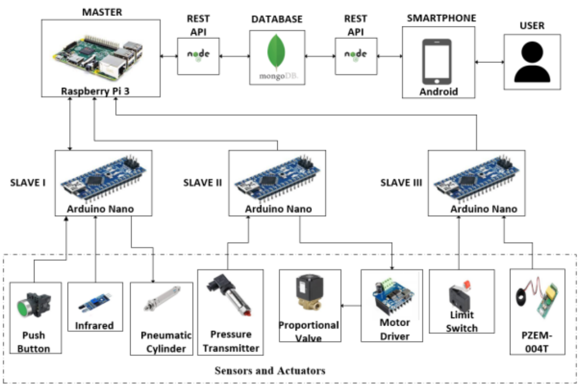

Figure 2. System Architecture

Figure 2 shows that the system consists of three main components: at the field level, there are sensors and actuators; at the control level, there are Arduino and Raspberry Pi; at the monitoring level, there is a mobile application designed using Flutter. Arduino acts as a slave for control and sensor reading. Slave 1 is used for controlling the stamping process and detecting objects using push buttons, infrared sensors, and a relay for

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solenoid control. Slave 2 is used for reading the pressure transmitter and controlling the opening of a proportional valve to regulate air pressure. Slave 3 is used for calculating the workpiece using limit switches and reading the PZEM-004T module.

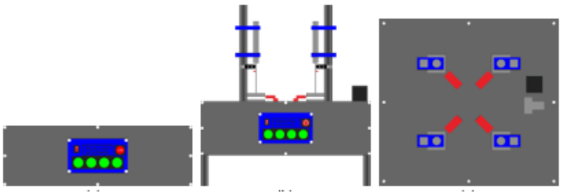

Figure 3. Mechanic Design

Figure 3 represents the mechanical design of the prototype press machine. The materials used include aluminum plates, aluminum profiles, and acrylic. The left part of Figure 3 shows the control panel, which includes 1 switch to control indicator lights, 4 push buttons for press machine control, and 1 emergency button to stop the process. The middle part of Figure 3 shows the front view of the prototype press machine, where the control panel, cylinder, and aluminum profiles as cylinder supports can be seen. The right part of Figure 3 shows the top view of the prototype press machine, featuring infrared sensors, cylinder mounts, proportional valves, and pressure transmitters.

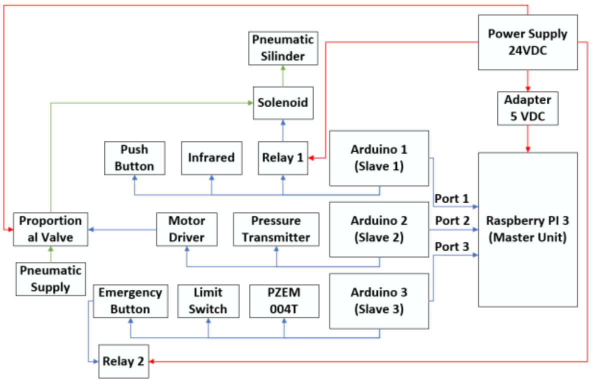

Figure 4. Electrical Circuit Schematic

In Figure 4, there are three colored arrows: red represents the voltage source, blue represents input/output signals, and green represents the air pressure source. The ports on the Raspberry Pi will be connected to three Arduinos. Arduino 1 is connected to Relay 1, infrared sensors, and push buttons for controlling the stamping process. Arduino 2 is connected to the pressure transmitter and motor driver for controlling the opening of the proportional valve and reading the air pressure value. Arduino 3 is connected to the PZEM-004T module, limit switches, and an emergency button to monitor the power source value, count the products, and stop the stamping process in emergency situations. Through the integration of Raspberry Pi and Arduino, this system is capable of advanced control with various sensor components and actuators. The purpose of using a master and slave configuration is to avoid delay caused by the queue of sensor and actuator data.

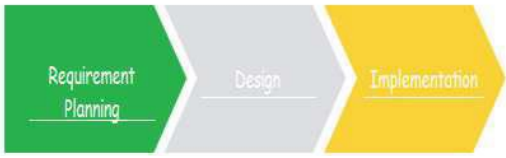

Figure 5. Rapid Application Development Method [21]

In the information system design, the method used is rapid application development [21] to expedite the process of developing the information system. From Figure 5, this method is divided into three stages: (i) requirement planning, (ii) design, and (iii) implementation. In the first stage, requirement planning, all the needs and requirements of the information system are defined as the demands that need to be fulfilled.

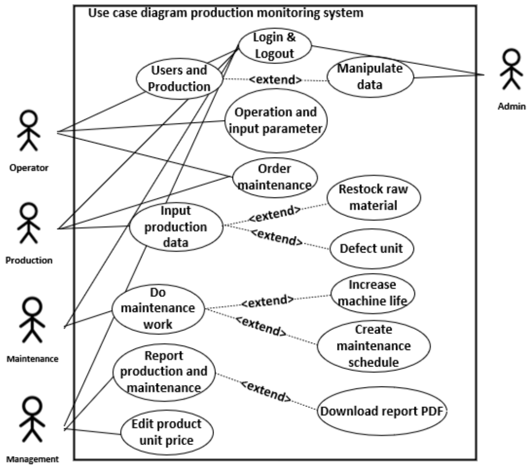

Figure 6. Use Case Diagram

A use case diagram is constructed to describe the interactions of information within a system. In Figure 6, there are five main actors in the system. The admin has access to user data management and production machine data management. The Operator has access to machine operations such as inputting parameters and sending machine repair requests. The Production personnel have access to production control, including inputting defect units, adding product stock, and sending machine repair requests. The Maintenance personnel have access to machine repair and maintenance tasks. The Management personnel have access to generating production reports, maintenance reports, and modifying unit prices of products.

After completing the requirement planning for the information system, the next step is to create a user interface design and database system design. Next, the design of the application menu page for the information system is created, and the design is presented in the form of a diagram.

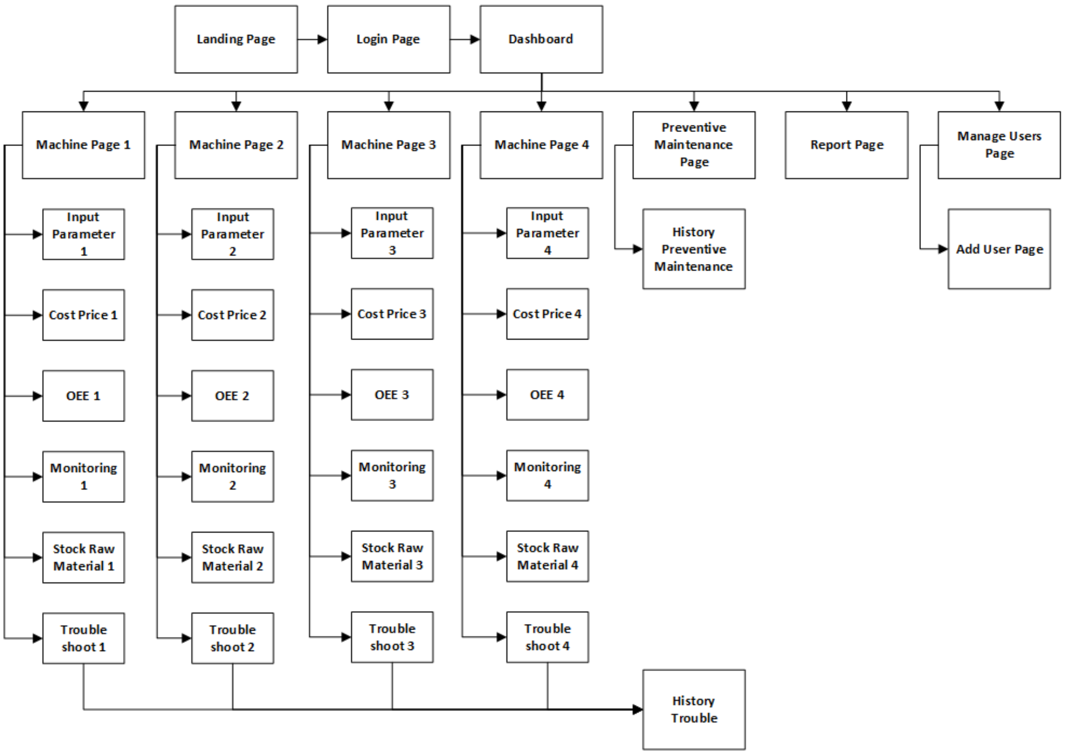

Figure 7. Menu Page Design

The menu page design functions to detail the access paths to each page in the application. In Figure 7, the first page accessed by users upon opening the application is the landing page. Afterward, users enter the login page by pressing the button on the landing page. The dashboard page serves as the main page after logging into the application. The dashboard page provides access to seven pages, namely machine pages 1-4, preventive maintenance page, report page, and manage users page. On the machine pages 1-4, users can access input parameter pages machine 1-4, cost price pages machine 1-4, OEE pages machine 1-4, monitoring pages machine 1-4, stock raw material pages machine 1-4, and troubleshoot pages machine 1-4. The troubleshoot pages machine 1-4 provide access to the history trouble page. The preventive maintenance page provides access to the history preventive maintenance page. On the manage users page, an admin can manipulate user data and add new users through the add user page. The conclusion from the Figure 7 is that this application has a total of 37 pages and has a page stack starting from the landing page consisting of 6 pages.

Subsequently, a database design is created for the information system in the form of a class diagram. Each class will have attributes representing the data that needs to be stored. Each attribute in the class will become a column in the table, while each object of the class will become a row in the table Figure 8 represents the database design for the production monitoring system using MongoDB.

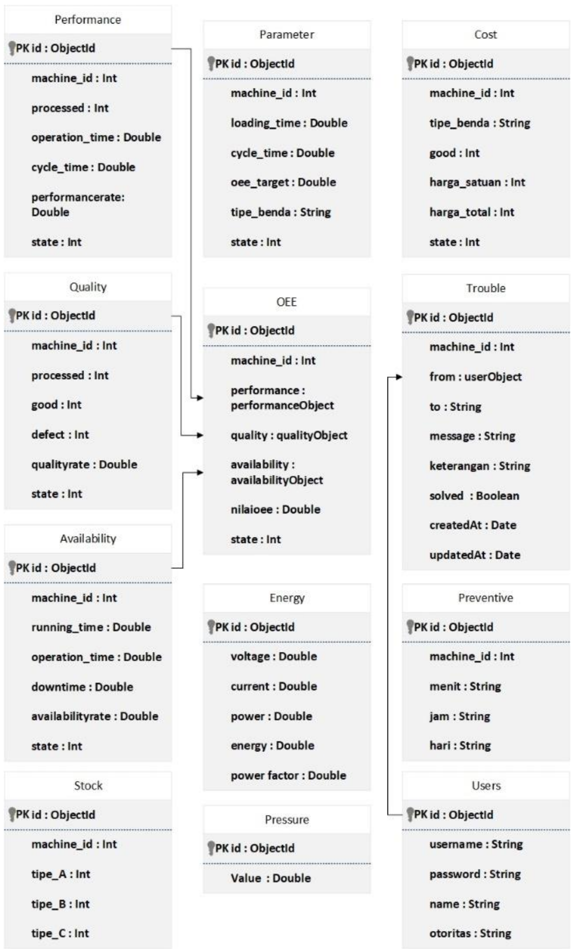

Figure 8. Database Design

Figure 8 shows that there are 12 main tables in the MongoDB database design, where each table has an ID as the primary key, but there are no relationships between tables. The Users table stores user information for the application. The Parameter table stores user input data when initiating the production process. The Pressure and Energy tables store data from the pressure transmitter and PZEM-004T module, respectively. The Performance, Quality, Availability, and OEE tables store data for calculating the OEE value of the machine. The Stock table stores the quantity of available raw materials. The Cost table stores data from the calculation of sales for the produced good products. The Trouble table stores manual input data on machine issues, which then triggers a notification in the form of a machine problem message. The Preventive table stores data for machine maintenance schedules, and when the time comes, the system automatically sends notifications to the maintenance team to perform machine maintenance.

2.3 Implementation and Testing

Once the design phase is complete, the next step is the implementation phase of the software and hardware components. In software implementation, the appropriate programming language and framework are used to translate the design into executable code. Meanwhile, in hardware implementation, each component is assembled and arranged according to the design specifications. Subsequently, software and hardware integration take place.

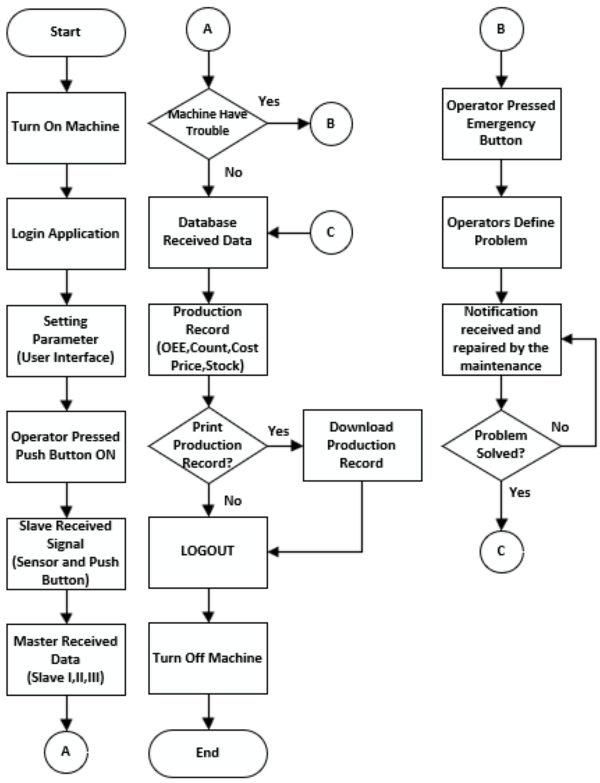

Figure 9. Production Proccess Flowchart

Before implementing the software and hardware, it is necessary to create a process flowchart for the production machine to provide a detailed overview of the operational flow. Figure 9 represents the Flowchart for the production process, starting with turning on the machine. The user is then required to log in to the application. After logging in, the user needs to input the required parameters such as loading time, cycle time, OEE target, and object type. Subsequently, the slave will receive data from sensors and push buttons, and then send the data to the master unit via serial communication. The master unit will receive the data from the slave and initiate the production process. If any issues occur during the production process, the user can inform the maintenance team by creating a trouble order to report the problem. Once the user creates the order, the maintenance team will receive a trouble notification and proceed with the necessary repairs. The repair history will be stored in the database for record-keeping. During the production process, if no issues arise, the user can monitor the production progress and download production reports. After the production process is completed, the user can log out and turn off the machine.

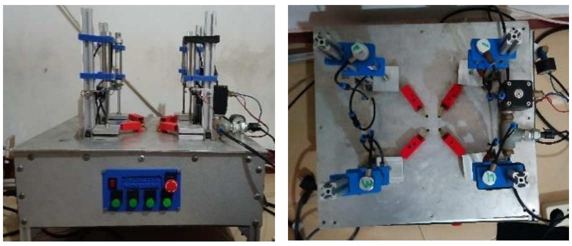

Figure 10. Implementation of Mechanic Design

Figure 10 represents the implementation result of the mechanical design of the press machine prototype. It shows the front view of the previously designed press machine prototype. The materials used for construction include aluminum plates, aluminum profiles, and acrylic. The front view reveals the presence of a control panel, limit switches, infrared sensors, proportional valves, and pressure transmitters. Additionally, the top view of the press machine prototype is depicted, showcasing four cylinders that function to apply pressure on the workpiece. Each cylinder represents a separate machine, resulting in a total of four available machines, and four infrared sensors are present to detect the objects. The top view also displays a pressure gauge, proportional valve, and pressure transmitter.

After completing the implementation of the mechanical design, the next step involves the implementation of the hardware and software components. The implementation process entails examining the machine's condition when it is not operational and reviewing the corresponding application interface. By doing so, the results can indicate whether the system has been successfully integrated or not. Figure 11

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showcases the machine's inactive state alongside the associated application interface. Within the application interface, a red label with the text 'Not-Connected' is visible, indicating that the machine is currently inactive and lacks an internet connection.

Figure 11. Nonactive Machine Condition

The following is the condition when the machine is active. In Figure 12, the application interface displays a green label with the text "Connected," indicating that the machine is currently active and connected to the internet.

Figure 12. Active Machine Condition

After completing the implementation phase, several tests were conducted on the prototype press machine. The purpose of these tests was to evaluate the system's effectiveness and functionality. The initial test focused on the sensors to ensure their accurate readings. For the PZEM-004T module, the readings obtained were compared against the calculated results using formula [17]. Formula 1, the first formula utilized was the apparent power formula.

$$S = V \ x \ I \tag{1}$$

S is the apparent power value, V is the voltage value, and I is the the current value. Formula 2 is used to calculate the power factor (PF).

$$PF = \frac{P}{S} \tag{2}$$

PF is the power factor value, P is the real power value, and S is the apparent power value. Additionally, the formula for calculating power is Formula 3.

$$P = V \ x \ I \ x \ PF \tag{3}$$

P is the power value, V is the voltage value, I is the current value, and PF is the power factor value. Formula 4 is used to calculate energy (E).

$$E = P \ x \ t \tag{4}$$

E is the energy value in kilowatt-hours (kWh), where P is the real power value and t is the time value in hours.

The second test is the notification testing to assess the appropriateness of the messages and determine the time it takes for them to be received by the user. The third test is the functional suitability testing using the black box method [22]. This test is conducted to evaluate the success rate of the features in the mobile application. The application's functions are assessed based on three metrics: Functional Adequacy (FA), Functional Implementation Coverage (FIC), and Functional Implementation Completeness (FICM)

The fourth test is the validation of OEE calculations. This test is conducted to validate the OEE results in the application against the calculations using the OEE formula. The OEE value is influenced by the performance rate, availability rate, and rate of quality [9]. Formula 5 is the OEE formula.

$$OEE = Availibility \times Performance \times Quality \tag{5}$$

The availability rate is calculated based on the machine's operating time (uptime) and the time required to prepare everything before the machine starts running (loading time) [11]. Formula 6 is the formula to calculate the availability rate:

$$Availability\ rate = \frac{[(Loading\ Time - Downtime) \times 100\%]}{Loading\ Time} \tag{6}$$

The performance rate represents the point that can be used to determine the efficiency of the machine in performing its tasks when producing products [11]. Formula 7 is the formula to calculate the performance rate*:*

$$Perf.rate = \frac{Processed\ amount \times cycle\ time \times 100\%}{Operation\ time} \tag{7}$$

The quality rate is a calculation of the production based on the number of products that have good quality [11]. Formula 8 is the formula to calculate the quality rate*:*

$$Q.rate = \frac{[(Processed\ amount - defect\ amount) x 100\%]}{Processed\ amount} \tag{8}$$

This validation process helps to confirm that the OEE measurements align with the expected outcomes and provide meaningful insights into the manufacturing process's performance.

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3. Results and Discussions

After successfully creating and integrating the prototype press machine with the application, the next step is to perform testing on the elements of the production monitoring system. This includes testing the implemented application pages and four categories of testing: (i) sensor testing, (ii) notification testing, (iii) Functional Suitability testing, and (iv) OEE validation testing.

3.1 Main Application Pages

When users access the application, they will enter the landing page. From the landing page, users can press the login button to proceed to the login page. Users are prompted to enter a valid username and password, and if not, a warning popup will appear indicating that the username or password is incorrect, as shown in Figure 13.

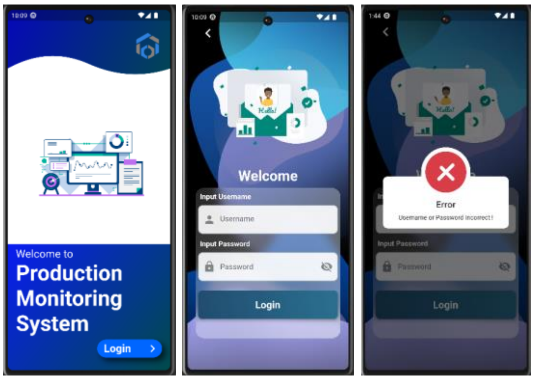

Figure 13. Landing Page and Login Page

Next, the machine monitoring page in Figure 14 includes the production monitoring page, which provides real-time information about the production process. Users with production authority can input defect units after the production process is completed. Additionally, there is a monitoring feature for air pressure displayed through a gauge and a graph. Lastly, the system includes real-time monitoring of electricity usage. This feature is designed to assess the electrical conditions and monitor electricity usage during machine production.

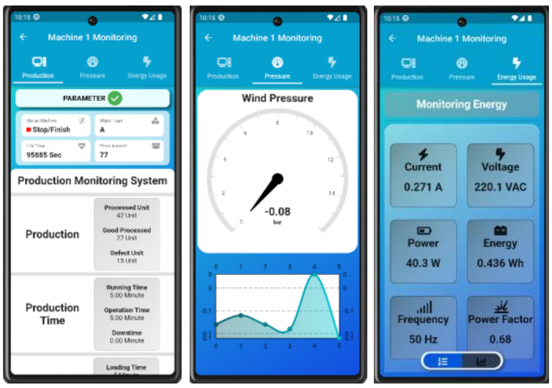

Figure 14. Monitoring Page

Next, there are the Input Parameter and Preventive pages. On the Input Parameter page, the operator is required to input several parameters before initiating the production process. On the Preventive page, it provides information regarding the machine maintenance schedule. The maintenance team has the ability to manage the machine maintenance schedule, as depicted in Figure 15.

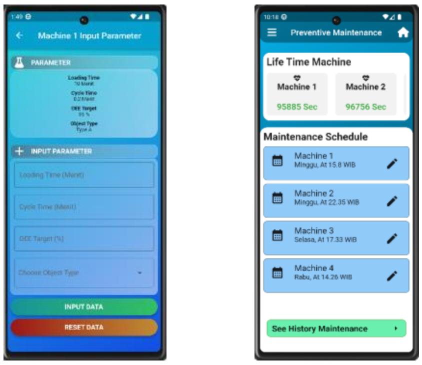

Figure 15. Input Parameter Page and Preventive Page

Figure 16 is the OEE monitoring page, which provides detailed information about the machine's effectiveness. The OEE value is automatically calculated during the production process. The OEE page layout can be seen in Figure 16.

Figure 16. OEE Monitoring Page

Finally, the report page allows a user with management authority to generate and download production reports in PDF format, as shown in Figure 17.

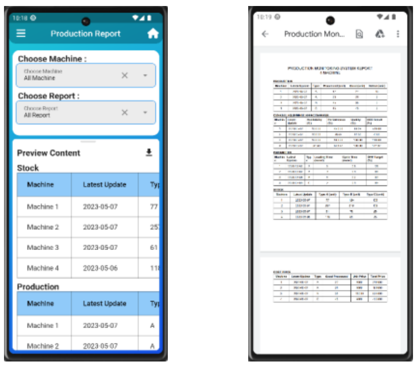

Figure 17. Report Page

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3.2 Testing Sensors

The limit switch is used to count the number of processed products. The testing of the limit switch function is performed by activating the machine, and the limit switch is activated by the cylinder pressing against it. The reading result can be observed on the user interface.

Table 2. Limit Switch Test

Machine	Production Amount (unit)	Reading Results (unit)	Error (%)
1	50	49	2.04
2	50	50	0
3	50	50	0
4	50	50	0
Average			0.51

From the test results presented in Table 2, it is evident that there is a comparison between the production count and the readings obtained from the application. Machine 1 exhibits an error rate of 2.04%, while the other machines have an error rate of 0%, resulting in an average error rate of 0.51%.

The Pressure Transmitter is utilized for monitoring the air pressure value utilized by the prototype press machine. The testing of the pressure transmitter is carried out by comparing the values read on the application with the values observed on the pressure gauge.

Table 3. Pressure Transmiter Test

No	Pressure Gauge (bar)	Pressure Transmitter (bar)	Error (%)
1	2	1.97	1.5
2	2	1.99	0.5
3	2	2	0
4	2	2.02	1
5	2	1.97	1.5
Average			0.9

Table 3 presents the data obtained from the pressure transmitter testing performed five times. The results of the testing indicate an average error of 0.9%. This discrepancy can be attributed to the higher measurement accuracy of the pressure transmitter in comparison to the pressure gauge, which has an accuracy of 0.5.

Table 4. Power Test

No	Voltage (V)	Current (I)	PF	Power (W)	With Formula (W)	Error (%)
1	220.7	0.266	0.63	36.90	36.985	0.22
2	221.2	0.266	0.63	37.00	37.069	0.18
3	220.8	0.267	0.63	37.10	37.141	0.11
4	221	0.268	0.63	37.20	37.314	0.30
5	218.1	0.266	0.63	37.40	37.129	0.72
Average						0.306

The PZEM-004T Module in the prototype press machine serves to monitor voltage, current, power, energy, and power factor values during the active operation of the prototype press machine. Power testing is carried out by comparing the values displayed on the user interface with mathematical calculations using the power formula. In Table 4, the power testing results are presented based on the readings of the module. The power factor (PF) value is obtained from the readings taken by the PZEM-004T. However, to verify its accuracy, the power factor value can be determined by calculating the apparent power value (S) in Formula 1.

$$S = V\ x\ I = 220.7\ x\ 0.266 = 58.70\ VA \tag{1}$$

Once the value of apparent power (S) is known, the power factor can be determined by dividing the real power (P) by the apparent power (S) in Formula 2.

$$PF = \frac{P}{S} = \frac{36.90}{58.70} = 0.63 \tag{2}$$

With the known values of voltage (V), current (A), and power factor (PF) obtained from the readings of PZEM-004T, the magnitude of real power can be calculated in Formula 4 and 4.

$$P = V\ x\ I\ x\ PF \tag{3}$$

$$P = 220.7\ x\ 0.266\ x\ 0.63 = 36.985\ W \tag{4}$$

From the calculation, the value of real power is obtained as 36.985, while the power reading (W) obtained from the PZEM-004T module is 36.90. The error between the two values is found to be 0.22%.

Table 5. Energy Test

Load (W)	Initial Value (KWh)	End Value (KWh)	Reading Result (KWh)	With Formula (KWh)	Time (Hours)
38.8	2.326	2.346	0.020	0.0194	0.5
38.5	2.326	2.365	0.039	0.0385	1
37.8	2.326	2.385	0.059	0.0567	1.5
37.5	2.326	2.403	0.77	0.0749	2
37.2	2.326	2.423	0.097	0.0930	2.5

The energy (E) testing is conducted by activating the machine at regular intervals of 0.5 hours. This is done to determine the amount of energy (E) consumed by the machine. By knowing the load value (P) and the operating time (t) of the machine, the energy (E) result is obtained in Formula 5 and 6.

$$E = P\ x\ t \tag{5}$$

$$E = \left(\frac{37.86}{1000}\right) x\ 1.5 = 0.0567\ KWh \tag{6}$$

From the calculations, the energy (E) value is determined to be 0.0567 kWh with a usage time of 1.5 hours. However, the reading from the PZEM-004T module with a usage time of 1.5 hours is 0.059 kWh. There is a difference of 0.23 kWh. It can be concluded that the energy used by the prototype press machine is approximately 0.19 kWh every 0.5 hours.

3.3 Notification

There are two types of notification tests conducted, namely user input notifications to the maintenance team

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to address any issues that occur, and automatic notifications based on the machine's condition or pre-scheduled maintenance, which are received through Telegram.

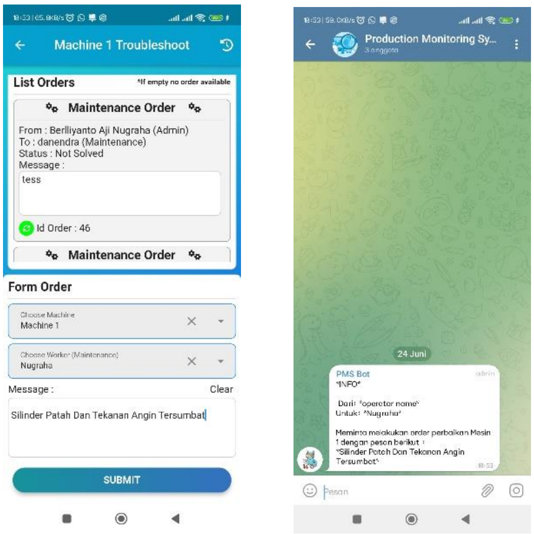

Figure 18. Manual Notification

Figure 18 shows the results of user input notifications. The messages conveyed are in accordance with the users written message. These notifications are necessary if an operator encounters any issues with the machine during the production process.

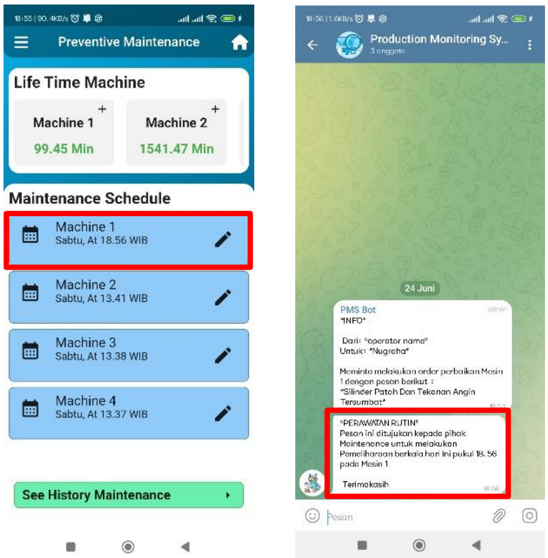

Figure 19. Automatic Notification

In Figure 19, automatic notifications will be sent when the scheduled maintenance time arrives. The schedule set in Figure 19 is Saturday at 18:56 WIB, and the message was received at the same time. This indicates that the notification can work properly according to the specified schedule determined by maintenance.

From the notification testing results, it can be concluded that the notification messages function properly and the conveyed messages are accurate. Table 6 displays the message delivery time to reach users via Telegram, resulting in an average message delivery time of 1.04 seconds. The speed of message reception is influenced by the connectivity of the devices used.

Table 6. Notification Time

No	Sent Time	Received Time	Status	Difference (sec)
1	12:30:00	12:30:00.75	Received	0.75
2	12:31:00	12:31:00.74	Received	0.74
3	12:32:00	12:32:01.24	Received	1.24
4	12:33:00	12:33:01.35	Received	1.35
5	12:34:00	12:34:01.14	Received	1.14
		Average		1.04

3.4 Functional Suitability Test

Table 7 represents functional testing to assess the success of the features utilized in the Android application. The values range from 0 (zero), which is considered poor, to values approaching or equal to 1 (one), which are considered good ($0 \leq X \leq 1$). Meanwhile, FA represents the functional adequacy of the application's functions, FIC represents the functional implementation coverage of the application's functions, and FICM represents the functional implementation completeness of the application's functions.

Table 7. Functional Suitability Test

Feature	FA	FIC	FICM
Login and Logout	1	1	1
Add New User	1	1	1
Input Parameter	1	1	1
Production Monitoring	1	1	1
Monitoring Pressure	1	1	1
Monitoring Listrik	1	1	1
Add Raw Material Stock	1	1	1
Automatic OEE Value	1	1	1
Preventive Maintenance	1	1	1
Maintenance History and Trouble	1	1	1
Production Record and Report PDF	1	1	1
Notification	1	1	1
Average	1	1	1

The results from the testing in Table 7 indicate an average value of 1, indicating that the application features are functioning properly.

3.5 Validation OEE Test

The validation testing of OEE calculation was performed through production simulation on the prototype press machine. The readings obtained from the user interface were compared with the results calculated using the OEE formula. The validation testing of OEE values was conducted on each of the four machines. Table 8 presents the results of the Overall Equipment Effectiveness calculation validation.

With the given values of loading time (LT), downtime (DT), and operation time (OT), the availability formula can be utilized.

$$Availability\ ratio = \frac{Loading\ time - Downtime}{Loading\ time}\ x\ 100\% \quad (7)$$

$$Availability\ ratio = \frac{10-0.28}{10}\ x\ 100\% = 97.2\% \quad (8)$$

The results in Table 8 illustrate the testing of availability ratio calculations for 4 machines (M), which resulted in an average calculation error of 0.065%.

Table 8. Availability Ratio

M	LT (min)	OT (min)	DT (min)	Read Value (%)	With Formula (%)	Err (%)
1	10	9.72	0.28	97.08	97.20	0.12
2	10	9.23	0.77	92.33	92.30	0.03
3	10	9.78	0.22	97.78	97.80	0.02
4	10	9.77	0.23	97.61	97.70	0.09
Average						0.06

With the known values of process, good process, and defect, the quality formula can be utilized.

$$Rate\ of\ Quality = \frac{processed - defect}{processed}\ x\ 100\% \quad (9)$$

$$Rate\ of\ Quality = \frac{48-3}{48}\ x\ 100\% = 93.75\% \quad (10)$$

The results in Table 9 indicate that the testing of the rate of quality calculation for the 4 machines (M) yielded an average calculation error of 0.00%.

Table 9. Rate of Quality

M	Process (unit)	Good Process (unit)	Defect (unit)	Read Value (%)	With Formula (%)	Err (%)
1	48	45	3	93.75	93.75	0.00
2	92	91	1	98.91	98.91	0.00
3	29	29	0	100	100	0.00
4	47	45	2	95.74	95.74	0.00
Average						0.00

With the known values of cycle time (CT), process unit, and operation time (OT), the performance formula can be applied.

$$Perf.efficiency = \frac{Cycle\ time\ x\ Processed}{Operation\ time}\ x\ 100\% \quad (11)$$

$$Perf.efficiency = \frac{0.2\ x\ 48}{9.72}\ x\ 100\% = 98.77\% \quad (12)$$

The results in Table 10 demonstrate the testing of the rate of quality calculation on 4 machines (M), resulting in an average calculation error of 0.04%.

Table 10 Performance Efficiency

M	CT (min)	Process (unit)	OT (min)	Read value (%)	With Formula (%)	Err (%)
1	0.2	48	9.72	98.8	98.77	0.04
2	0.1	92	9.23	99.64	99.67	0.04
3	0.3	29	9.78	88.93	88.96	0.03
4	0.2	47	9.77	96.25	96.21	0.04
Average						0.04

After obtaining the values of availability ratio, rate of quality, and performance efficiency, the next step is to calculate the OEE value using the OEE calculation formula as shown in Table 11.

Table 11. Overall Equipment Effectiveness

M	AR	RoQ	PE	Read Value (%)	With Formula (%)	Err (%)
1	97.08	93.75	98.8	89.92	90.00	0.08
2	92.33	98.91	99.64	91.00	90.99	0.01
3	97.78	100	88.93	86,96	87.00	0.04
4	97.61	95.74	96.25	89.94	89.99	0.05
Average						0.05

With the known values of availability ratio (AR), rate of quality (RoQ), and performance efficiency (PE), the OEE formula can be applied.

$$OEE = Availability\ x\ Quality\ x\ Performance \quad (13)$$

$$OEE = 97.20\%\ x\ 93.75\%\ x\ 98.77\% = 90.00\% \quad (14)$$

From the calculations, the Overall Equipment Effectiveness (OEE) value for machine 1 is 90.00%, while the reading from the application is 89.92%. There is an error of 0.8%, which can be attributed to the OEE program's limitation of displaying only two decimal places.

Based on Table 11, the validation results of the Overall Equipment Effectiveness (OEE) calculations yielded an average error of 0.05%. The results indicate that the OEE readings in the application have an automatic reading accuracy of 99.95%.

4. Conclusion

Based on the conducted research on the production monitoring system for the prototype press machine, the following conclusions can be drawn. The production monitoring system has been successfully implemented on the prototype press machine, utilizing the Flutter framework for the application interface. It allows monitoring of sensor values and real-time display of production data and history. Furthermore, it can assess machine performance using the Overall Equipment Effectiveness (OEE) method, with a calculation accuracy of 99.95%. The developed system also effectively sends notifications through Telegram, enabling maintenance personnel to promptly address machine issues and perform scheduled maintenance. The notification delivery time to users is approximately 1.04 seconds.

For future research, it is recommended to enhance the notification system by incorporating automatic production data reporting. This feature would enable users to directly download reports without the need for logging into the application.

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